Emergency Medical Imaging

Editor: Robert F. Dondelinger

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EDITORIAL

BY **ROBERT F. DONDELINGER**

On this International Day of Radiology, it is appropriate to think back to the early days of the discovery of the rays.

Wilhelm Conrad Röntgen, professor of physics at the University of Würzburg, Germany, discovered x-rays, which are named after him in many languages including German, on Friday, November 8, 1895 in the late afternoon when the shimmery autumn daylight had sufficiently darkened. He could observe a pale green light appearing on a fluorescent screen, placed close to a cathode ray tube in operation in his laboratory. On December 22, after intense experimentation with the mysterious radiation, Röntgen obtained a 'radiograph' of the hand skeleton of his wife Elsa. He had written up the physical properties of the new rays in a few weeks' time without including a mathematical formula. Röntgen submitted his article entitled 'Physical properties of a new kind of radiation' to the medical-physical society of Würzburg on Saturday, December 28 that same year.

Röntgen's manuscript was immediately accepted for publication by the editor of the society journal without review or correction and the article appeared in the society journal in the beginning of January 1896.

Röntgen had written to his friend and former schoolmate at the University of Zürich, Franz S. Exner, professor of physics at the University of Vienna, about his discovery in the first week of December 1895 and had included some of his radiographic documents. On Saturday, January 4, 1896, Exner convened a small group of scientists and entertained them by showing around the new photographs from his friend. Among the invited guests was Ernst Lechner, a physicist from Prague who informed his father, editor of the Viennese newspaper *Neue Freie Presse,* on the same evening. Much to the surprise of those who had been present the night before, they read the printed news of the discovery of a revolutionary radiation on the right lower corner on the front page of the Sunday edition of the journal. The name of the discoverer was misspelled in the hurry of typesetting during the night: Routgen instead of Röntgen.

Already on December 28, Gustav Kaiser, instructed by Exner on how to produce the Röntgen rays, had obtained the first medical radiographs ever, at the University of Vienna. The documents were presented the next day at a medical meeting. It is difficult to know the exact day, however, as some today believe that the date marked on the still-preserved radiographs is apocryphal.

On January 13, 1896, Röntgen was summoned before the German emperor Wilhelm II in Potsdam to give a demonstration of the properties of 'his' rays. The emperor had been pressed by his high military command, who wanted to know if the rays, which are capable of penetrating solid matter, could be of any military use and in such case wanted that they should remain secret!

Finally, ten days later, on January 23, Röntgen gave a public lecture at the medical-physical society of Würzburg that was also attended by German army officers. The news of the discovery published in Vienna was reprinted by all prominent newspapers worldwide during the first two months of 1896. Never before had a scientific discovery been made known so rapidly on both sides of the Atlantic Ocean.

Physical experimentation with Röntgen rays went forward with tremendous speed. First photographs using a fluorescent screen were presented in Italy on January 25, 1896; a first somewhat primitive prototype of a fluoroscope was presented in Italy, called a 'cryptoscope', and in the USA called 'skiascope' as early as February 6. A method of intensifying the signal obtained on radiographs with reduced exposure time was discovered in New York the next day, and, on March 17, Thomas A. Edison cabled from New York to Lord Kelvin in London triumphantly, that, after having tried close to two thousand chemicals in less than two months, he had discovered a compound for making such powerful fluoroscopy screens that radiographs become unnecessary! More than one thousand articles were published during 1896 and several books written, which reported on experiences with x-rays. Röntgen showed no interest in the development of their medical applications, and only towards the end of his life was he submitted to a radiograph himself.

Since that time, Röntgen rays have come a long way. After the introduction of conventional tomography in the nineteen-twenties and of the image intensifier in the fifties, their last revival was the discovery of computerised axial tomography in the late sixties. Other alternative sources of energy, capable of analysing the structure of the human body and collecting information on its functions have emerged thereafter along with cross sectional imaging techniques: non-ionising ultrasound as well as magnetic resonance and nuclear medicine.

Those readers of this publication who live in a country with a mixture of industrial and post-industrial economy are highly privileged. In their homeland, medical care is organised by the state in such a way that not only the basic needs, but also the more liberal expectations of the population are largely satisfied and both public and private health insurance coverage is generally provided. The population takes the availability of up-to date medical facilities for granted. Hospitals are located at a reasonable distance from home and are reachable in a comfortable amount of time. In an emergency they expect, when admitted even to a medium-sized hospital, that a well-staffed emergency department, open day and night, is the rule. Modern medical equipment is expected to be at hand and serviced round the clock by experienced physicians.

Around the globe, however, this is far from reality – in particular concerning the spread of medical imaging capabilities. About half of the world's population will never be radiographed during their lifetime, and three-quarters of mankind have limited access or no access at all to sophisticated medical diagnostic imaging, such as that described in this book. Twenty percent of the world's population, at the very best, benefits from the entire armamentarium of high-cost cross-section imaging, functional imaging, and therapeutic interventional radiological procedures in the management of an emergency situation. In large parts of the world, significant medical progress could be achieved simply by installing low cost rudimentary radiographic units, such as those promoted and quality-certified by the World Health Organization (WHO) including basic or portable ultrasound machines. Simple standard x-ray equipment, if widely spread in rural regions of underdeveloped or emerging countries, would bring a dramatic change in the management of emergencies. This could be done by diagnosing or excluding the presence of a fracture, confirming rough diagnoses of intrathoracic disease or evidencing certain abdominal emergency conditions.

Unfortunately, manufacturers of x-ray equipment show limited interest in such a programme. They prefer to concentrate on selling high cost sophisticated instrumentarium that is renewed every five years. In addition, governmental authorities of some of those emerging countries prefer to invest in a few prestigious high cost pieces of equipment, to be installed in selected show-case hospitals and located in the capital ('capital syndrome') or in the few largest cities of their country, neglecting the needs of the predominating rural population.

Emergency medical imaging, as we conceive it today, developed only recently. There was a time, some 45 years ago, when I was a medical student, when emergency departments were equipped with only simple x-ray facilities. The latest, newly acquired, tilting radiographic table or tomographic table was installed in the 'central' department of radiology. Out-of-fashion radiographic equipment was transferred to the emergency department, to make room for the next generation of equipment in the central department. Radiologists considered assignment to the eccentrically located emergency department rather to be a punishment than stimulating work or a promotion.

All this has changed dramatically. Digitised radiography, ultrasound and computerised tomography, reporting using speech recognition software and immediate communication of the written report, digitised archiving of medical imaging: all these novelties have entered the emergency department. Computerised tomography may even be present in the shock room itself in trauma centres.

The polytraumatised patient is a medical entity unto him or herself and deserves special attention. Trauma is an unexpected event and strikes individuals who one second earlier were in good condition. It kills predominantly people of younger age groups and, apart from the human suffering involved, has enormous social and economic implications. More years of life are lost by trauma than by cardiovascular disease and cancer together. However, due to the lack of lobbying in favour of trauma patients, notably by the pharmaceutical industry, the amount of money invested in trauma prevention and research expenditures in management of trauma patients remains ridiculously low, in comparison with that allocated to investigating chronic medical diseases.

In everyday practice, it takes only a few seconds to cross-section image the admitted trauma victim from top to bottom, while his or her resuscitation continues uninterrupted. The policy regarding picking up and transporting the victim has changed from 'load and go' to 'stay and play'. Formerly, paramedics were sent out to collect patients at the site of an accident and bring him or her to the hospital as rapidly as possible, now specialised emergency physicians and anaesthesiologists resuscitate and stabilise the victim on site. Computerised tomography units that are installed in an ambulance, 'scanbulance', are now being tested.

In the following pages, you will have the opportunity to learn that medical imaging is capable of identifying with high precision various pathologies that can translate into emergency situations. Experienced radiologists, including younger staff members, who deal with emergency medical imaging on a daily basis have joined together with radiographers and kindly agreed to participate in this project, sharing with you their experience.

I express my warm thanks to all who have offered their time to contribute. Thanks to their competence, they made my editorial job extremely easy. I address my warmest thanks to the ESR Media and IDoR Management Department of the European Society of Radiology (ESR) for the efficient work which we accomplished together.

The following pages present interviews with Dr. Elizabeth Dick, president-elect of the European Society of Emergency Radiology (ESER), and Dr. Joseph S. Yu, current president of the American Society of Emergency Radiology (ASER), which absolutely deserve your attention. Both radiologists devote much of their clinical radiological time to emergency patients and contribute, through the respective societies they lead, to education in and promotion of their subspecialty. You will find a vivid description of the daily work of an emergency radiologist on both sides of the Atlantic in their particular environments. They describe the scene in their respective hospitals and countries. You may be interested in the differences conforming to the very dissimilar models of healthcare organisation adopted in their countries. They stress using the available imaging modalities discriminatingly, emphasise the importance of teamwork, and allow a glimpse into difficulties, such as a shortage of qualified radiologists, for which teleradiology might be a partial answer.

It must be hoped that you will enjoy reading but without ever having need of medical imaging in an emergency situation.

Liège, November 8, 2017

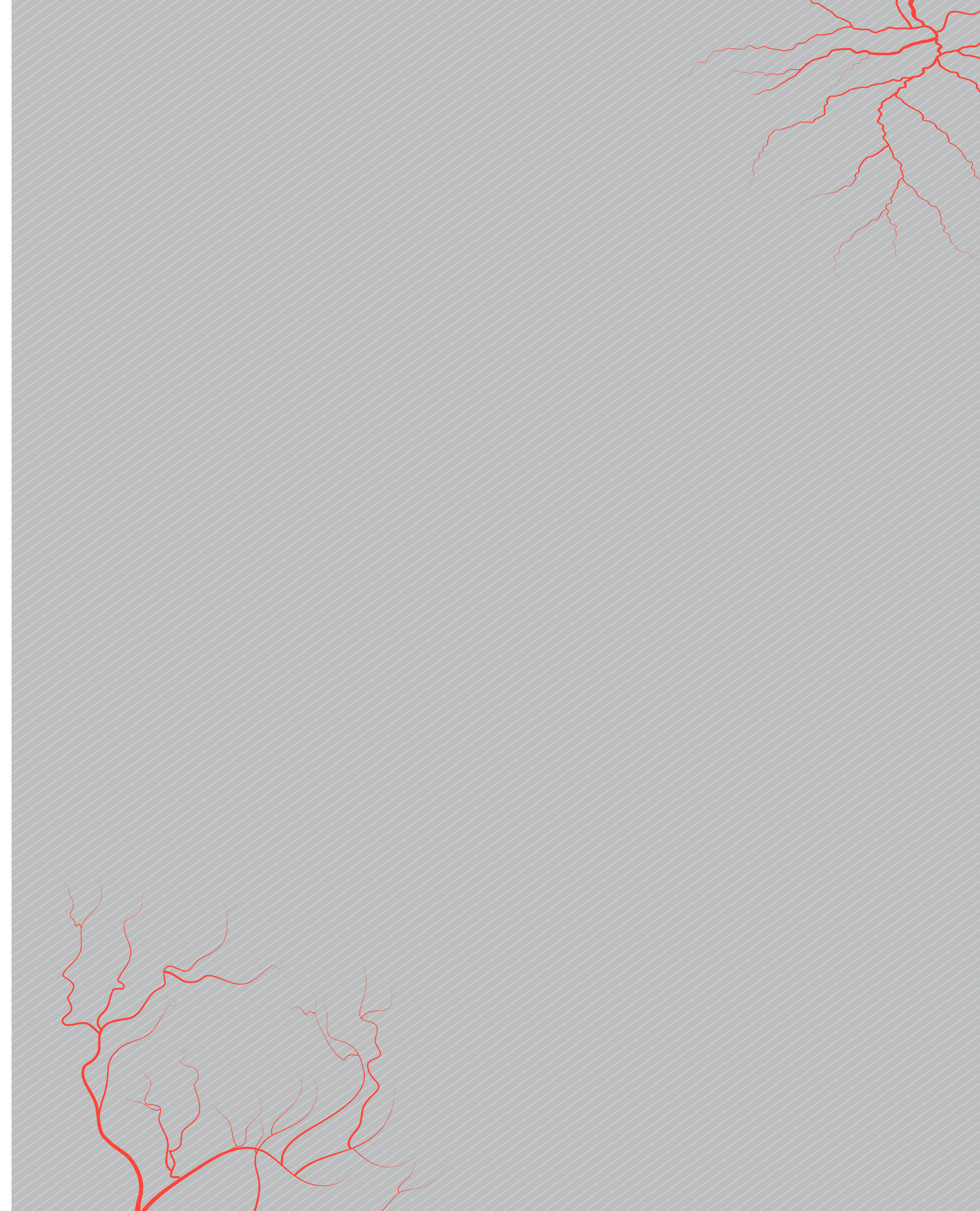
PROF. ROBERT F. DONDELINGER

accomplished his medical studies at University of Montpellier, France, from 1969 to 1974, followed by a one-year internship and residency training in radiology at the Department of Radiology of University Hospital St. Eloi, Montpellier from 1974 to 1978. He defended an inaugural doctoral dissertation on abdominal computed tomography in 1977.

Prof. Dondelinger was in charge of Visceral Radiology at the Department of Radiology of Hospital Centre of Luxembourg (Grand-Duchy of Luxembourg) from 1979 to 1991. He was appointed Head of the Department of Medical Imaging at University Hospital Sart Tilman, Liège, Belgium, and Full Professor of Radiology at University of Liège from 1991 to 2009. He is an Honorary Professor of Radiology at University of Liège and continues to practice as a consultant in the Department of Medical Imaging which he began in 2009. Prof. Dondelinger has given lectures and scientific presentations at many international scientific meetings, has participated regularly in teaching programmes organised by the European Association of Radiology and other organisations or scientific societies and has directed courses, hands-on workshops and practical demonstrations in interventional radiology throughout the world. He has (co-)edited books and authored book chapters and many scientific papers devoted to interventional radiology. He has served on numerous advisory and editorial boards of European and international scientific journals.

Prof. Dondelinger was a founding member of the Cardiovascular and Interventional Radiological Society of Europe (CIRSE) in 1985, treasurer from 1997 to 1998 and secretary general from 1999 to 2001, as well as being founding president of the European Society of Thoracic Imaging (ESTI) in 1993, President of the Society in 1997, founding member of the European Society of Gastrointestinal and Abdominal Radiology in 1990, president in 2003, President of the Royal Belgian Society of Radiology in 1999, and President of the Royal Belgian Society of Gastro-enterology in 2000.

Prof. Dondelinger was made an Honorary Fellow of the Royal College of Radiology, London, UK, in 2004 and is an honorary member of other national and international radiological societies. He earned the title of Laureate of the University and the Swiecicki II Prize of the University of Montpellier in 1977 and the P. Masson Prize of the French Society of Radiology in 1977. Prof. Dondelinger was a recipient of the Mackenzie Davidson Medal of the British Institute of Radiology in 2000 and a recipient of the Gold Medal of the European Society of Gastrointestinal and Abdominal Radiology in 2006. Prof. Dondelinger was named Knight of the Order of Merit of the Grand-Duchy of Luxembourg in 2015.



SEVERE SHORTAGE OF RADIOLOGISTS IN THE UK CREATES A GROWING DEMAND FOR TELERADIOLOGY SERVICES AND FORCES HOSPITALS TO INCREASINGLY OUTSOURCE THEIR USE AFTER HOURS

AN **INTERVIEW** WITH **DR. ELIZABETH DICK,** IMPERIAL COLLEGE LONDON, UK, PRESIDENT ELECT OF THE EUROPEAN SOCIETY OF EMERGENCY RADIOLOGY (ESER)

Could you please describe the role of the radiologist in a typical emergency department in your country?

It varies. In many hospitals, traditional model remains; radiology and emergency departments are distant from each other. There may be one or two consultant radiologists with an interest in emergency imaging who are the 'go to' radiologists for the emergency team during the day. After hours, on-call radiologists will be the point of contact, but they are busy with many services, and increasingly may be remote from the hospital they cover. Teleradiology often is used to deliver after-hours care, with obvious advantages. The result is an inevitable loss of personal interaction between the radiology and emergency departments. However, set against this traditional model is the 'gold standard'. Since 2010, a network of major trauma centres was set up across the UK to deliver excellence in trauma care. In these centres, radiologists usually are an integral part of the trauma team, and the CT scanner is usually co-located in the emergency department. This has a ripple effect: Not only is trauma imaging improved, with resulting lower morbidity and mortality, but all emergency patients benefit from a closer relationship between radiologists and the emergency department team.

What does a typical day in the emergency department look like for a radiologist?

I start my day at 7am by checking all the reports from the night before so that I can speak to the emergency teams as they do their ward rounds at 8am. Our radiology registrars and residents do two, twelve-hour shifts (8am to 8pm), so this is a good opportunity for the on-call registrars to discuss cases they found particularly challenging. Like all hospitals, we perform more imaging examinations each year. On average, there are at least 25 patients who get imaging (mainly CT) overnight, which means a huge responsibility for the radiology registrars on call. Although they may reach out to the duty consultant during their call, for most scans, registrars issue a report based on their own findings. We regularly audit their reports, and the discrepancy rate is very low – probably due to the fact that they strive to work hard to learn. Also, they get a lot of training and support before, during and after being on call.

Teamwork is crucial in the emergency department. How is this accomplished in your department and who is involved?

We have three or four consultants with a special interest in emergency imaging with whom the emergency department and radiology registrars may consult. The most important attribute for emergency radiologists is to be approachable; I would never want a junior doctor to think twice before calling me to ask for help. The best way to achieve this is to hold regular meetings during the week. In our department, we meet every morning at 7am in acute imaging, where consultants meet juniors and informally review cases. Also, we meet during emergency physicians' training and at the major trauma multidisciplinary meeting, both of which occur weekly. I also make sure that I come down to the emergency department periodically, usually to attend major-trauma calls. Most importantly, emergency imaging cannot be a one-person service. To ensure that as many emergency physicians and radiologists as possible have rapport with one another, I have senior registrars rotate their attendance at the emergency-radiology teaching. All the emergency physicians attend these sessions, where they discuss interesting cases from the week, and the radiologist leads a lively discussion of the imaging and clinical learning points. The meeting is informal, and it provides a great learning forum for both the emergency and radiology registrars. It also means that when members of the emergency or radiology team make contact, they already know each other.

How satisfied are you with the workflow and your role in your department? How do you think it could be improved?

Workforce is our biggest constraint; we do not have enough radiologists in the department to ensure that all reporting is done quickly, particularly after hours. My ideal would be for the picture archiving and communication system (PACS) worklists for radiology-emergency imaging to be nearly empty (e.g. as soon as a case gets loaded on PACS, a radiologist jumps in to start the report). In an ideal world, all emergency imaging would be reported within an hour by a registrar (which does happen because registrars are on a dedicated emergency rotation) and then reviewed by a consultant within six hours (which doesn't happen). Currently, the scans are reviewed within 24 hours by a consultant, and, as I said, the discrepancy rate is low. A particular concern is that our arrangements for weekend coverage are piecemeal. Although many of us would like to introduce a seven-day work week (i.e. routine reporting lists for weekends), the hospital's financial constraints make this impossible. At the moment, individual consultants usually come in and check reports over the weekend, but the system is not formally established. Other hospitals across the UK have accepted that the concept of in-house radiologists reporting ALL emergency cases is unachievable because of the radiologist shortage. Therefore, outsourcing to private teleradiology companies is common in the UK. In fact, the majority of UK hospitals make use of teleradiology, and after-hours imaging is one area where outsourcing is most popular.

Which modalities are used for different emergencies? Could you please give an overview sorted by modalities?

Plain x-rays remain the mainstay for emergency imaging, and it is important not to skip this step in the rush to perform more complex investigations. In the case of a patient with a twisted-ankle injury, subtle bony avulsions can be hard to identify on MR, even though the associated soft-tissue injuries are obvious. But matching the plain radiograph side by side with the MR makes it easy to appreciate where the bony avulsions have occurred.

Ultrasound is still an important modality in the UK. For example, appendicitis often will be diagnosed by ultrasound, but, of course, this requires expertise. All junior radiologists become accomplished at ultrasound and receive good, supervised training. So, I anticipate that ultrasound will continue to be a useful and important modality in the future of emergency radiology.

CT is of course the key investigation for many emergency patients, and, like the rest of the world, we are experiencing an annual increase in its usage. At my own institution, the number of CTs performed on call has quadrupled over the last six years, and I cannot see how the trend would reverse. Although some may say that we 'over image', I believe that we make a significant difference in most cases. Whereas 25 years ago, patients with an 'acute abdomen' would frequently be taken straight to surgery for an exploratory laparotomy, today patients rarely are taken to surgery without some form of imaging to ensure that surgery is warranted.

Our interventional radiology colleagues play an active role, particularly in trauma, and they work closely with the trauma surgeons. For example, a patient with active splenic bleeding may have the condition initially embolised in interventional radiology and then rushed to surgery for a splenectomy, which is easier to perform in the absence of active bleeding.

We run an MRI service around the clock for neurological emergencies, including cord compression and unstable cord injuries. This service inevitably requires significant radiographer expertise. Like all hospitals, we have to think about education and training of our radiographers to retain expert staff.

Is teleradiology an issue in emergency radiology? If yes, how so, and how often is it used?

Teleradiology is used frequently and increasingly in the UK because of the serious radiologist shortage I mentioned earlier. There are obvious advantages to teleradiology. However, the demand is huge, which can lead to problems for teleradiology companies similar to those in traditional hospital settings (e.g. not enough radiologists to do the reporting). Many radiologists who work in teleradiology also work in the public hospital system, so the pool of potential reporting radiologists is relatively limited. It is vitally important that teleradiologists not be disadvantaged in their work compared with on-site, hospital radiologists. Teleradiologists should have easy, immediate access to all the previous imaging studies and reports on every patient. Also, teleradiologists should be able to easily access patients' electronic records while reporting imaging studies to look up other relevant clinical data, such as blood test results and previous histopathology, if necessary. This requires a high standard of seamless information-technology connectivity.

Are emergency radiologists active anywhere other than emergency departments? Do they have other non-emergency roles, or other emergency roles in other departments?

At major trauma centres, radiologists are an integral part of the trauma team; they attend trauma calls and take part in governance, education and planning. Good examples are the recent major-trauma events in London and Manchester. At my institution in London, we have a mass-casualty event, on-call rotation for terrorist attacks. During the recent London Grenfell Tower fire, at least seven radiologists attended immediately. The first radiologists on the scene were able to calculate the precise number of radiologists needed and quickly call upon additional or specialised colleagues over the following 24 hours.

Do you have direct contact with patients and if yes, what does it entail?

Radiologists attend trauma calls to do focussed assessment with sonography for trauma (FAST) scans where needed, which is the first point of contact. This may be followed by interventional radiology or ultrasound examinations over the next few days. Trauma patients may have problems down the line. For example, they may develop pain due to fracture malunion or avascular necrosis. I particularly enjoy follow up with these trauma patients 6 or 12 months later, when they develop problems during rehabilitation. At this stage, I perform a musculoskeletal ultrasound, in combination with MRI or CT, and I work with the rehabilitation and orthopaedic consultants to help these patients return to normal life.

How are radiologists in your country trained in emergency radiology? Is emergency radiology a recognised specialty in your country?

This is a project for the future! We do not have an emergency radiology subspecialty in the UK, but all registrars are extensively exposed to emergency radiology throughout their training, both on call and during their subspecialty training. There is obviously much interest in emergency radiology in the UK; whenever the British Society of Emergency Radiology (BSER) runs a course, it sells out quickly and more courses are added in response to the demand.

Please feel free to add any information and thoughts on this topic you would like to share.

The BSER was set up in 2014 in response to the growth of emergency radiology as a formal discipline in the UK. This society runs annual meetings with workshop-based training in emergency radiology, which are popular with trainees and consultants alike, as well as contributing to the national imaging meetings. The BSER also advises the Royal College of Radiologists on all emergency imaging related topics and provides information on scanning protocols and imaging in special situations such as terrorist attacks.

DR. ELIZABETH DICK, BSC, MD

has worked as a consultant radiologist and honorary senior lecturer at Imperial College London since 2002.

She completed her radiology training in London at St. Bartholemew's, the Royal Free and Great Ormond Street Hospitals. She completed a two-year, body MRI fellowship at Imperial College, earning her doctorate in the process, followed by a musculoskeletal fellowship at Duke University in North Carolina, United States, with Professor Clyde Helms. As the trauma and emergency radiology lead, she set up Imperial College as a major trauma centre. She also set up an imaging primary-healthcare liaison service for the area. Dr. Dick is a director of medical education at Imperial College and leads the faculty development programme, as well as running a maternity mentorship scheme for the trust. She teaches, interviews, recruits and educates future doctors from school age onward. She was an examiner for the Royal College of Radiologists (RCR). She has set up numerous popular national courses including the Fellowship of Royal College of Radiology (FRCR) Royal Free course and a body MRI workshop. She has a keen interest in emerging technology, and set up the first-wave, training website for the RCR. She has published a CD, two books, several chapters and more than 50 peer-reviewed and non-peer-reviewed articles. Dr. Dick has a national and international profile, publishing and speaking worldwide. She is President of the British Society of Emergency Radiology, and President Elect of the European Society of Emergency Radiology (ESER). She developed the webinar programme for ESER, a key part of the new European Diploma in Emergency Radiology (EDiR).

IN THE UNITED STATES, TECHNICAL ADVANCES IN CT, SUCH AS DUAL-ENERGY CT, REMAIN AT THE FOREFRONT OF RADIOLOGICAL INNOVATIONS IN EMERGENCY DEPARTMENTS

AN **INTERVIEW** WITH **DR. JOSEPH S. YU,** OHIO STATE UNIVERSITY, COLUMBUS, OHIO, UNITED STATES, PRESIDENT OF THE AMERICAN SOCIETY OF EMERGENCY RADIOLOGY (ASER)

Please summarise the innovations and trends in state-of-the-art emergency and trauma radiology? In other words, what's new in emergency radiology?

Over the years, there have been many innovations that have moved the needle in favour of the patient in regard to emergency radiology. The technological advances in CT have remained at the forefront, largely because imaging is so fast; the equipment had become ubiquitous; and the limits in resolution have been pushed further so that we are able to look for and find very small pathology, be it in the bone or in the soft tissue. There are few instances where CT has not contributed to the care of patients in the emergency department, particularly in cases of severe trauma, such as victims of motor-vehicle collisions.

These days, the most exciting advance in CT is the advent of dual-energy CT, a relatively new technology that uses x-rays of two different strengths to create an image. A standard CT scanner uses a single, polychromatic x-ray beam. This beam penetrates tissues, and images are produced based on the amount of attenuation of these x-rays (i.e. how much of the x-ray is not transmitted through the tissue) and how closely the energy of the x-ray exceeds the binding energy of the inner electron shell. Tissue attenuation can be manipulated by changing the strength of the x-ray beam. A dual-energy CT uses both the standard x-rays (at 140 kVp) and a second, less powerful, x-ray (at 80 KVp), thus expanding the versatility of the CT scanner. The significant advantage of this type of scanner is the ability to exploit the effects of certain chemicals or substances in the body. For instance, typically we use iodinated intravenous contrast material to enhance the vascularity of tissues. Dual-energy CT can select for iodine and create exquisite pictures of the blood vessels, as well as identify locations of contrast extravasation arising from injured organs that are leaking blood. It can improve the quality of scans markedly in patients who have metal in their bodies, such as artificial joint replacements, by selecting the energy that reduces artefacts; or it can differentiate between the types of kidney stones, thus influencing the proper treatment. Material separation allows visualisation of noncalcified gallstones, and helps distinguish it from cancer so that therapeutic decisions are more precise. An important application in trauma patients is detection of bone marrow oedema to assess subtle fractures that previously could only be done with MR imaging. MR imaging in acute trauma patient is not always possible. The potential application of this technology is bright for future tumour imaging.

What do you think are the most significant changes you have seen in emergency radiology since you began your training?

There have been numerous advances and innovations introduced during the past two decades that have dramatically influenced the manner in which radiology contributes to the care of patients in the emergency department.

First, technological advances remain the driving force that has allowed imaging to keep up with demand in the emergency department. A huge advancement is the advent of multidetector computed tomography over a single-source CT. It created an unprecedented escalation in CT use, with an exponential growth from 1990 to 2005. Much of that growth occurred in emergency departments across the country. During this period, there was roughly a three-fold increase in the number of CT studies performed. Multidetector CTs made it possible to scan much faster, which allowed the ability to scan organs, such as the heart with a single breath-hold, and eliminated respiratory artefacts that previously had the potential to degrade image quality. Additionally, faster scanning introduced imaging in different vascular phases, and the development of CT angiography has largely replaced catheter-based diagnosis. Other technological advances include image reconstruction into three-dimensional anatomic depiction, which improved the understanding of bone and soft-tissue trauma; and the introduction of newer applications, such as CT colonography. However, the explosion of new technology also added to the complexity, as well as to the number, of images that accompanied each study.

Secondly, the most important innovation in the emergency department is the evolution of around-the-clock, in-house staffing using full-fledged emergency radiologists (i.e. board-certified or board-eligible radiologists who have completed a diagnostic radiology residency). This provides high-quality, final interpretations of imaging procedures performed on all emergency department patients and on inpatients who require emergent imaging. Historically, after-hours imaging procedures performed in the emergency departments of academic institutions were given a preliminary reading by a radiology resident, who then reviewed the studies with a board-certified faculty member the following morning. Any discrepancies in interpretation were reported to the emergency department staff, and, if necessary, the patient was called back for additional evaluation or change in treatment. This often meant the care of the patient was performed by an entirely different team of doctors. In many smaller emergency departments, the initial, primary reads were often made by non-radiologists. There were two major events that contributed to the creation of a 24-hour, in-house model. The first was a ruling by the Medicare, the federally funded payer in the United States, that payment for services rendered in the emergency department would go to only one provider, and that billing for the study would be reimbursed only if interpretation of studies was simultaneous with patient treatment. The second event was the rapidly accelerating use of CT, which required a level of expertise that often exceeded a non-radiologist's scope of practice.

Thirdly, the picture archiving and communication system (PACS) has revolutionised radiology. This advancement has changed the way images are accessed and stored in institutions, and has dramatically improved clinicians' access to these images from anywhere in the world. With digital images, anyone with an electronic device or computer can view a patient's study. This has promoted a transparent method of patient care; created efficiencies that were not present before; and elevated the quality, timeliness, and delivery of treatment.

Please describe the role of the radiologist in a typical emergency department in the United States?

Radiologists perform one of the most critical tasks in the emergency departments of many institutions. They serve as the diagnostic hub where all patients who require imaging studies flow through. When multiple trauma patients do present, they consume the undivided attention and access to equipment that radiology offers; all other patients wait as the polytrauma victim receives an array of services in a brief, but intense, time interval. However, the vast majority of emergency department admissions are patients with acute, self-limiting processes or those with complications of one or more systemic conditions that require hospitalisation. These patients also need prompt radiologic consultation and imaging in order to justify hospital admission and to begin therapy. As such, a close relationship between radiology and emergency medicine makes the enterprise more efficient.

The actions of the radiologist influence the outcome of many patients, but especially polytraumatised patients who have been involved in motor-vehicle collisions or have suffered penetrating injuries from gun violence or industrial accidents. In our department, we employ six subspecialty emergency radiologists, only one of which works during daytime hours (8am to 5pm). Therefore, interpretation of all emergency department studies is a shared responsibility with subspecialty radiologists in other sections. Because the interpretation of daytime examinations performed in the emergency department take precedence over outpatient studies and non-emergent examinations performed on inpatients, the workflow design dictates that all imaging studies from the emergency department are colour-coded and prioritised in the PACS. These studies appear as 'first study to read' by an algorithm that moves these examinations to the top of every worklist, independent of subspecialty, so that emergency department patients receive expeditious attention throughout the department.

What does a typical day in the emergency department look like for a radiologist?

I work in a large, academic institution with approximately 1,600 hospital beds. We are considered a tertiary care centre and we have a Level 1 trauma designation by the American College of Surgeons, which means that we can accommodate all types of emergencies. It requires 24-hour, in-house coverage by general surgeons and prompt care available by orthopaedic surgery, neurosurgery, anaesthesiology, emergency medicine, radiology, internal medicine, plastic surgery, oral surgery and critical care.

The emergency department has more than a 100-bed capacity. The radiology department provides in-house, around-the-clock coverage of our emergency department throughout the year, including weekends and holidays. Our emergency radiologists have their reading rooms physically located within the emergency department and adjacent to four trauma bays, each capable of handling two trauma patients at a time. We work in three shifts that overlap by 2 to 4 hours during peak times. Two shifts are 8 hours long and a third is 10 hours long. In a typical 24 hour day, we will interpret 50 to 80 CT examinations, 20 to 30 MR examinations, and about 12 to 20 ultrasound studies in addition to about 150 to 200 radiographs between three radiologists. On average, three to six Level 1 trauma patients are flown in to us via a two, dedicated helicopters, distributing trauma patients between two Level 1 hospitals in our city.

The patients we evaluate in our department present with a wide variety of conditions, including musculoskeletal injuries resulting in fractures dislocations, and muscle and ligament tears; blunt trauma that produces a spectrum of pathology from liver lacerations to pneumothoraces; penetrating injuries arising from knife or gunshot wounds; in addition to severe multiorgan injuries often seen in polytrauma patients. We assess ischaemic or thrombotic events that result in strokes, ischaemic bowel or necrotic tissue. As a stroke centre, each patient has a timer, initiated from the onset of symptoms, so that treatment is rapid and offers the best chance of recovery. Infections are common. Conditions such as necrotising fasciitis are life-threatening and require expeditious access to imaging so that the extent of disease may be documented, either for preoperative assessment or as a baseline for progression. As a heart hospital, a large number of patients who present with symptoms that suggest an evolving heart attack have a unique pathway to the angiographic suites for diagnosis and administration of thrombolytic therapy.

Teamwork is crucial in an emergency department. How is this accomplished in your department, and who plays the most crucial roles on your team?

Teamwork is important in any part of medicine, but it is particularly critical for successful evaluation of an acutely ill or traumatised patient. Nowhere is this more evident than when a Level 1 trauma patient arrives in the emergency department. A patient who has suffered severe multiorgan trauma from a motor-vehicle accident, for instance, requires cooperation between the attending emergency physician, who is part of the teaching faculty, and any number of residents from different departments. Once the patient has been triaged and the appropriate imaging studies have been ordered by the emergency physician, the general surgeon or the orthopaedic surgeon will then take the lead for the subsequent care of the patient, depending on what is discovered through imaging. In these trauma patients, a standard battery of imaging includes radiographs of the chest and pelvis, and CT examinations of the cervical spine, abdomen/pelvis, and often the head. Additional radiographs and CTs are requested based on physical examination. It is not unusual for a severely injured patient to undergo additional CT of the chest, and the rest of the spine, and to have additional radiographs performed of the extremities. Patients who suffer penetrating injuries from knife wounds or gun-shot wounds often end up in the care of cardiac surgeons or neurosurgeons, depending on the magnitude of their injuries.

The commonality in all of these types of trauma is the contribution of the emergency radiologist, who provides instantaneous, final interpretation of all studies generated during the care of the traumatised patient. In our department, the goal is to have less than one hour of turnaround time for all studies in the emergency room, but we aim for 30 minutes for the majority of patients. The emergency radiologist also works closely with the radiology technology staff to ensure that images are ready to be interpreted as soon as they are completed, so that a final report may be generated. If patients bring CDs of images from another institution, the radiologist imports these images to the PACS and provides interpretive support for these outside studies. Generally, radiologists report their findings directly to the emergency physician or the lead trauma surgeon who has assumed primary care of the patient.

Are you satisfied with the workflow and your role in your department? How would you like to see it improved?

Yes, we are satisfied with the workflow and the contribution of the emergency radiologist to the department. The workflow is a culmination of the efforts of many individuals in multiple departments. The institution is supported by a large IT department that oversees the network, servers, computers, data flow and storage of information. We collaborate with members of our own informatics team, which facilitates the distribution of studies, maintenance of departmental servers, and a smooth functioning workflow, so that each section is working at maximum efficiency. We have 10 years of patient-file storage in our department, but retrieval of prior studies requires methodical directives and implementation of careful selection criteria to enable a rapid retrieval without impairing the speed of image delivery to the PACS, since a large storage archive can slow the speed of the PACS. This affects how quickly one can scroll through a study with multiple images like CT or MRI; move from one patient to another; and manipulate images, such as three-dimensional pictures.

Providing an environment that is optimal is expensive and requires the availability of recurring financial resources and investments. Avoiding change leads to stagnation quickly. Having leadership in an institution that always considers factors that increase the efficiency of patient care delivery in a digital world is important and one of the major things that ultimately adds to our job satisfaction.

Which modalities are used for different emergencies? Could you please give an overview, sorted by modalities? Which modalities are most essential to emergency room practice?

In most instances, radiography is the standard imaging modality to get an overview of the chest, abdomen, pelvis, or appendicular skeleton. It is an adequate technique to evaluate the bones for fractures in trauma, lungs for pneumonia, or free air in the abdomen.

CT is the workhorse in the emergency department for neuroradiological, abdominal, and cardiovascular conditions. Non-contrast CT is used to assess most cases of headaches, which may be an indication of a haemorrhage, stroke, aneurysm or cancer. CT of the spine is used in patients who have back pain after significant trauma or in whom the radiographs are positive for fracture. This allows full evaluation of all of the areas that are involved. In an acute polytrauma scenario, a patient frequently undergoes a head CT, chest CT, abdomen and pelvis CT, and spine CT, when necessary. Abdomen pain also is amenable to evaluation with CT and in these situations, both enteric and intravenous contrast generally are administered. CT also is an effective modality to search for gas or inappropriately located air. Since many infectious processes result in the collection of gas, CT is particularly useful. CT detects acute blood products, so it is often used to evaluate whether patients who present with decreased haemoglobin are actively bleeding or have accumulated a haematoma.

MRI is most useful for assessment of soft tissues, owing to its superior contrast resolution. Specific tissue types are depicted differently in the various imaging sequences used on MR. It is relatively easy to differentiate between scarring, acute swelling, fluid containing structures, solid masses, vascular structures, and tissues that contain blood products. It is useful to search for radiographically occult fractures of the wrist or hip; or for evaluation of the disc if a disc protrusion is suspected as the cause for acute neurologic symptoms. In the spinal column, it is the modality of choice when spinal cord impingent, nerve disease, or disc infection is suspected. It is the primary modality to evaluate for acute ligament tears, such as the anterior cruciate ligament in the knee; tendon pathology such as rotator cuff tears in the shoulder; and soft-tissue injury, such as a muscle contusion. It is the preferred modality in evaluating for soft tissue or bony infections, both in acute and chronic situations, since contrast resolution of MRI is unparalleled. It also is frequently used in evaluating patients with cancer who may present with an acute complication such as a pathologic fracture, nerve impingement, or acute haemorrhage.

Ultrasound also has a role in the emergency department. It is an effective method to search for free fluid in the abdomen; to assess soft-tissue masses as either solid or cavitary; and to evaluate the vascularity of certain conditions, such as arteriovenous malformations that can present with pain or a mass.

Is teleradiology an issue in emergency radiology? If yes, how so, and how often is it used?

Not all emergency departments require the same quality of coverage. Level 1 trauma centres differ greatly from a small, rural hospital in terms of the types of patients who present to the emergency department. Because the needs are different, and owing to a relative shortage of radiologists willing to work after hours or at night, teleradiology has flourished and is used in many institutions to cover emergency radiology patients. Only about 27% of academic institutions provide 24-hour attending coverage of the emergency department by board-certified or board-eligible radiologists. More than 75% of academic centres continue to provide preliminary interpretations of night-time studies performed by residents with different experiences. It requires tremendous departmental and institutional resources to provide 24-hour, faculty coverage. There also are variations in payment and time-off compensation that are expected by those who provide this service. It is an issue of scale and affordability. As Medicare continues to exert pressure for contemporaneous interpretation of imaging procedures in emergency department patients, teleradiology groups are stepping in to provide these final readings for many institutions.

Are emergency radiologists active anywhere other than emergency departments? Do they have other nonemergency roles, or other emergency roles in other departments?

In many departments, an emergency radiologist performs a dual role by interpreting imaging studies in their respective subspecialty and to providing subspecialty coverage of the emergency department. This is particularly true in neuroradiology, where final interpretations often are required to begin treatment. For instance, this is especially applicable in patients who present with an evolving stroke, where time is of the essence and initiation of appropriate therapy is critical for a favourable outcome. In other situations, the complexity of the vascular anatomy in the brain necessitates a subspecialist to read MR or CT angiographic studies to facilitate therapeutic intervention, such as embolisation of a bleeding vascular malformation or coiling an aneurysm.

Alternatively, emergency radiologists, who frequently work in shifts, may be called upon by the chief or chair of the radiology department to contribute their expertise during routine work hours to assist a section in the department that may be short-staffed because of meetings, vacations or attrition. Since it is in the scope of the emergency radiologists' practice to interpret a broad spectrum of studies and modalities, and recognise a wide latitude of pathologic conditions, they are nimble and may easily be deployed into various areas of a department in the event of a staffing need.

Do you have direct contact with patients, and if yes, what does it entail?

My contact with patients is limited to three types of interactions. First, I have an opportunity to speak to patients whenever there is a need for an interventional procedure, such as an emergent joint aspiration to exclude or confirm an infected joint. Generally, a limited physical examination is required by our institution prior to the procedure, and this allows the radiologist to search out any prior studies that may accompany the patient, and also gives the patient time to ask questions. A second opportunity arises when a patient has questions prior to an imaging procedure. Because we are located within the emergency department, patients have access to radiologists whenever they have a specific question related to their imaging study, or if they have a particular question or concern. We encourage the technologists to call us when a patient has a question. The third opportunity is when patients having a CT or MRI suddenly become symptomatic after intravenous administration of contrast media. When this occurs, radiologists respond rapidly and provide treatment if necessary.

How are radiologists in the United States trained in emergency radiology? Is emergency radiology a recognised specialty in the United States?

There are two common pathways for a radiologist to train in emergency radiology. In both instances, the physician must first complete a diagnostic radiology residency after medical school. Then the radiologist may seek a direct pathway by choosing a fellowship that is dedicated to emergency radiology. Currently, there are 13 of these in North America. The other pathway is more conventional; the radiologist selects a diagnostic fellowship in neuroradiology, musculoskeletal imaging, thoracic imaging, or body imaging. After completing either fellowship, the radiologist focuses on the care of the urgent and emergent patient.

In the United States, emergency radiology is not a recognised subspecialty of diagnostic radiology by the American Board of Radiology (ABR) as a specialty track for certification. However, it has been recognised by many major radiologic societies as a specific educational track, including the largest radiologic society, the Radiological Society of North America (RSNA). The American Society of Emergency Radiology (ASER) has been in existence for nearly 30 years and its flagship journal, *Emergency Radiology,* has been published since 1994. Other international societies dedicated to emergency radiology formed in Europe and Asia.

One of the impediments to emergency radiology becoming a subspecialty of radiology is the demarcation from general radiology, even though the conditions and diseases that present to the emergency department are clustered around very specific acute and subacute pathology. Additionally, knowledge requirements in general radiology include classifications that often are not appropriate to the urgent patient, and the breadth of certification questions are of greater latitude than the entities that fall in the scope of the emergency radiologist's practice. There are ongoing efforts to bring these differences to light with the ABR and to work toward a certification process that would be specific for this group of radiologists.

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is currently the vice chairman of academic affairs and education; and professor of radiology and orthopaedic surgery; and obtained his medical degree from the Ohio State University in Columbus, Ohio, United States. After completing a residency in diagnostic radiology there, he trained with Dr. Donald Resnick at the University of California in San Diego, California. Since then, he has authored more than 300 papers, chapters and abstracts, and given 170 national and international lectures, including 20 visiting professorships. He is the author of Musculoskeletal Imaging: Case Review, *now in its 3rd edition and on the best-selling list of musculoskeletal textbooks. He was co-editor of the 2008 American Roentgen Ray Society (ARRS) course syllabus, 'State-of-the-Art Emergency and Trauma Radiology' and in 2015, of 'Problem Solving in Emergency Radiology', endorsed by the ASER. To date, Dr. Yu and coinvestigators have received more than $11 million in grants, including the Osteoarthritis Initiative Grants. He currently serves as president of the ASER. He has served on numerous national and international committees in many organisations, including the ABR, American College of Radiology (ACR), International Skeletal Society (ISS), ARRS, and the RSNA. Dr. Yu has received honorary fellow status in the ASER and ACR.*

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3D IMAGING IN THE EMERGENCY ROOM

3D IMAGING IN THE EMERGENCY ROOM: USEFUL DIAGNOSTIC TOOL OR GADGET

BY **SEBASTIAN LESCHKA, SIMON WILDERMUTH, HATEM ALKADHI**

Radiological imaging has become one of the most relevant factors for rapid and accurate diagnostic workup of patients in the emergency department.

Early diagnosis and initiation of treatment facilitated by radiological imaging has a relevant influence on a patient's outcome, and the time to treatment is a critical factor for life-threatening emergencies.

While conventional x-ray and ultrasound are still performed often, modern imaging modalities such as magnetic resonance imaging (MRI) and in particular computed tomography (CT) are increasingly used for the diagnostic workup of patients with traumatic and nontraumatic emergencies. Technical improvements in CT technology in the past years has resulted in superior spatial resolution and increased scan speed and permit the reconstruction of high quality images at any plane.

Imaging of emergency department patients increased from 41% of patients being imaged in 2002 to 47% in 2012 according to the 2012 US National Hospital Ambulatory Survey.
A retrospective data review of abdominal imaging in emergency departments from 1990 to 2009 found an increased usage of abdominal imaging per 1,000 emergency department visits of 19%, mainly caused by an 18-fold increase in the usage of abdominal CT scans while the number of conventional x-ray abdominal examinations decreased by 82%.
A recent study demonstrated that results of CT studies in emergency situations frequently changed physicians' diagnoses and admission decisions, and that diagnostic uncertainty was alleviated. Moreover, the usage of whole-body CT in trauma patients has been suggested to have reduced overall mortality compared to an approach using conventional x-ray imaging and ultrasound.

The timely diagnostic workup performed on emergency department patients facilitates decisions regarding treatment and possible hospital admission. Factors under the radiology department's control that influence the time to diagnosis are the patient's room time in the CT suite, correct choice of CT scan protocol, optimised workflow, and the time required for interpretation of images by the attending radiologist. Improvement of the radiological report turnaround time has been the topic of several investigations in the past. Surveys demonstrated that the satisfaction of emergency department physicians with radiological services principally depends on aspects of quality including the clinical accuracy of the report (*'getting the answer right'*) and addressing the clinical question asked by the ordering physician (*'answering the right question'*). The second-most important issue determining satisfaction of the referring physician is the timely arrival of the radiological report. Hence, radiologists need to quickly gain a comprehensive overview of all the images in order not to delay the initiation of treatment.

Nowadays the radiologist is subject to a huge number of image viewing and interpreting options. While source transverse images remain most important for interpretation of cross-sectional imaging studies, radiological workstations capable of dedicated 2-dimensional (2D) and 3D post-processing techniques allow for displaying and reformatting images according to individual needs, which support the interpreter in the visualisation of images and rapid navigation through the volumetric datasets.

IMAGE INTERPRETATION FROM PAST TO PRESENT: A DRAMATIC CHANGE IN THE RADIOLOGIST'S LIFE

Two decades ago, the radiologist's image interpretation process was simpler than today. CT studies usually consisted of a relatively small number of images (e.g. about 100 images from a spiral CT scan). Although some reprocessing of images could be performed directly at the scanner, once recorded on film the major image properties such as contrast, sharpness, brightness, noise and windowing were fixed and immutable. The image display systems of those times were a light box, and 'high-end display tools' were used for lightening and darkening areas and for magnifying smaller sized details. Measurements were performed on filmed images using a conventional ruler and the printed size scale and pathological findings were labelled using an adhesive tape or marking pen.

Today, image viewing has improved dramatically compared to the above-described process. Advances in CT technology allow for the depiction of isotropic voxels providing equal dimensions along the x, y and z-axis, representing a fundamental step from cross-sectional to true 3D imaging because isotropic voxels are a prerequisite for accurate post-processing algorithms. Modern multidetector row CT systems produce vast amounts of images per CT study, and the radiologist must now view hundreds or thousands of images per examination (e.g. a coronary CT angiography may consist of more than 5,000 images). Thus, recording all images on film is no longer practicable. Images are currently viewed on workstations using a Picture Archiving and Communication System (PACS) or dedicated radiological software packages for image interpretation, navigation, and post-processing. The intuitive and fast-working user interfaces of modern workstations permit the manipulation of the images on the fly including zooming or electronic caliper measurements and using pre-set window and level display settings for viewing. Interpretation of the studies on dedicated radiological workstations using varied post-processing algorithms renders complex anatomy as volumetric structures. The detection of disease is enhanced and sometimes more time-efficient when using 3D tools. Moreover, 3D imaging can increase confidence in the diagnosis and supports communication of the radiological findings to referring physicians. Recent studies have shown that using 3D reconstruction techniques for interpreting volumetric data improves the speed of recognition and interpretation of a variety of clinical conditions.

POST-PROCESSING TECHNIQUES

Image post-processing is the manipulation of radiographic images with the aim to derive additional image information. 2D and 3D post-processing techniques including multiplanar reformation (MPR), maximum intensity projections (MIP), shaded surface display (SSD) and volume rendering (VR) have become routine applications and are included in standard software packages on stand-alone or PACS workstations. Advanced imaging and post-processing tools including computer-aided diagnosis (CAD); vessel centreline extraction for the analysis of vessel diameter and degree of stenosis and composition of atheromatous plaque; perfusion and dual-energy analysis; and organ or bone segmentation tools often need to be purchased separately.

Multiplanar reformations

Multiplanar reformation (MPR) is the simplest post-processing technique that provides alternative viewing perspectives of the volumetric image dataset in coronal and sagittal as well as any other plane. MPR images are obtained by reordering the voxels in the selected image plane excluding those voxels outside the image plane and using conventional window settings. In addition, curved MPR can be performed in which all voxels contained in a user-selectable curved surface are displayed as a single 2D image. Curved MPRs permit the radiologist to follow tortuous structures in their entirety along their anatomical path in a single 2D image which is particularly helpful for visualisation pathology in tortuous anatomical structures such as the vasculature, the intestine and the pancreas.

MPRs are important for visualisation of skeletal disorders (Figure 1A) and in CT angiography studies, but may also add value by providing a quick overview in other scenarios with coronal and sagittal reformats. Increasing the slice thickness of an MPR can improve the image impression in CT studies with increased scatter noise by averaging the attenuation of more voxels for the displayed voxel thereby reducing the effect of attenuation outliers from image noise. Ultra-thick MPRs with a slice thickness of 500mm provide the impression of a conventional plain film radiograph and may be used as a substitute for a baseline image in pelvic trauma patients for whom the initial conventional radiography was withheld.

Maximum intensity projections

Maximum intensity projections (MIP) resemble MPR images by displaying the volumetric dataset in transverse, coronal, or sagittal and often a curved 2D image, but differ in the reconstruction principle: While in MPR images the voxels in the selected volume are displayed as the attenuation average of those voxels as parallel lines traced from the viewpoint to the plane of projection, with MIP images only the voxel with the highest attenuation is displayed for each line (Figure 1B). As a result, the generated MIP image is a 2D projection of a volumetric dataset usually lacking depth information contained in the original data. To add a 3D impression, a series of MIP images can be generated, each one obtained from a slightly more angulated viewpoint as the preceding one creating the perception of rotation, which is of interest when analysing complex vascular structures. MIP images improve the visualisation of dense structures such as contrast attenuated vessels, calcifications, surgical clips, and foreign bodies; also the time needed to analyse complex structures in different planes and with a non-linear course may be reduced compared to viewing the source transverse images alone. Since the MIP technique is computationally fast, it is possible to generate in real-time MIP images with any desired slice thickness, and therefore it is feasible to scroll through the whole scan volume in both directions. This results in improved recognition of dense structures because they are displayed in more than one reconstructed MIP image and are always displayed at maximum size. However, an important shortcoming of MIP images is that high-density structures will obscure information from less dense anatomic structures in the same projection line, for instance the intravascular contrast in vessels may be masked by severe calcified deposits in the arterial wall or by the presence of vascular stent grafts.

Minimum intensity projection

Minimum intensity projection (MinIP) is a variant of the MIP technique in which only the minimum voxel attenuation along a line from the viewer's eye is selected as the value of the corresponding display pixel, thereby highlighting hypodense voxels in the volumetric dataset. The use of MinIP may help the radiologist to evaluate the extent and morphology of

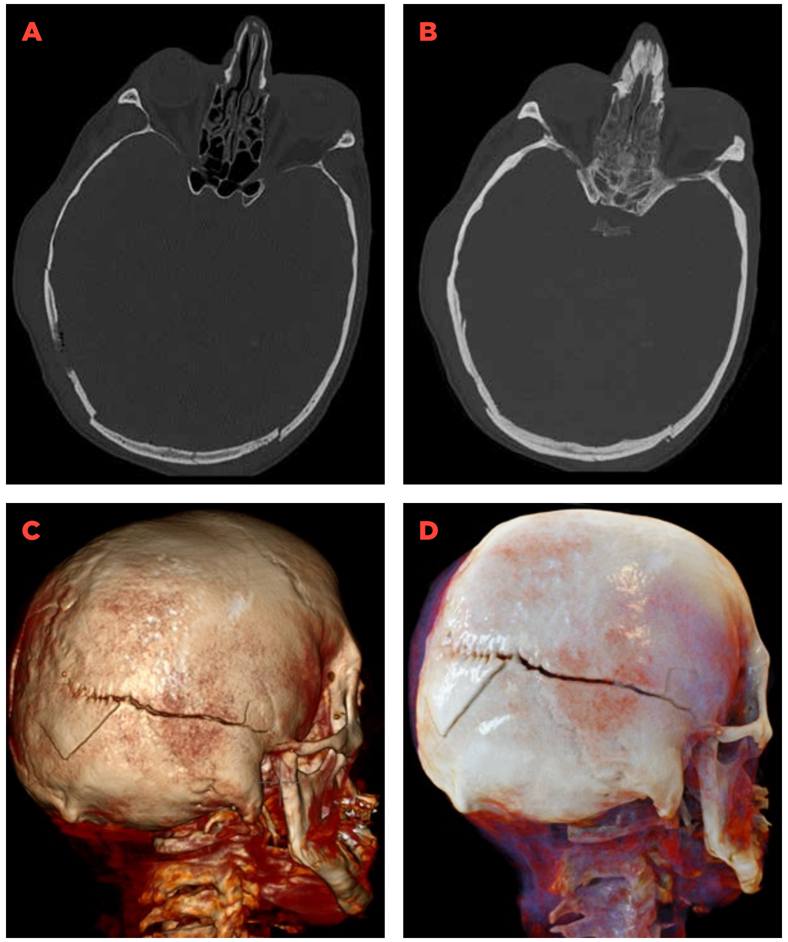


FIGURE 1

43-year-old female patient after blunt head trauma. (A) Transverse MPR provides detailed information regarding the various fracture lines. (B) Thin MIP reformation (thickness 10mm) obscures image information by displaying only those voxels with the highest attenuation in the reformatted image. (C) VR image provides an overview of the course of the fracture lines including depth information. (D) CR adds realistic illumination to the 3D image providing a natural representation of the skull.

low-attenuating structures such as the airways in the case of inhaled foreign bodies.

Shaded surface display

Shaded surface display (SSD) is a process in which apparent surfaces are determined within the volume data and an image representing the derived surface is displayed. In this technique thresholding is commonly used to define the object of interest by comparing each voxel density within a dataset to a threshold value. The surface of the resulting object is then modelled as a number of overlapping polygons derived from the boundary of the selected region of interest while the remainder of the dataset is not displayed. The surface information model is then used to calculate a perspective visualisation based on a selectable observer position and virtual light source positioning.

The principle diagnostic utility of SSD is its ability to represent with great detail structures of a specific density with a clear volume depth cue and may be used for studying fine details such as articular bone surfaces. Moreover, SSD provides superior speed in image rendering compared to other 3D image post-processing techniques, though typically exploits real-time user manipulation of view perspective and virtual light sources and thereby enhances user interactivity. One major limitation of SSD is the simplification of the resulting image with frequently less than one tenth of the dataset being used for SSD image display. Visualisation of other structures requires the successive interactive exclusion/inclusion of different tissue types by varying the threshold and resizing/trimming the region of interest, thus making the interpretation process time-consuming particularly in an emergency situation. Consequently, SSD is almost obsolete today and has been replaced by the volume rendering (VR) technique.

Volume rendering technique

Volume rendering technique (VR) represents a 3D post-processing technique to display the entire volumetric image dataset. VR uses predefined attenuation threshold levels assigned to a specific colour and opacity to determine the tissue represented in each voxel of the volume dataset. Then, for each voxel in the volume dataset the weighted sum of the percentage of each tissue type represented in the voxel is calculated to determine the overall colour and transparency of each voxel. The 3D volume is displayed by simulating rays of light which are projected through the 3D volume that contains the classified voxels. Each voxel which is crossed by the simulated rays modulates the colour of the light depending on the assigned colour and transparency and contributes to the final projection and final image also influenced by partial-volume effects. Finally, 3D perception in the projected image can be enhanced by implementing additional effects such as reflection and shadows on the surface of the rendered image (Figure 1C). The resultant VR images contain image depth information whilst maintaining the 3D spatial relationship. Thresholding, lightning and opacity parameters can be interactively changed and allow a combined display of different aspects such as opaque and semi-transparent structures, thus making this technique optimal for interactive data exploration but inappropriate use of rendering parameters has the hazard of masking findings in the dataset.

Although high computational performance is required for the rendering process, VR has become standard in commercially available radiological software packages and can be considered presently to be the most important 3D post-processing technique. VR is particularly of interest when demonstrating radiological findings to the surgeon or referring physician as the coloured 3D images are frequently easier to understand for non-radiologists than the 2D reformations. Advanced display functions are available including flying-through, flying-around and multiple views of the volume data with independent parameters in equal segments of the displayed window.

Cinematic rendering

Cinematic rendering (CR) has been recently implemented into clinical routine but is currently provided by a single vendor only. It represents a more recent image post-processing technique, sharing similar rendering concepts with VR by including the segmentation of data based on voxel attenuation and using colour look-up tables taking into account opacity and brightness. However, CR differs from VR regarding lighting properties. In general, lighting in 3D rendered images such as VR and CR is a function of ambient, diffuse and specular light properties. In both techniques, the brightness of each voxel is defined by the distribution of these light properties which results in different lighting of different body parts relative to the artificial light source introduced into the volume, giving rise to 3D impressions of the images.

In VR, the individual differences in light emitted onto the voxels are rather small as only one light ray per pixel is modelled. In contrast, CR uses a more complex path-traced lighting model integrating an immense number of light rays, each with different paths to affect each pixel of the rendered image. As a result, the complex physics of the lighting effect can model shadows, ambient occlusion, multi-scattering, and colour transmittance and there are sophisticated camera models as well, which include concepts such as aperture, exposure and shutter speed.

Since the number of light paths which can be traced is in theory infinite, and tracing of light paths is computationally expensive, Monte-Carlo simulations are used to generate a randomised subset of light paths with adequate distribution. In addition, the path-traced CR lighting model takes into account the effect of lighting on other voxels and subsequent reflections; also the effect of body parts blocking the trace from the artificial light source to other structures introduces shadowing into the images. High dynamic range rendering light maps are used for illumination, which lead to natural illumination of the rendered data, in contrast to the more synthetic light sources used in VR (Figure 1D). As a result of the differences in lighting functions, image depth and shape perception are enhanced in CR images providing a more natural and physically accurate presentation of the medical data as compared to conventional VR.

CR images may be – similar to VR – particularly useful in depicting high-contrast structures such as contrast-enhanced vessels and bones. However, despite the potential benefits of CR compared to VR in the visualisation of volume datasets, there is a higher computational demand required for CR because of the more complex lighting model. Therefore, interactive manipulation of the CR image is currently characterised by repetitive recalculation processes.

ADVANCED TECHNOLOGIES TO AID THE RADIOLOGIST

Computer aided diagnosis tools can automatically search an image or dataset and mark candidate abnormalities for re-review by the radiologist. CAD tools have been demonstrated useful for nodule detection in mammograms, chest radiographs and lung CT. CAD has also been implemented to assess filling defects in the pulmonary arteries thereby aiding as a second reader potentially reducing the hazard of false-negative interpretations.

Advanced segmentation tools provide algorithms for threshold-based semi-automatic or

even automatic virtual removal of bones and vasculature from the dataset after contrast injection or for highlighting these structures and removing the remainder from the dataset, easily creating detailed anatomical images of the axial and appendicular skeleton or the entire vascular tree.

Automatic registration of anatomical landmarks in the volumetric dataset helps to align reconstructions to anatomic structures including aligning sagittal reconstructions of the spine to the vertebrae centreline in patients with scoliosis. Another tool permits automatically stretching the rib into lines for the easy assessment of fractures of the thoracic cage in trauma imaging.

APPLICATION OF 3D IMAGING IN THE EMERGENCY ROOM

Vascular emergencies

Vascular emergencies are commonly evaluated by CT angiographic studies. MPR can be used to define the longitudinal extent of vascular pathology. Reformations aligned perpendicular to the vessel centreline, thus displaying the entire vessel midline on a single 2D image, are used to accurately measure luminal diameter and to define the degree of vessel stenosis. Curved-planar reformations may be helpful to assess tortuous vasculature. Post-processing with MIP can produce images resembling that of catheter angiography – in particular when bony structures have been removed from the dataset by the means of semiautomatic or automatic bone removal software. Volume and cinematic rendering enhances the planning of subsequent surgical procedures for pulmonary arteries, acute aortic syndrome, vascular aneurysms as well as peripheral artery disease. VR and CR are particularly useful in displaying the extent of the pathological process to the referring physician and surgeon and in demonstrating the relationship of the pathology to neighbouring anatomical structures.

Abdominal emergencies

Abdominal emergencies of non-intestinal organs are frequently interpreted on axial images alone whereas MPR in coronal and sagittal planes are helpful to follow the course of the intestine, easily allowing an adaptation of the imaging planes optimized to the bowel segment in question.

Multiplanar viewing is extremely useful to determine the transition point from dilated to non-dilated intestine in the case of bowel obstruction and to identify the cause of obstruction. In ureteral stone disease oblique-coronal reconstructions are more effective for precise stone localisation and measurement than axial images. Oblique-coronal reconstructions of CT urography provide images similar to conventional excretory urography.

Trauma imaging

In trauma imaging, MPR in coronal and sagittal planes as an adjunct to transverse images is performed on a routine basis to convey information about the course of a fracture or the extent of deformities and the precise quantification of the displacement of osseous fragments. Curved MPRs can aid in the detection

FIGURE 2

56-year-old male patient after blunt chest trauma. Curved MPRs of the ribs reveal at one glance multiple bilateral rib fractures. Such image post-processing techniques can ease and quicken the analysis of CT images in the emergency setting.

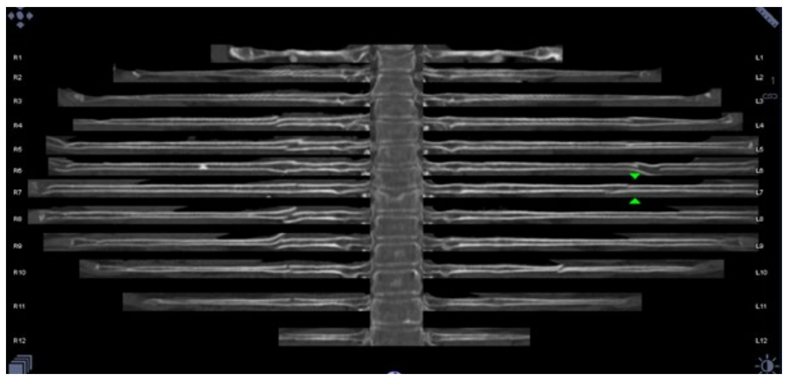
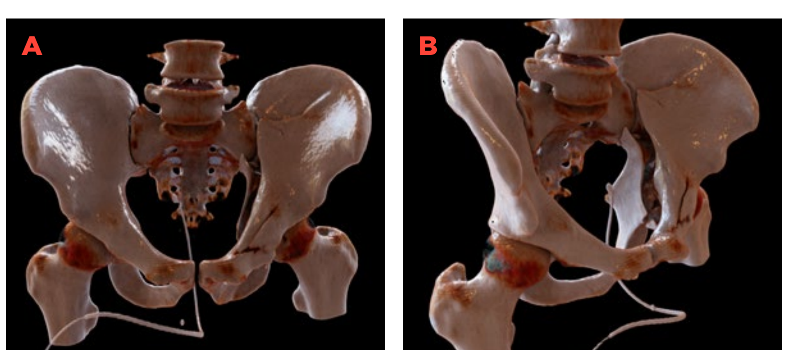


FIGURE 3

42-year-old male after motor vehicle accident. (A and B) Cinematic rendering images of the complex left-sided pelvic fractures. Note the lighting effects leading to a realistic visualisation of the anatomy.



of rib fractures with an acceleration of the reading time of trauma patient chest CTs (Figure 2). 3D reconstructions such as VR or CR display a comprehensible view of damage and are used to demonstrate complex fractures and complicated spatial information about the relative position of fracture fragments (Figure 3). The combination of CT angiography and 3D post-processing in trauma imaging can be used to demonstrate the dislocation of fracture fragments and their relationship to the arteries.

SUMMARY

In conclusion, the rapid acquisition speed of modern multidetector-row CT together with high spatial resolution of the produced images has accelerated the diagnostic workup of patients with traumatic and nontraumatic conditions in the emergency room. As the number of images per CT study have greatly increased over the years, the use of digital viewing and navigation tools are mandatory. 2D and 3D post-processing techniques expedite the comprehensible view of complex anatomy and support the radiologist in providing a time-efficient diagnosis and provide data that affect patient management. In addition, 3D imaging enhances communication of the radiological findings with surgeons and referring physicians. Advanced post-processing tools such as computer-aided diagnosis or structure segmentation tools on today's radiological workstations have undergone an automation process. CT studies are already automatically prepared even before the radiologist opens the images for the first time due to presets provided for the visualisation and segmentation of osseous structures and vascular systems or the coronary arteries.

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2

BLEEDING BRAINS AND CUT CORDS

BLEEDING BRAINS AND CUT CORDS: IMAGING OF NEURO-TRAUMA

BY **CORMAC O BRIEN, MARTIN ARRIGAN, RONAN KILLEEN, GRAEME MCNEILL**

BRAIN AND SPINAL TRAUMA: THE PROBLEM

The human nervous system is an exquisitely complex and sensitive series of interconnected cells that function to control everything that we do, see and feel. Every thought and action originates in our brain and must be transmitted down through our spine and peripheral nerves. Unlike other parts of the body, the brain and spinal cord, collectively referred to as the central nervous system (CNS), have very little capacity for repair. Damage can have catastrophic permanent consequences for the patient.

Brain and spinal cord injuries are common and carry a high likelihood of morbidity and mortality having potentially devastating impacts on the lives of those affected and their families. The most common causes are motor vehicle accidents, trauma and sporting injuries. Patients who do survive are often left with severe permanent neurological deficits, some being left unable to walk or perform their activities of daily living (ADLs) independently. Brain and spinal trauma have massive social and economic costs in society. Patients who injure their spinal cord can be paralysed, suffering from quadriplegia or paraplegia depending on where and what type of injury occurs.

The population who suffer injuries to their spinal cord and brain are disproportionately young with most of their lives left to live. The severity of injury can range from minor to catastrophic or fatal. Data from the Centre for Disease Control in the United States of America suggests that 1.6 million head injuries occur in the US each year with over 50,000 deaths and 70,000 permanent neurological deficits. The 2016 report from the Surgeons' National Trauma Data Bank survey demonstrates that injuries resulting from falls account for 44% of trauma incidents while motor vehicle collisions accounted for 26% of all cases.

Diagnostic imaging plays an important role in decision making for immediate patient management as well as in assessing for potential long-term complications. The true level of minor brain and spine injury may be underestimated as patients can be reluctant to present for fear of implications for their work.

Traumatic Brain injury (TBI) refers to a brain injury resulting from direct or indirect trauma. TBI covers a diverse range of injuries and it results in a broad set of outcomes such as cognitive deficits, memory disorders, attention loss, impaired executive functioning, increased risk of mental health issues such as post-traumatic stress disorder or depression, headache, and sleep disturbances.

Injuries to the vertebrae are common and they can put the patient at risk of spinal cord injury with associated potentially permanent neurologic deficits. Traumatic spinal cord injury (SCI) can have a profound impact on a patient's physical and psychosocial well-being. The incidence of traumatic SCI is estimated to be 30 to 80 new cases per million inhabitants per year. The major causes of spinal trauma are falls, traffic accidents, sports and blunt impacts. The cost to individuals and society is enormous due, once again, to the predominance of injuries in younger people with otherwise long life expectancy. Although SCI remains a devastating injury, the standard of care has improved steadily over the years with the involvement of intensive monitoring and rehabilitation in the post-acute phase. Rapid diagnoses with an accurate and detailed characterisation of the injury are vital to make sure the patient gets the right treatment in a timely manner. Quick identification of fractures, haematomas, and other compressive lesions on the spinal cord can help guide surgical intervention and improve outcomes. Imaging helps to diagnose complications early, before they may have caused irreversible damage and can help predict long-term outcomes. The radiologist plays a pivotal role in the gathering, interpretation and communication of this information.

THE CHALLENGE OF DIAGNOSIS AND THE ROLE OF RADIOLOGY

In an emergency setting the clinician needs to obtain the relevant information as quickly as possible. The initial history and neurological examination is the most important instrument for the assessment of the severity level of brain and spinal cord injury. This is primarily achieved through asking the patient about their symptoms and performing a primary and subsequent secondary survey. The primary survey involves a rapid assessment of the patient's airway, breathing, circulation and neurological status. When the patient is stabilised, this is followed by a secondary survey which involves a top to toe examination to identify the presence of other injuries. Frequently patients have several compounding and distracting injuries; they may be in pain, in a state of intoxication or may not be fully conscious. Patients with spinal or brain trauma may even be asymptomatic during initial assessment. Certain common examination findings such as reflex testing can often be unreliable in the acute phase as the acutely injured patient may be suffering from a 'spinal shock' at or below the level of injury. In high pressure trauma situations where every second counts it is often impossible to take a full neurological history and perform a full examination. Alertness and consciousness are assessed clinically using the Glasgow Coma Scale (GCS) (table 1).

Before the 1970s when computed tomography (CT) imaging began to emerge, it was extremely challenging to assess a patient with suspected brain or spinal trauma. At that time the standard of care included plain radiographs looking for broken bones in the skull or spine with subtle signs such as an air-fluid level in the sinuses to suggest fractures. It was often impossible to be certain what was going on in a person's brain or spine. The full diagnosis often would only have been discovered during post-mortem examinations.

Early aggressive treatment can have a massive impact on the outcome for patients after head and spinal trauma. The ability to visualise and diagnose problems with the brain, spine and skull can allow assessment of their operability. The images give the surgeons the opportunity to see exactly where the bleeding or injury is and it helps them plan the best approach to the surgery; the optimal point at which to make the incision or place a therapeutic pressure-relieving hole in the skull to relieve pressure in a swollen brain.

Prognostic information is important to patients and their families. In the early days after an injury, patients and their families want to know what level of function they can hope to achieve and whether they will be able to perform self-care activities such as feeding, bathing, and clothing. Even in the short history of radiology, CT is a relatively recent phenomenon. Since its introduction, CT has revolutionised the management of acute brain and spinal trauma. Nowadays there is consensus that acute traumatic injuries in the brain and spine are best initially evaluated by CT. CT imaging, also known as 'CAT scanning', was first developed in the late sixties by British engineer Godfrey Newbold Hounsfield of EMI Laboratories based on the work of physicist Allan Cormack who were both later awarded the Nobel Prize for their contributions to medicine and science.

CT scanners use narrow x-ray beams which travel through the skull and spine at a variety of angles. These various x-ray images are gathered and processed by computer calculation into a series of highly detailed two dimensional slices. The variation in the amount of x-ray beams being blocked by different tissue or bone mean that different parts of the brain and spinal cord are brighter and darker. Anatomical and pathological data is then collected and processed in multiplanar reconstructions enabling the radiologist to visualise the brain in different planes. The first clinical CT scanners were designed to assess the head and brain, with larger models that could image the spine only emerging later. Brain imaging was the natural choice for initial studies both as the technology grew out of a diagnostic need and the fact that it was easier to scan brains than other parts of the body. The original scanners took several hours to acquire the raw data for a single scan or 'slice' and it took days to reconstruct a single image from this raw data. CT has made great improvements in speed, comfort and resolution. Faster scanning helps to reduce artefacts such as patient motion. This is particularly useful in brain and spinal trauma cases as patients are often confused, agitated and in severe pain. Great work has been done to maintain image quality with significant reduction in radiation dose. Nowadays modern CT scanners collect 16 slices of data in less than a second, at a low dose, and reconstruct high quality images almost instantaneously.

Magnetic resonance imaging (MRI) avoids ionising or x-radiation, instead using the variation produced when the body is placed in a strong magnetic field. MRI uses both static and dynamic magnetic fields to generate signals from water protons in the human body. T1 and T2 times refer to the length of time it takes for the spinning of the proton to return to normal after a magnetic pulse is applied in the longitudinal and transverse directions respectively. These combined developments in the imaging of brain and spinal trauma meant that radiologists were suddenly able to diagnose critical and urgent pathology in the brain and spine that would have been impossible in a living person only a decade previously. Complications of trauma such as epidural haematoma or spinal cord compression can be identified in the acute phase using the modalities of CT and MRI with a much higher sensitivity and specificity than physical examination. This means that the patient can get appropriate timely treatment that results in vastly improved long term outcomes.

How and when to image?

Imaging is invaluable in the initial assessment of patients presenting to the emergency department after trauma of the brain and spinal cord. Radiologists play a vital role in tailoring the study to gain as much information as possible (e.g. the use of intravenous contrast with a scan timed to assess for vascular damage) without jeopardising patient care or safety. Patients with moderate or severe

TABLE 1

Glasgow Coma Scale

CLINICALLY	RESPONSE	SCORE
Eye Opening	Spontaneously	4
	To Speech	3
	To Pain	2
	No Response	1
Verbal Response	Orientated to time place and person	5
	Confused	4
	Inappropriate Words	3
	Incomprehensible Sounds	2
	No Response	1
Motor Response	Obey Commands	6
	Move to localised pain	5
	Flexion withdrawal from pain	4
	Abnormal flexion	3
	Abnormal extension	2
	No Response	1
Total Score	Best Response	15
	Comatose	8
	Totally Unresponsive	3

brain or spinal trauma will often receive a CT scan immediately. In some cases patients can be monitored for a period of time instead of getting scanned. The role of imaging in minor trauma is more difficult and several evidence-based algorithms have been developed for diagnostic imaging. The most commonly used clinical criteria that we use to help us decide which patients with minor head and spinal trauma should get a brain or cervical spine CT are known as the Canadian CT Head Rules and the Canadian C-Spine rules (table 2). Guidelines like these help decide when it is safe to avoid imaging, thus reducing cost and radiation exposure to patients.

Intoxicated patients present a challenge as not only are they more susceptible to trauma, they are often harder to assess. Chronic alcohol consumption can impact brain size which means that there is more room in the skull and more chance that an injury will cause a problem. Other important factors that should be considered are that children are less likely to have any signs or symptoms; this can lower the threshold to image when there is a significant mechanism of injury. Patients on long-term blood thinners, for indications such as heart arrhythmia and stroke or heart attack prevention, will have an increased bleeding risk and if they do bleed an increased risk of it being catastrophic. Very high risk trauma cases such traffic collisions are often imaged in the absence of physical findings.

TABLE 2

Canadian Head CT Rules

CANADIAN HEAD CT RULES	IDICATIONS FOR SCAN IN CASES OF MINOR TRAUMA
HIGH RISK	GCS < 15 at 2 hours
	Suspected open or depressed fracture
	Signs of base of skull fracture
	Over 2 episodes of vomiting
	Age over 65 years
MEDIUM RISK	Amnesia of events leading up to impact
	Dangerous mechanism of injury such as pedestrian struck by a vehicle

CT scanning is excellent at identifying acute injuries that need urgent neurosurgical interventions such as a bleed causing a mass effect in the brain. CT provides excellent information about bones and haemorrhage as well as characterising foreign bodies such as metal. It is cheap, rapid and readily available. Images are processed using complex computer algorithms to differentiate soft tissue, air and bone. Images through any area of the brain can be retrospectively processed if finer detail is required. 3-D reconstructions can be created to act as an aid to surgical planning or to present information to the referring doctors (Figure 1). Even in patients who do not need immediate surgery, CT scanning can be used to identify and monitor pathology that will need close follow-up.

Patients who have small bleeds in their brain are often re-scanned after a short interval to make sure the bleed hasn't enlarged or that they are not developing swelling and oedema of the brain. Sometimes the appearances on imaging can lag behind actual damage and examinations performed in the first three hours can underestimate the damage that has been caused. If the initial CT shows small or moderate size collections of blood, subarachnoid bleed or extradural bleeds, then they are usually admitted and rescanned in 24 hrs if there is any clinical deterioration.

MRI brain studies are usually used several days after acute injury. MRI brain is rarely used in the emergency setting as the acquisition of images takes a relatively long time and is very susceptible to patient motion. In addition, it is difficult to monitor unstable patients in the MRI scanner. Patients with significant collections of blood which are detected early often end up going on to get neurosurgical intervention and can make an excellent functional recovery with adequate care.

Normal CT brain or spinal cord does not fully exclude pathology. CT is limited with regard to subtle injuries such as microstructural white matter damage, spinal cord oedema or diffuse vascular injury and does not adequately assess the spinal cord (Figure 2). MRI is extremely sensitive and may help the diagnosis especially in cases where the patient is difficult to assess, but it can take up to an hour to perform a full scan which can delay treatment decisions.

CONDITIONS PICKED UP ON BRAIN AND SPINAL IMAGING

Intracranial pressure (ICP)

The most urgent and potentially treatable complication on head trauma is increased intracranial pressure (ICP). The brain lies in a rigid skull with minimal free space to expand. If blood builds up inside the skull, intracranial

FIGURE 1

3-D reconstruction of an intracranial angiogram.

FIGURE 2

Diffuse axonal injury. This patient presented after head trauma with a normal CT brain. This image demonstrates multiple dark areas in the left frontal lobe (white arrow) on gradient echo MRI consistent with magnetic susceptibility from haemorrhagic diffuse axonal injury.

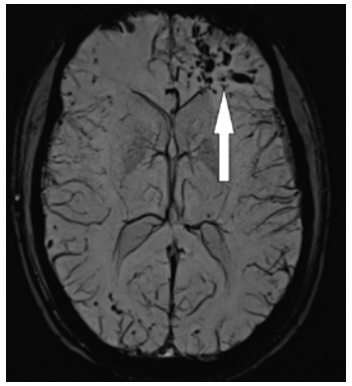


FIGURE 3

Non-contrast CT scan of the brain demonstrating normal sulci (white arrows) on the right side of the picture with loss of sulci due to a bleed on the left side of the picture (black arrows).

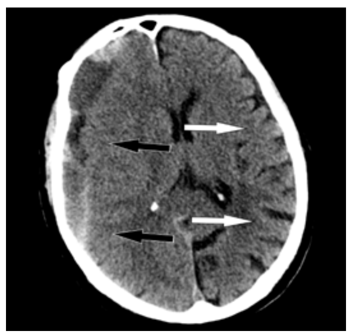
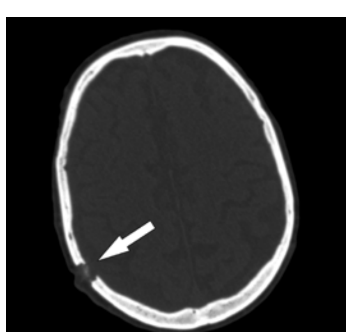


FIGURE 4

CT scan of the brain performed to assess the skull shows a defect in the right of patient's skull, consistent with a 'Burr Hole': an emergency procedure used to allow drainage of blood and reduce pressure on the brain.



pressure increases. When ICP exceeds a critical point, parts of the brain can be displaced and herniate with catastrophic consequences. The vessels supplying and draining the brain come under pressure and supply can be cut off with that part of the brain getting too little blood resulting in ischaemia and possibly eventually necrosis or ending in infarction (Figure 3). Acute blood in the brain can be deposited in the cerebrospinal fluid (CSF) containing ventricles. This blocks the absorption of CSF with subsequent build-up of fluid in the brain known as hydrocephalus. Alternatively, ICP can increase if the brain becomes swollen in what is referred to as cerebral oedema. If increased pressure is suspected, the immediate treatment involves osmotic agents, hyperventilation and surgical evacuation. Surgical evacuation involves the release of pressure by either creating a small hole in the skull known as a Burr hole or more commonly a segment of the skull is removed in what is known as a craniotomy (Figure 4).

Herniation

Brain herniation is a potentially devastating complication of increased intracranial pressure. This is when brain in one part of the skull moves to another compartment or when a part of the brain is squeezed out of the skull towards the spinal canal. Herniation is often fatal due to the effect on blood flow and resulting 'brain death' due to compression of the brainstem. Once the complications of herniation have developed, it is often too late to intervene. The role of imaging in emergency situations is to identify the features of impending herniation, where quick neurosurgical intervention

may save the patient's life and avert disaster (Figure 5).

Diffuse axonal injury (DAI)

Diffuse axonal injury refers to damage to neurons caused by rapid shearing, rotational and deceleration forces in the brain tissue, and is very common in car accidents. It can tear and damage the long cables which carry signals in the brain called 'axons' and impair or destroy their ability to carry signals around the body. Up to 20% of patients with moderate to severe TBI will have a normal CT brain on the day of admission.

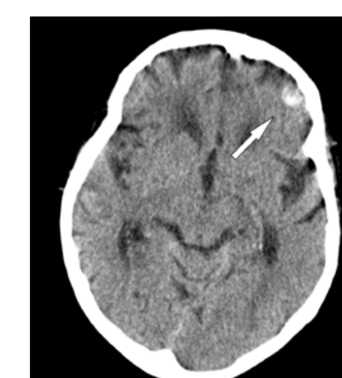
DAI is identified in most cases of lethal brain injury and it is likely that DAI is a major mechanism of severe disability in TBI survivors. MRI is more sensitive than CT for DAI or shearing injury. DAI is often initially considered in patients who lost consciousness at the moment of impact where the clinical exam is far worse than the findings on initial CT scan. DAI is often diffuse, frontal and bilateral occurring in the deep white matter and at the grey-white matter interface. The volume and quantity of lesions correlates with the likelihood that the patient will have a poorer outcome. Haemorrhagic DAI are seen as foci or high attenuation on CT. However DAI is non-haemorrhagic in the majority of cases and CT is therefore often normal. MRI is a much more sensitive modality for the detection of DAI. Consequences are serious with patients who recover usually demonstrating lingering effects such as headaches and cognitive deficits. Patients with widespread MRI abnormalities or brain stem

FIGURE 5

CT scan demonstrating herniation of the brain (white arrow) in this patient with acute bleed.

FIGURE 6

Acute bleeds show up as bright areas of high attenuation on CT scans (white arrow).



injuries will usually show minimal neurological recovery even if the CT is normal and there is no evidence of raised ICP.

Haemorrhage

In the context of trauma, the ability to diagnose and rule out intracranial bleeding is one of the primary responsibilities of the radiologist. The most frequent indication for referral is that of 'query haemorrhage'. The job of recognising, diagnosing and treating traumatic causes of intracranial haemorrhage is the day-to-day bread and butter of an emergency radiologist. Brain imaging is used not only to detect bleeds but also to monitor for complications such as mass effects and herniation. As the western population ages there are increasing numbers of patients who are taking long term blood thinning medications for a variety of reasons. Many of these treatments are revolutionary and increase overall survival for a broad cross-section of the population. The trade off with new anticoagulation medication is the increased risk of a bleed if a patient suffers even mild head trauma and increased risk of that being a catastrophic event if they do bleed (Figure 6).

Bleeding can be within the substance of the brain or intra-parenchymal or overlying the outside of the brain in an extra-parenchymal or extra-axial location. There are several layers of tissue between the brain and the bony skull. The thin pia layer which lies directly on top of the brain, the arachnoid layer which covers this, and the thick dura layer which lies just inside the skull. We divide extra-axial bleeds into extradural (between the skull and dura layer), subdural (between the dura and arachnoid), and subarachnoid (between the arachnoid and brain). Haemorrhages can lead to brain herniation, oedema and hydrocephalus, causing significant morbidity and mortality.

Bleeds can have a variety of appearances on CT depending on the acuity of the blood. In acute trauma, blood is very bright. If the radiologist is able to identify a swirl pattern within the bleed, this suggests that the patient is bleeding actively and is an indication for emergency treatment. If a patient is very anaemic with a low haemoglobin level, it may be difficult to detect the blood. Initially bleeds are brighter than the brain matter. Following the first 24–72 hours the blood begins to become darker, appearing as dark as the brain and later even becoming as dark as cerebrospinal fluid after about 1 month (Figure 7).

MR imaging has enhanced the evaluation of intracranial haemorrhage. The MRI appearances of blood evolve as the bleed matures. After a few hours the haemoglobin in the red blood cells loses its oxygen and becomes deoxy-haemoglobin. This concentration of red blood cells with fibrin causes low signal on T2 weighted MRI images. As the mixture is broken down, the deoxy-haemoglobin changes once again, this time into methaemoglobin, which has a strong magnetic signal in an MRI scanner and shows up easily. If tiny bleeds are reabsorbed as the brain is healing, they will often leave behind traces of iron from the blood known as hemosiderin deposition; dedicated MRI sequences known as gradient echo or susceptibility weight imaging are exquisitely sensitive at picking up such deposits.

Intraparenchymal haemorrhage

Traumatic bleeds in the substance of the brain, known as haemorrhagic contusions, are very common in patients with trauma. They are most severe where the brain collides against the skull, which is typically at the base of the brain in the frontal and temporal lobes. When the brain collides against the skull, this is called a 'coup injury'. If the brain bounces back and hits the side of the skull opposite to where the trauma is being inflicted, this is called 'contra-coup injury' (Figures 8A, 8B). Bleeds show up as bright areas of high attenuation on CT, often with a surrounding rim of dark low attenuation oedema. MRI is also effective at demonstrating both the bleed and the swelling. Imaging is vital as these patients often develop complications of mass effect and increased pressure in the skull. Imaging aids the physician in planning and optimising the timing of life-saving pressure-reducing surgeries.

Sub-arachnoid haemorrhage (SAH)

This refers to bleeds between the brain and the layer immediately adjacent to it called the arachnoid. Traumatic subarachnoid haemorrhage is usually close to the site of impact or over the top of the brain, unlike haemorrhage associated with aneurysms that are usually centred at the base of the brain. SAHs are more common in children and the elderly. They often lie adjacent to a contusion. Before the arrival of CT the only way to diagnose them would be to perform a lumbar puncture to obtain a sample of spinal fluid looking for traces of blood products. CT is faster, safer, less invasive and almost as sensitive as CSF

FIGURE 7

CT scan of the brain showing a chronic subdural bleed demonstrating older blood which is lower in attenuation or darker (white arrow).

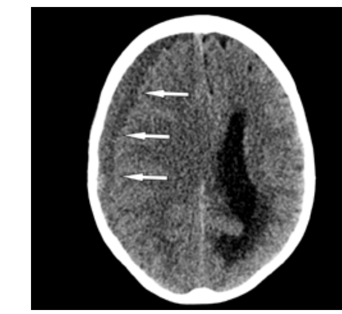


FIGURE 8

CT scan of the brain demonstrating a 'coup' injury with intraparenchymal bleed and oedema in the anterior part of the brain, near where the patient was struck in the head.

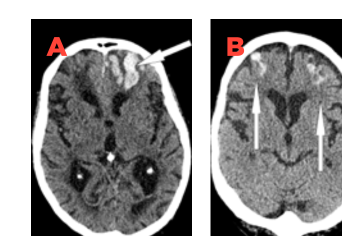


FIGURE 9

CT scan showing a cerebral contusion (white arrow) with subarachnoid extension into the ventricles (black arrow).

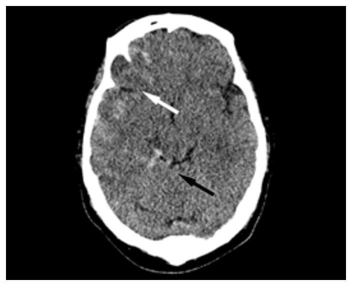
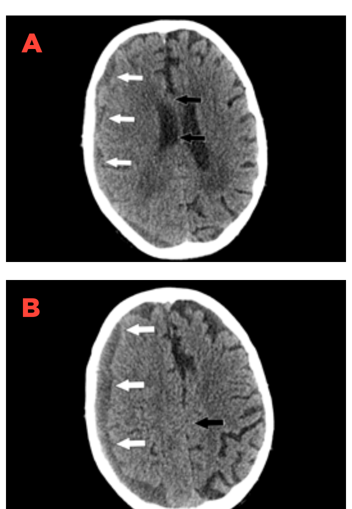


FIGURE 10

CT scan demonstrating a subdural haematoma (white arrow) with midline shift and effacement of the ventricles and sulci (black arrow) on the right side.



analysis. Modern MRI techniques are said to be even more sensitive but CT is more appropriate for use in the emergency setting. If blood extends into the ventricles it can block the flow and reabsorption of cerebrospinal fluid in the brain leading to a build-up of pressure and hydrocephalus (Figure 9).

Subdural haemorrhage (SDH)

This is a bleed between the arachnoid and the dura layer overlying the brain which expands slowly as these bleeds originate mostly from low pressure veins. Small subdural haemorrhages can be relatively subtle on CT when they spread along the skull in a convex manner. As the bleed matures and a clot forms it becomes darker; approaching the attenuation of normal brain after a few days which can lead to diagnostic difficulties. The role of the radiologist is to identify dangerous features that require urgent surgical decompression such as mass effect, shift of midline structures, or brain herniation (Figures 10A, 10B, 11A, 11B).

Epidural haemorrhage

Epidural or extradural haemorrhage is a bleed just inside the skull which can expand with ferocious speed and is often associated with skull fractures. These haemorrhages are associated with damage to an artery, these carry flowing blood at high pressures which explains why epidural haematomas can grow very quickly. Patients often present with a 'lucid interval' after trauma where they recover temporarily and prompt imaging is vital in reaching the diagnosis. By the time the patient develops symptoms it may be too late to intervene. There can be a subsequent rapid decline as the blood builds in the skull compressing

and displacing vital parts of the brain. Timely identification of an epidural haematoma is vital. Surgery to evacuate the blood saves lives. CT is the optimal method for evaluation and demonstrates a bright lens-shaped appearance. It may cross the midline but does not cross sutures unless there is a fracture across the sutures (Figure 11C).

Foreign bodies

Foreign bodies can injure the brain and spinal cord with direct laceration, shock wave transmission and cavitation. Imaging patients who have been involved in high impact trauma or who have been injured with knives or projectiles provides a massive diagnostic challenge.

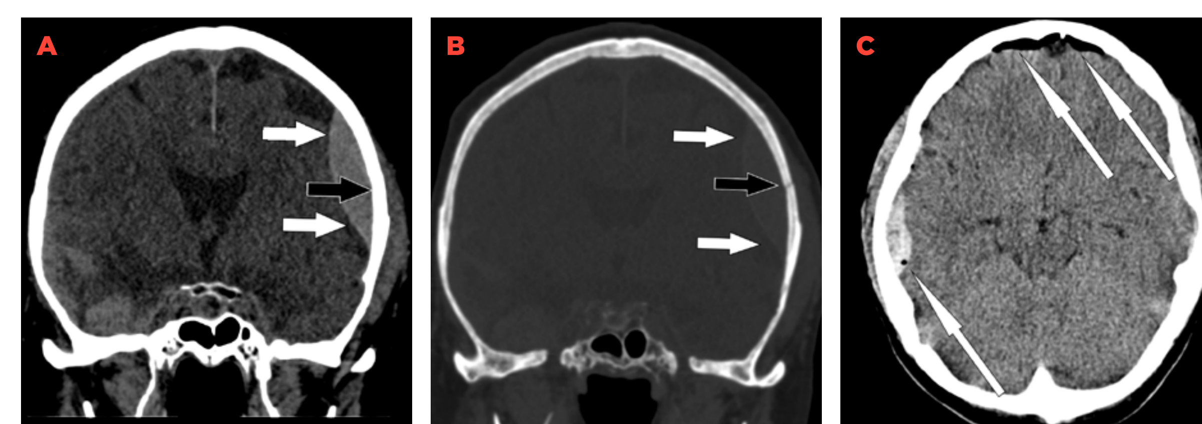
The best initial modality is often CT. If there are pieces of the object left in place, this may degrade and lower the quality of images produced. MRI is an alternative that is not as sensitive to artefacts such as beam hardening but this comes with a significant risk that the magnetic field may dislodge any retained pieces of metal and cause further injury (Figure 12).

Vascular: dissection aneurysm and fistulae

If the mechanism of injury is concerning for vascular injury, i.e. stabbing or projectile, then the radiologist has several options for imaging the blood vessels. Imaging is used to detect damage, plan the best way to repair

FIGURE 11

(A/B): CT scan demonstrating an epidural haematoma (white arrow) with an associated fracture through the left side of the skull (black arrow). Note that the blood is a similar shade of grey to the adjacent brain, suggesting that it is not acute.
(C): Extradural haematoma with associated skull fracture. There is a small black focus in the bright blood (white arrow) which tells the radiologist that there is gas inside the skull vault; this indicates a skull fracture and a significant mechanism of trauma.



the vessels and gather information about the size and location of any lesions. Endovascular angiography is the gold standard where a narrow catheter tube is passed over a wire into the brain arteries via the arteries in the leg or the arm using fluoroscopy in the interventional radiology suite. This directly establishes the shape and condition of the arteries. This technique has the advantage that the radiologist could potentially intervene and treat the patient during angiography. CT angiography is a non-invasive alternative that allows excellent assessment of blood vessels.

In many trauma cases, patients will have a range of complicating injuries which could make a big open operation unsafe, meaning that endovascular repair which is less invasive is frequently preferable. If a vessel is bleeding and cannot be fixed it many need to be occluded. The first port of call in the emergency room remains an initial non-contrast CT brain. Giving iodinated contrast initially can obscure a bleed. Contrast shows up bright on CT and can appear similar to blood in the acute phase. CT angiogram can be performed by injecting contrast before and during scanning. The scan can be timed to allow assessment of the arteries or veins. Magnetic resonance angiogram is an alternative option which can characterise the blood vessels using a variety of techniques often without the use of contrast. CT and MRI angiography have the advantage of being lower risk than invasive angiography with fewer complications and providing additional information about the outer wall of the blood vessel and about the surrounding brain tissue (Figure 13).

FIGURE 12

Radiograph and CT showing a dense foreign body in the left sphenoid sinus (red arrow). There is a small dark area on the skull radiograph in keeping with air in the skull (white arrow). This patient received a gunshot wound to the head.

Ischaemia

The brain is a highly metabolic organ which uses an enormous amount of oxygen and any interruption in blood flow can cause immediate and permanent damage. Most of the injuries that take place in a trauma situation such as bleeding or fracture can result in a part of the brain becoming poorly supplied by blood.

SPINAL CORD INJURY

When it comes to spinal cord injury, time is critical and unnecessary delay in treatment can have a massive impact. Selecting the most appropriate examination, performing the scan and reporting the results to the team as efficiently as possible is vital. The job of the radiologist is threefold: rapid depiction of the spinal cord, identification of unstable injuries, and helping to figure out which patients need immediate surgery. Compression of the spinal cord can cut off sensation and motor function to everything below that level. Imaging quickly can help identify an area of the cord that is under pressure so that it can be fixed before it becomes irreversible (Figure 14). For low-risk patients, plain radiographs are commonly used in conjunction with clinical assessment. Clinical findings include altered sensation, limb weakness and urinary incontinence. Standard x-ray images are inexpensive and available but not very sensitive. CT is more sensitive for detecting injury and is often used in the first instance to assess moderate and high risk injury. For assessing the spinal cord directly, MRI is essential. MRI can be used as the first investigation in patients who are very high risk or to further characterise potential

FIGURE 13

In this 31-year old female a filling defect is shown in the basilar artery (white arrow) following a road traffic accident. This patient had an injury to one of the arteries in the neck (not shown) that supplies the basilar artery. The basilar artery is the main blood supply to the back of the brain and blockage can result in a stroke.

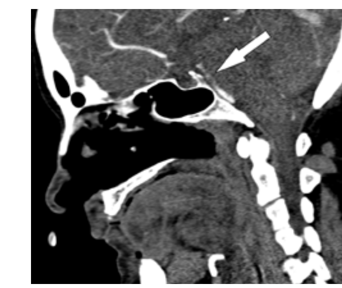
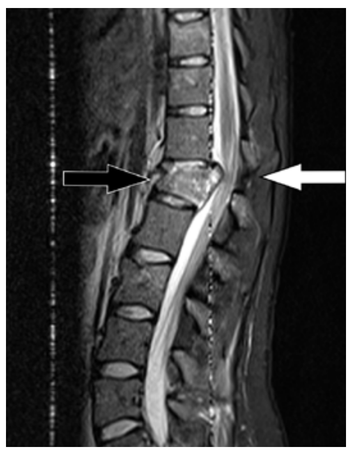


FIGURE 14

T2-weighted MRI of the spinal cord demonstrates swelling and oedema of the upper cervical cord (white arrow) with a complete transection through the lower cord (black arrow).

FIGURE 15

MRI demonstrating burst fracture of the spine (black arrow). The swelling of the spinal cord shows up excellently as an area of high signal (white arrow) on this T2 weighted sagittal MRI sequence.



spinal cord injury detected on CT. Trauma MRI provides excellent information on the cord and soft tissue structures such as muscles, ligaments, discs and nerves. MRI spine images are most commonly from side to side, in a sagittal plane. This compares to CT images which are usually acquired from the top down in an axial transverse plane and the information reformatted into all other directions and viewpoints. Axial transverse top-down MRI images of the spine are very good at identifying clinically relevant lesions such as disk herniation or haematomas that can cause spinal cord compression but sagittal images allow the radiologist to compare different sections of the cord in one image and they have great prognostic value.

The main sequences are fluid sensitive sagittal T2 to evaluate the cord with a 'gradient echo' sequence that is used to detect small haemorrhagic cord contusions. Fat-supressed STIR sequences can help to evaluate for bone damage. The presence of a fracture increases the chances of a spinal cord injury as does the presence of degenerative bone disease such as osteophytes (Figures 15, 16A, 16B). The extent of spinal cord injury (SCI) can be evaluated on MRI. There are several signal patterns that correlate with prognosis. The degree of maximal cord compression, extent of cord haemorrhage and degree of swelling have a direct correlation with outcome and this information helps guide decisions on how urgently to intervene. The prognosis can vary from the best predicted outcome in a normal appearing cord where the architecture is preserved, with worsening outcome if there is single or multi-level oedema, with the worst outcome associated with mixed haemorrhage and oedema or architectural distortion such as

transection and penetrating injury. The higher the injury in the spinal cord the greater the level of functionality that will be lost.

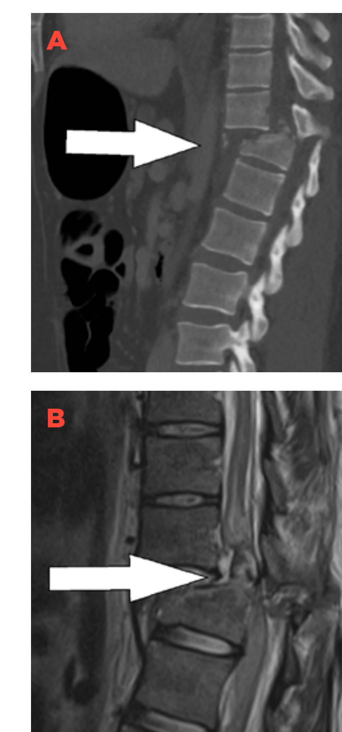
MRI is not only used as a primary investigation or to evaluate damage picked up on CT but also used in cases where CT scans are completely normal. In some cases initial investigations with radiographs and CT may be normal but the spinal cord may still be damaged. 'Spinal cord injuries without overt radiological abnormality' (SCIWORA), a term first coined in the 1980s, occurs when there is discrepancy between what is seen on CT and what is found on clinical examination and history taking. It is a common indication for MRI. Risk factors to suspect SCIWORA are having been subjected to blunt trauma or suffering from early or transient symptoms of neurologic deficit. Spinal cord injuries can and do occur in the absence of injury to the bony spinal column. SCIWORA injuries underline the importance of MRI in evaluating acute spinal cord trauma.

SUMMARY

Brain and spinal trauma can have catastrophic consequences for patients and their families. The pathway for patient assessment and treatment has evolved and changed dramatically over the past number of decades. Cross-sectional imaging allows us to visualise what is going inside the brain and spinal cord in ways that would have been unthinkable only 50 years ago. CT and MRI scanning allow us to gain information on the presence and extent of damage to the brain and spinal cord which affects treatment and helps save lives. With advances in technology, scanning is becoming ever faster, safer and more accurate, and patients can now be scanned in a matter of seconds. Radiologists can help guide the best imaging methods, diagnose urgent injuries, and direct and help enact lifesaving treatments.

FIGURE 16

(A): CT Spine with a displaced fracture of the twelfth thoracic vertebral body. (B): T2-weighted MRI which demonstrates a complete tear across the spinal cord, transection (white arrow) at this level.



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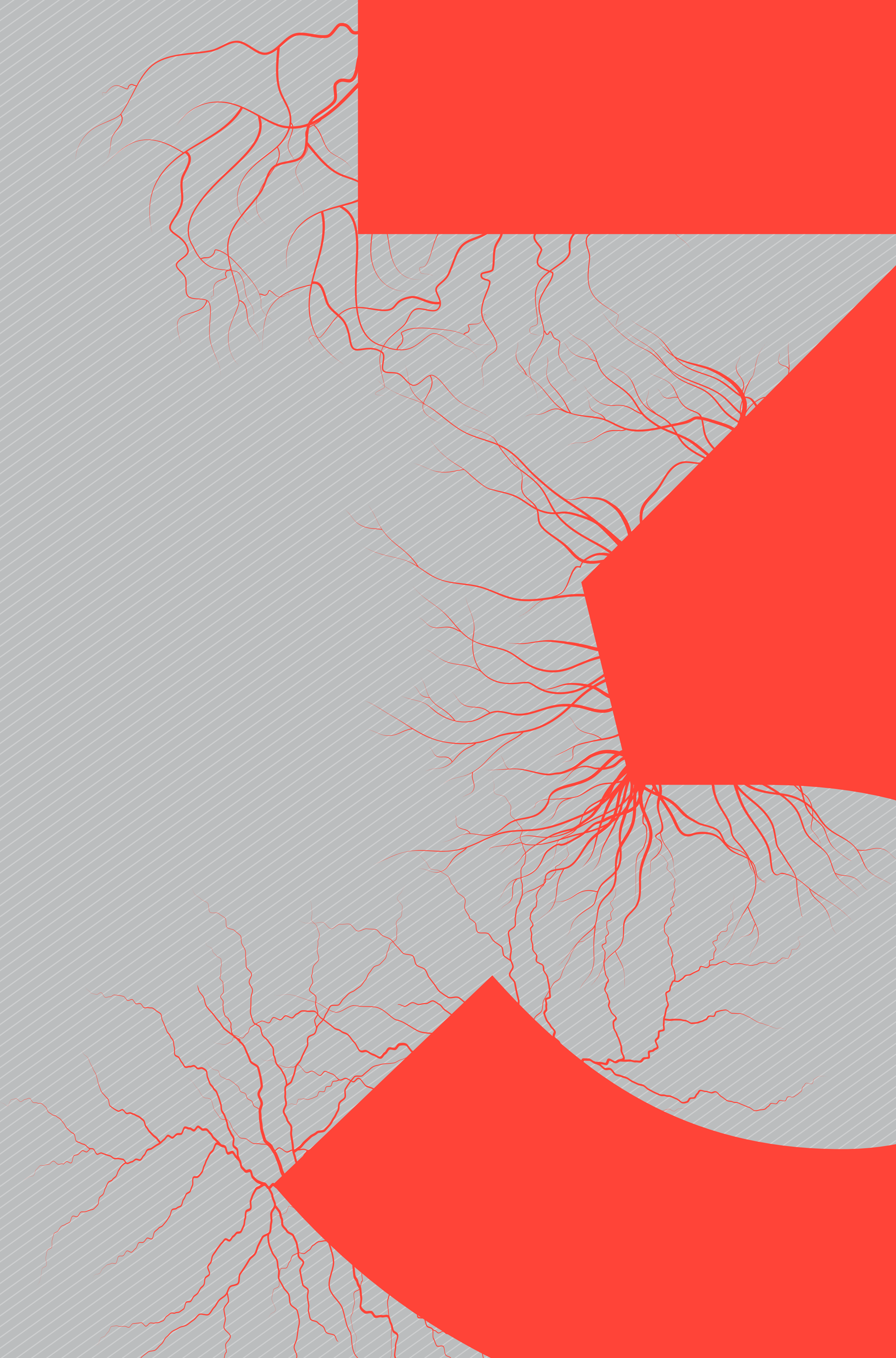


3

A SEARCH-LIGHT THROUGH THE FOG

A SEARCHLIGHT THROUGH THE FOG: IMAGING OF NON-TRAUMATIC NEURO-EMERGENCIES

BY **ASIF MAZUMDER**

Imaging is they keystone of many patient pathways.

However, many acutely unwell patients with neurological disorders present without a history of trauma. Trauma is the dramatic face of medicine that is often portrayed on late evening television specials and long running hospital dramas. However, non-traumatic neurological illness can be catastrophic to the patient and can lead to chronic disability or indeed death if not diagnosed and treated early. Confusingly, many diseases that do not require emergency treatment can mimic other more pressing conditions, which can be testing for the physicians at the bedside. The trusty stethoscope, tendon hammer and red lapel pin has thus made way for more advanced technology to help decipher the complexity of acute neurological conditions. The onus now falls on neuro-imaging to help unmask the patient's underlying pathology and the dependence on this technology continues to increase as imaging increases in sophistication, and more treatments become available.

With the advancement of imaging technologies, the speed of acquisition of brain imaging has increased exponentially, to it now being possible to acquire a volumetric computerised tomography (CT) study of the head in seconds. In fact, it can take longer to take the patient to and onto the scanner than it takes to acquire the images. This rapid assessment tool now enables doctors to evaluate patients who were impossible to diagnose or scan previously, such as those who are unable to lie still for a long period of time and patients who are critically unwell. These can now be rapidly evaluated with CT imaging, saving time and increasing the chance of making a crucial finding.

Magnetic resonance imaging (MRI) clearly has an advantage over CT in that it does not expose the patient to ionising radiation, and provides excellent detail of the different structures within and around the brain (called tissue contrast). This method, especially within the brain, has proven to be invaluable in making subtle findings. MRI technology continues to forge ahead in leaps and bounds, and not just for research purposes within the academic sphere. Increased field strength imaging at three tesla (3T) is now commonplace, and has helped in many diseases including in the management of patients with epileptic seizures, enabling better detection of subtle lesions near the edge of the brain that can be potentially treated with surgery, curing the epilepsy and potentially removing the need for medication. Progress presses forward, with even higher field strength imaging giving us more even more detailed views of the brain, including the arterial blood vessels and hippocampus, the latter a key structure in memory and seizures (Figures 1 and 2).

FIGURE 1

The image depicts a modern 64 slice CT scanner, able to rapidly acquire images of an ailing patient that can be reconstructed in three planes quickly and easily.

FIGURE 2

The picture shows a modern three tesla (3T) MRI scanner that is able to produce high quality imaging of the brain and spine.

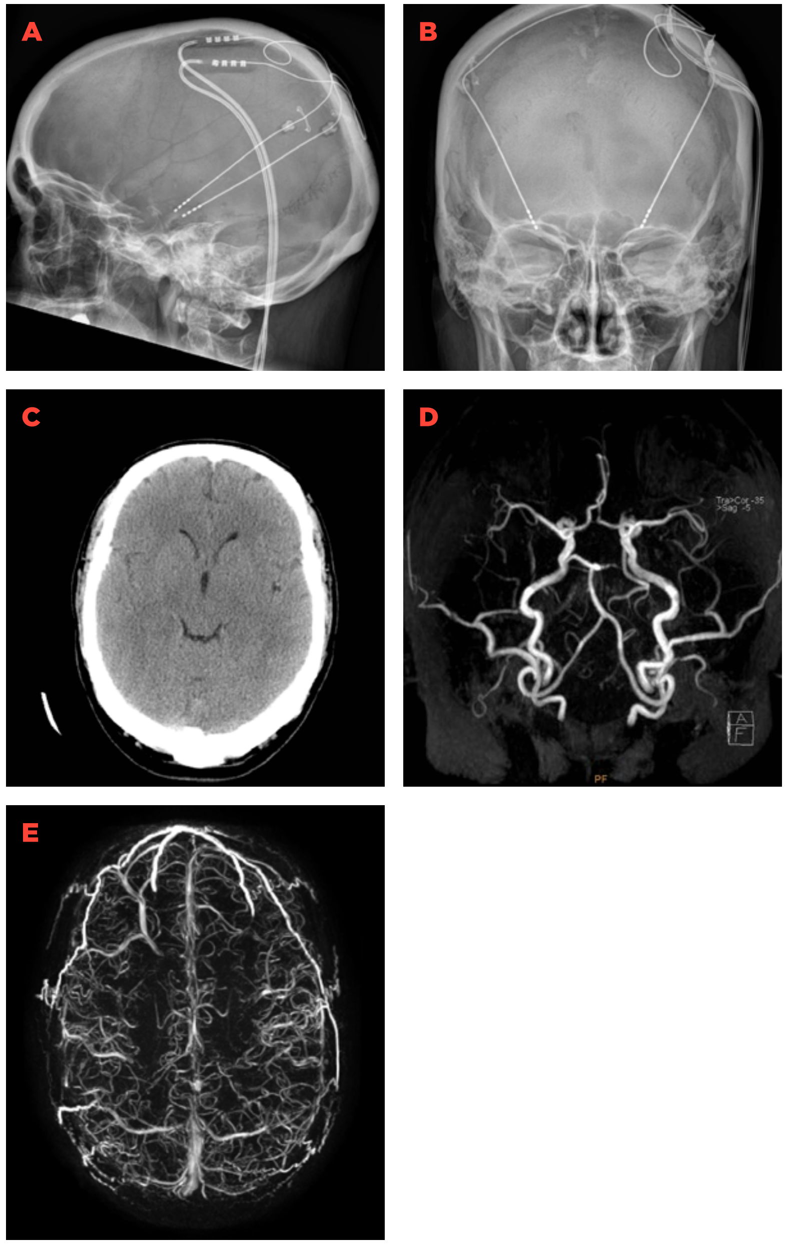


FIGURE 3

(A and B) depict a now uncommon test of a skull radiograph which uses plain x-ray to image a patient. Note the lack of distinction of the brain soft tissue, rather only of bones and metallic objects. In these images, the wires visible are deep brain stimulating wires which are inserted for a movement disorder. These can become dislodged or fracture and so can be rapidly evaluated with this test. (C) shows an image from a CT scan of the head, revealing superior detail of the brain with this technique which also uses x-ray radiation. Finally, MRI shows how exquisite the detail we can evaluate is becoming, with (D) showing an image at 3T of the brain's arteries, and (E) showing the blood vessels of the brain at 7T, with fine vessels that were only visible using invasive angiography now becoming visible using non-invasive techniques.

However, MRI has significant disadvantages. Firstly, it is not suitable for patients with ferromagnetic implants, most commonly pacemakers, or those unable to tolerate the narrow bore of the magnet or close-fitting head coils. Again, in this area work continues in both making many medical implants 'MRI conditional' so that they can be scanned with appropriate safety checks, and also in increasing the use of 'open MRI scanners' that help patients with claustrophobic symptoms.

The indications for plain film x-ray imaging are declining, especially in the acute setting. X-rays are rarely printed out onto film nowadays, and in acute non-traumatic neuro-emergencies are rare. They are occasionally used to evaluate bone injuries, or by neurosurgical teams to assess the position and integrity of shunt tubes that drain the brain of fluid (Figure 3).

The predominant imaging tool used for emergency imaging remains CT due to speed, cost and widespread availability. The ability to rapidly evaluate the brain and skull in the emergency setting when a patient presents with a non-traumatic neurological condition has enabled emergency physicians to rapidly evaluate and appropriately refer conditions that previously may have remained undetected. It has also enabled those who are suitable for emergency medical, surgical and neuro-interventional treatment to be suitably identified and treated.

Acute neurological patients can present with a myriad of symptoms. These can range from reduced conscious level, loss of speech, paralysis of a limb or a 'grand-mal' seizure. The onus often falls on the attending clinician to decipher the mixture of findings to establish a diagnosis, and identify what conditions may need urgent treatment such as an ischaemic stroke from a blocked large arterial vessel feeding the brain or bleeding from a burst blood vessel. This is where imaging is key, and can make the difference. Over the next few sections we will review some key areas where neuroimaging has changed the approach to some of these conditions.

ACUTE STROKE

Since the turn of the 21st century there have been rapid developments in the treatment of acute ischaemic stroke. This is the process whereby the brain is starved of oxygen due to a blockage of a blood vessel supplying essential oxygen to the brain's neurons. The brain demands 15% of the output from the heart, and the brain's neural cells use 94% of this supply. Some of the developments in stroke management have been inspired by the revolution in the treatment of acute myocardial ischaemia in the late 20th century, which has led to a dramatic increase in the outcomes of patients with 'heart attacks'. Patients with acute brain ischaemia can present in a multitude of different ways, depending on the part of the brain that the stroke has affected. The condition is also complicated by different conditions presenting in the same way to the emergency department doctor.

The 'FAST' campaign in the UK, informs the public that when a person has a sudden onset of abnormality in their Face, Arm or Speech it is Time for them to attend hospital. This is one example of how increasing awareness of the signs of a stroke can help with getting these patients to hospitals quickly. The brain is exquisitely sensitive to a lack of oxygen, and the phrase often used is 'time is brain' when dealing with this category of acute emergency.

One mechanism by which brain injury can occur during a stroke is when the blood supply to the brain via one of the large arteries at the base of the brain is interrupted by a blood clot. The key to saving brain tissue from the damaging effects of a lack of oxygen is to remove the obstruction to blood flow caused by this blood clot. Until recently the established method was to use a powerful 'clot-busting' medication such as tissue plasminogen activator (tPA) to help dissolve the clot and so restore blood flow. This was proven effective in patients during trials in the late 1990s, and became commonplace management in the early 2000s in many hospitals.

Subsequently however, it was found that clots that are longer in length are less well dissolved by this treatment and so patients are less likely to recover blood flow to their brain tissues even when treatment with a clot busting agent via the veins is given. Therefore an alternative method of removing the clot from the blood vessel within the brain was pursued.

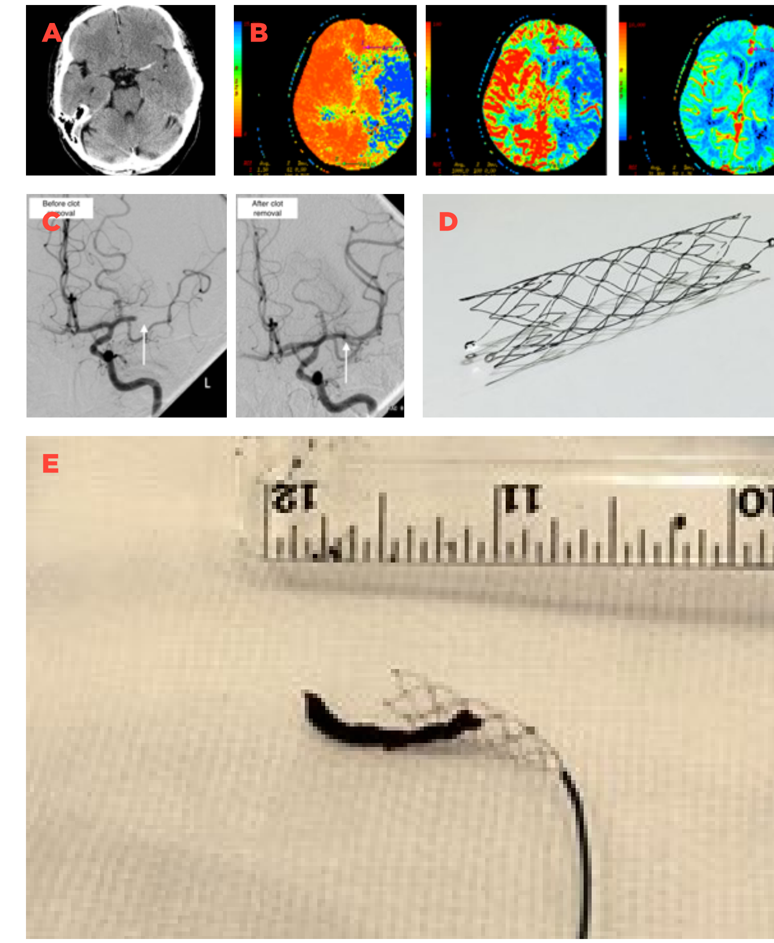
Imaging of the brain has been a complex process, with a history of many different and creative methods employed by neuroradiologists over the years. This has included injection of air into the cerebrospinal fluid, called pneumencephalography. Thankfully, techniques such as this have been superseded in modern imaging. The imaging of blood vessels has been revolutionised by the Seldinger technique, developed by the Swedish radiologist Dr. Sven Ivar Seldinger in 1953. This enables radiologists to access the body's arteries via the main artery in the groin, the femoral artery. Via this artery, a flexible plastic tube or catheter is passed up through the main artery of the body, the aorta, to the level of the heart. A wire is used to help guide the catheter into the appropriate position, under the guidance of x-ray imaging. Once at the level of the heart, during neuro-imaging procedures the catheter is passed into the main arteries supplying the brain, either the large carotid arteries that supply the majority of the brain tissue, or the smaller vertebral arteries at the back of the neck.

This technique of cerebral angiography is the platform from which the development of mechanical clot removal, or thrombectomy was developed. A larger catheter at the base of the neck can be used as a delivery system during this procedure to access and remove clots within the arteries of the brain that cause acute ischaemic stroke (Figure 4).

The clot can be retrieved either by direct aspiration using a vacuum, or with a mechanical retrieval device. These devices range from helical shaped devices such as the MERCI retriever, to the most commonly used SOLITAIRE stent which is opened into the clot. This technique has been developing over the last 15 years, and was strongly supported in 2015 when five pivotal randomised control trials published their findings. These trials: MR CLEAN, REVASCAT, ESCAPE, SWIFT PRIME and EXTEND-IA, showed a significant benefit of using these devices with improved outcomes for patients where these devices

FIGURE 4

(A) depicts a CT study showing a dense clot on the left side of the brain, in one of the main arteries known as the Middle Cerebral Artery (MCA). This supplies a large area of the brain controlling many vital functions. Figure (B) (other but similar patient) shows perfusion imaging depicting a 'mismatch' between the area of the brain that has been damaged already through a lack of oxygen, and the area of the brain that is potentially salvageable, called the 'ischaemic penumbra'. (C) on the left shows the vessel prior to being opened up, where the dye cannot pass the blockage, and on the right shows the vessel opened after the clot has been removed, with the dye able to pass into the smaller vessels that were being starved of blood. Figure (D) shows an example of a stent and (E) an example of an extracted clot.



were used to remove clots blocking cerebral arteries.

The key role for neuro-imaging in the acute setting is to evaluate the brain to firstly establish if there is an alternative diagnosis for the patient presenting with symptoms of an acute stroke. This would predominantly be done using CT, and be used to exclude acute bleeding within the brain which can present with similar findings at the bedside but cannot be treated using this technique. Another reason for imaging is to establish if there is a blocked blood vessel which would be suitable for being treated with thrombectomy.

Finally, it should be established that there is salvageable brain tissue that would benefit from the blood vessel supplying it being restored with flow. This is the ultimate aim of revascularisation therapy as there is little point restoring blood flow to cells that have demised. This can be established using different techniques, but the simplest involves reviewing the initial CT to evaluate for the subtle early swelling that the brain develops when starved of oxygen. Other techniques are often only performed at neuroscience centres, which are specialised in treating the brain, and involve use of injected contrast media to see areas of the brain that have reduced blood flow but where neuronal cells have not yet completely succumbed.

Now is when time is of the essence: if the clot is not removed promptly, more of the brain is lost. Should the situation be allowed to continue, the patient may also develop life threatening swelling and require neurosurgery to remove part of their skull (called a hemicraniectomy) (Figure 5).

Under the guidance of a team including a stroke physician and a radiologist, the patient is transferred to the angiography suite, where a radiologist trained in the technique, often an interventional neuroradiologist, will attempt to retrieve the clot if it has presented with enough time available, and restore blood flow to the brain. This can take minutes to hours to perform depending on the complexity of the procedure, but when it is successful can result in recovery of function on the angiography table, with restoration of the patient's ability to speak, move or see.

The development and confirmation of this technique as an essential part of the management of a patient with acute ischaemic stroke has led to many challenges for those involved. The thrombectomy procedure is one that can be highly complex and requires dextrous technical skills. Thus, it requires extended training and specialist facilities, which need to provide infrastructure. Establishing clear road maps for the management of strokes of this nature and ensuring there are services available round-the-clock for patients that need it is the next hurdle for stroke services in many regions.

FIGURE 5

(A) shows a patient's brain with part of their skull removed surgically, with figures (B) and (C) showing volumetric imaging which can be used to plan subsequent surgery to reconstruct the skull using a prosthesis.

SUBARACHNOID HAEMORRHAGE

In contrast to interruption of the blood supply to the brain resulting in an ischaemic stroke, the other common presentation for acute conscious-level deterioration in a patient is haemorrhage. Acute bleeding into the brain or the areas around the brain can often present with a variety of symptoms, the most common of which is headache. A specific type of headache is associated with blood within the space between the membranes surrounding the brain, called the subarachnoid space. The headache associated with this is characteristically a 'thunderclap' headache, with the sufferer experiencing 'the worst headache of my life' or similar description of intense severity. This can be accompanied by reduced consciousness, vomiting, neck pain or stiffness. This is well recognised as an emergency and these patients are often referred to the neurosurgical team.

Diagnosis of subarachnoid haemorrhage in the acute setting, if the patient presents within the first hours of their headache, is relatively straightforward, with CT imaging of the head being 100% sensitive and specific to the presence of acute subarachnoid blood within the first six hours of headache onset, decreasing to 93% within 24 hours of onset. This then decreases further to 50% if there is a delay of a week from the symptoms. Therefore, CT imaging is not reliable with delayed presentations, in which case MRI imaging is one possible test. More commonly, lumbar puncture becomes the next line of investigation. This procedure involves introducing a fine spinal needle through the back into the spinal canal where there is communication between the cerebrospinal fluid (CSF) spaces around the brain and that bathing the spinal cord and cauda equina nerve roots of the lumbar spine. The fluid that is removed is analysed for the presence of xanthochromia (from the Greek xanthos = yellow and chroma = colour), which is the appearance of the CSF when tainted by the presence of blood. CSF does not normally contain blood, and should be colourless.

Once there has been confirmation of subarachnoid haemorrhage, either on CT, via lumbar puncture CSF analysis or on MRI, the patient is then investigated for the presence of an aneurysm. This is initially done using a technique known as CT Angiography. This requires precise timing and injection of iodinated intravenous contrast via a pump injector. The contrast enters the circulation and opacifies the arteries of the brain, allowing visualisation of the source of bleeding. In the majority of cases, the bleeding into the subarachnoid space is caused by the presence of a swelling in the wall of the artery, called an aneurysm.

The aneurysm outpouching from the arteries within the brain is often a fragile delicate walled structure. These can be present due to underlying genetic conditions and

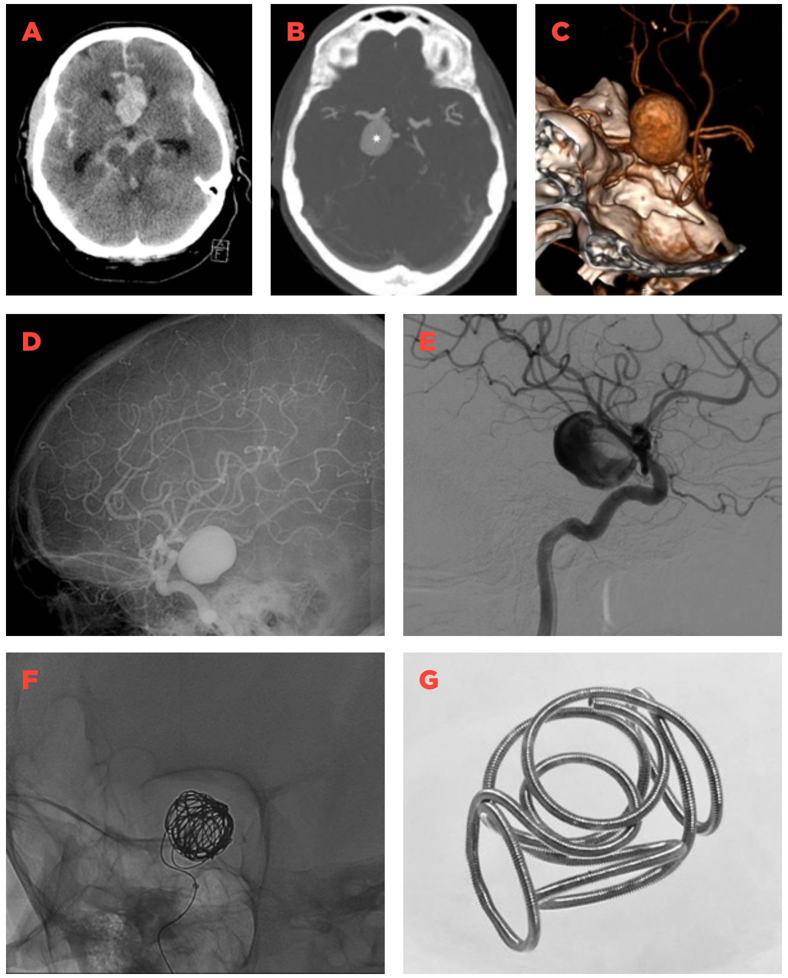


FIGURE 6

(A) depicts a patient with a large subarachnoid haemorrhage, with the dense bright white coloured blood extending along the spaces of the brain where it should not be. Figure (B), different patient, shows a large aneurysm (labelled with a star). (C) is an image of a reconstructed CT angiography study that shows how we are now able to plan procedures using neuro-imaging and advanced modelling software to see what an aneurysm will look like in 3D even before we have anaesthetised the patient. Figures (D and E) show a similar sequence using dye injected into the patient's groin, and (F) is taken during the coiling procedure with the metallic coils being delicately inserted into the fragile aneurysm sac under x-ray guidance. Finally figure (G) shows the 3D structure of one of the coils outside of the body.

can vary in their size and shape. As blood pulses past and into the aneurysm sac, a tiny defect or rupture in the wall can result in blood rushing out into the subarachnoid space, resulting in the presentation as a 'thunderclap' headache. This is an emergency and requires rapid assessment.

The treatment of patients with this condition has again been revolutionised by the development of tiny platinum coils that can be delivered into the aneurysm using interventional neuroradiology techniques. Prior to this, the only treatment of aneurysms was down to neurosurgeons, who needed to remove part of the skull, navigate potentially eloquent areas of the brain and search for the aneurysm through areas of bleeding which potentially obscured their views of the bleeding aneurysm. They then carefully deployed a clip across the base of the aneurysm, closing it off and stemming the flow of blood out into the subarachnoid space (Figure 6).

Since the development of endovascular techniques, the need to perform extensive invasive surgery of this nature has reduced. The technique, as with the method described to retrieve clots, involves accessing the arterial circulation via the femoral artery in the groin. Catheters are then passed to the cerebral arteries under guidewire guidance. Using micro-wires (often 0.3556mm in diameter) a catheter is positioned at the base of the aneurysm. Fine platinum coils are then positioned within the aneurysm sac and detached using electrolysis. One or more coils are then placed within the aneurysm using this technique, packing the aneurysm. Once it is sufficiently filled to consider it 'excluded' from the circulation of the parent vessel, the catheters are removed. The presence of the coils promotes clotting of blood within the aneurysm, and should be sufficient to stop the bleeding. The coils then remain in place for the life of the patient.

Coiling has provided a minimally invasive method for treatment of patients with aneurysmal subarachnoid haemorrhage. Trial evidence from ISAT (International Subarachnoid Aneurysm Trial) in 2005 provided supportive evidence for this method although a clear role remains for clipping aneurysms surgically, especially aneurysms that are of the shape not amenable to the coils staying within the sac or those difficult to access with endovascular techniques. The methods of treating aneurysms continue to evolve, with balloon assisting techniques, coated coils, 3D coils and stents changing methodology continuously, the role of interventional neuroradiologists continues to be a mainstay of treatment in acute subarachnoid haemorrhage.

CEREBRAL VENOUS SINUS THROMBOSIS

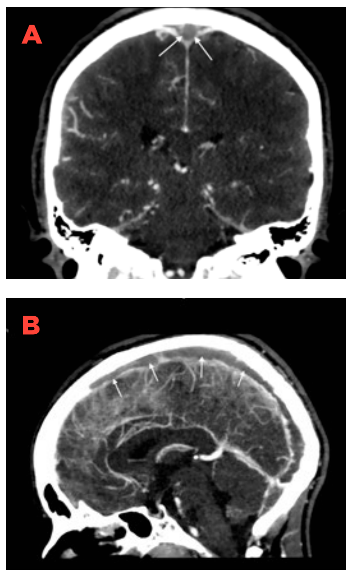
So far, we have concentrated on the intracranial arteries, as they are not only very important in providing the brain with essential oxygen, but also when damaged can cause catastrophic bleeding in and around the brain. In normal circulation, blood passes from the arteries, through the capillaries, delivering vital oxygen to the highly active and demanding cerebral tissues. The blood, depleted of oxygen, then passes into the veins, which drain the deoxygenated blood back to the heart. The brain has a complex network of veins to do this, which have variable anatomy. The larger venous structures are relatively constant amongst most people.

The venous system generally contains slower flowing blood, as the pulse wave pressure is dampened by the capillary bed within the brain tissues. However, under normal physiological situations, blood usually flows freely without problem. However, in certain circumstances, there is a greater propensity for clots to form (a pro-coagulant state) such as when there are certain medications in use (including the oral contraceptive pill), or if the patient has an inherited condition or a systemic condition such as sepsis or malignancy. In these situations, the blood can form clots within the brain's draining venous vessels.

The results of this are a spectrum of variable presentations, which can confuse and confound the clinicians. Patients can present with headache, confusion, nausea and vomiting. As you will have noted from the other conditions presented so far, this is not a specific constellation of findings, and so the attending doctor

FIGURE 7

(A and B) show how the large clot (marked with arrows) within the large draining vein across the top of the brain, the superior sagittal sinus, is causing a blockage.



must keep this rare but dangerous condition in mind when noting a constellation of headache presentations.

As the clot blocks off the venous vessel there is a build-up of backpressure, much like what would happen if you were to hold the end of a hosepipe flowing with water. This build-up of pressure results in initial swelling within the brain substance, called venous hypertension. Subsequently this can lead to fluid leaking out of the vessels into the surrounding brain, called oedema. This can cause deficits similar to patients presenting with acute ischaemic stroke such as weakness, or seizures if they affect the temporal lobes in the brain. Ultimately, this pressure can continue to lead to blood leaking out and bleeding into the brain substance (Figure 7).

The importance of recognising this condition early centres on commencing medication such as heparin to keep the blood 'thin'. This has been a mainstay of treatment since the 1940s, before which time people could progress to seizures, large bleeds in the brain or death. This medication can be used to help prevent the clot from extending further, and reduce the chance of haemorrhage. Imaging of the brain has helped pick up these patients earlier, and ensure they are treated in a timely fashion.

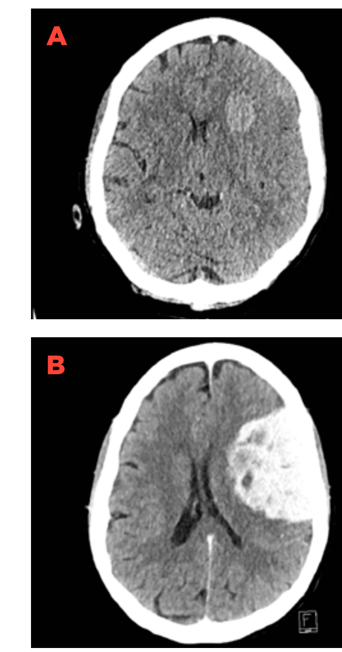
TUMOURS

Tumours in the brain can be benign or malignant, and can begin in the brain (primary brain tumours) or be from a cancer in the body that has spread to the brain (secondary brain tumours). In the United States of America, the American Brain Tumour Association and Central Brain Tumour Registry of the United States reported that 80,000 brain tumours are expected to be diagnosed over 2017. There are over 100 types of primary brain tumour, and they can present in a myriad of different ways depending on the part of the brain they involved. For example, a tumour within the area of the brain that controls movement, the primary motor cortex, will present with weakness. When brain tumours occupy an area of the brain, they disrupt or destroy the normal function of that region. However, although there are areas of the brain that have clearly attributed functions, others have more mysterious functions and consequentially require more scrutiny to bring to light at the bedside (Figures 8 and 9).

Thus, a patient presenting with a headache may not have a finding that is picked up with the normal bedside neurological examination, which is a good test for picking up gross findings of weakness, sensory disturbance or visual loss. However, the subtle evidence of a tumour within the parietal lobe such as being unable to recognise objects placed in the hand (astereognosis) or to recognise numbers or letters traced on the skin (graphesthesia) are more difficult to evaluate rapidly in the emergency department. Tumours within the dominant parietal lobe (on the left side in over 90% of people) can present with Gerstmann syndrome, which is a loss of the ability to write (agraphia), inability to count or perform mathematical calculations (dyscalculia), inability to distinguish fingers of the hand (finger agnosia) and left-right disorientation.

FIGURE 8

(A and B) show a brain scan prior to (A) and after (B) administration of intravenous iodinated contrast. This 'lights up' the brain tumour, in this case one arising from the lining of the brain called a meningioma, which may otherwise be difficult to detect as it is of a similar density to the brain.



HELP Emergency Medical Imaging

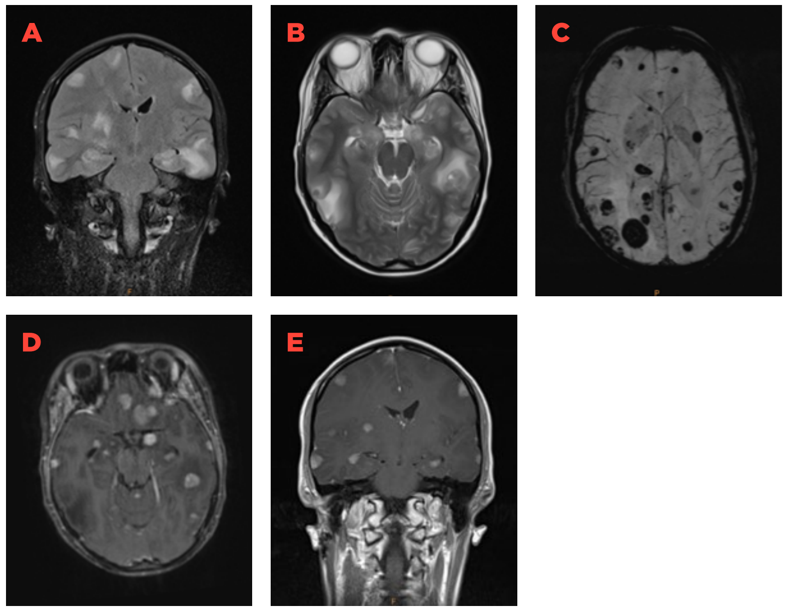


FIGURE 9

(A – E) show a patient with multiple tumour deposits within the brain, which show blood products and 'light up' with contrast, this time gadolinium contrast which is used with MRI. This patient presented with seizures, and has deposits in the temporal lobes which could have been the cause.

The latter is often found in radiologists as a common day-to-day discovery, so in isolation these findings are rarely of concern.

Tumours within the frontal lobes can present with alterations in mental state or behaviour. For example, a patient may present with a change in their personality, becoming aggressive when they were always placid in the past, or behaving inappropriately in social situations as though they were under the influence of alcohol or some other substance when in fact they are completely sober – these can be the signs of a tumour, and could have resulted in a referral to a psychiatrist. Indeed, patients are regularly imaged now to exclude such a mass prior to commencing psychiatric treatment, as these symptoms can overlap with those of a psychiatric illness.

Occipital lobe tumours often present earlier than others as they affect vision which is vital to most people's day-to-day functioning and so is noticed early. There is a rare condition called Anton-Babinsky syndrome (visual anosognosia) where the afflicted person suffers from cortical blindness, and has total or near-total loss of vision due to damage of both of the occipital lobes. Although blind, these patients affirm that they are able to see, and concoct a kaleidoscope of images that they can see, despite clear and irrefutable evidence that they cannot.

Temporal lobe tumours can present acutely to the emergency department as they involve structures which, when damaged, cause seizures. This is particularly relevant when the tumour involves some of the phylogenetically older parts of the brain with fewer layers than those of the neocortex,

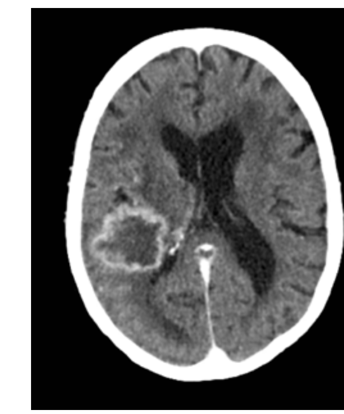
such as the frontal lobes. The hippocampus is one such structure, and is part of the archicortex, consisting of four layers of neuronal cells, in contrast to the six-layered cortex of the phylogenetically younger areas. We cannot currently resolve the layers of the cortex using imaging; however our techniques continue to improve, with seven tesla (7T) scanners now emerging from research settings to becoming CE marked for clinical use (Figure 10).

Aside from presenting with epileptic seizures, temporal lobe tumours can present too with complex and often vague symptoms, which at first can be confusing for the patient, their relatives and the attending doctor. There can be disorders of auditory perception (the primary auditory cortex is in this region), disturbance of language, and problems with memory. Unusual presentations of temporal lobe lesions include prosopagnosia, an inability to recognise faces, which plainly can overlap with the presentation of dementia, thus imaging has helped in reviewing these patients so that a hidden brain tumour is not overlooked.

Aside from damaging specific areas of the brain, tumours can also disrupt the flow of CSF through the brain, in particular through the ventricles of the brain. CSF bathes the brain and contains the essential nutrients that the brain requires, and also helps acts as a fluid cushion. A tumour that blocks the natural flow of CSF can cause a build up with the ventricles which are reservoirs of CSF within the brain. In this case the patient may present with headache, vomiting or visual disturbance, as the increase in pressure caused by the blockage is transmitted to

FIGURE 10

This image shows a 'ring enhancing' tumour within the right temporal lobe, in this case a primary brain tumour called a glioblastoma multiforme, a very aggressive brain tumour.



the eyes. This is a neurosurgical emergency, which can be abated by the introduction of a tube into the system to drain the fluid off. This life-saving procedure is easily diagnosed with a prompt CT scan, which can also be used to help plan surgery (Figure 11).

INFLAMMATION AND INFECTION

The brain and spinal cord has a built in defensive barrier against intruders, called the 'blood brain barrier'. This is a semi-permeable membrane which allows some substances to cross but not others. It consists of endothelial tissues which have tight junctions between them; in particular these restrict the movement of pathogens from the neurovascular circulation into the brain. Damage to this can result in the brain becoming infected and the patient becoming severely ill. Infection within the brain, much like infection elsewhere in the body, can cause inflammation, abscess formation and cell death. The inflammation can involve the lining of the brain, whereupon the resultant meningitis can be life-threatening.

One cause for inflammation within the brain that can present to the emergency department is one with a currently unknown underlying cause. Multiple Sclerosis (MS) in the United Kingdom was estimated in 2013 by a team from the University of Dundee to occur in 203 per 100,000 of the population, with 6,000 people being diagnosed each year with the condition. The key to multiple sclerosis is that, despite the as yet unexplained underlying cause, it has characteristic appearances on neuroimaging within the brain and the spinal cord.

The inflammatory process in multiple sclerosis involves the body's immune system mounting an abnormal response to the protein rich layers that surround the nerves in the central nervous system. This autoimmune process damages these myelin sheaths that have a normal function in supporting the conduction of nerve signals to and from the brain. When this occurs, it can leave a scar or 'plaque' within either the brain or spinal cord, and often has a characteristic location. Thus, acute imaging can identify this pattern of imaging presentation and lead the clinician to suggest an appropriate treatment of

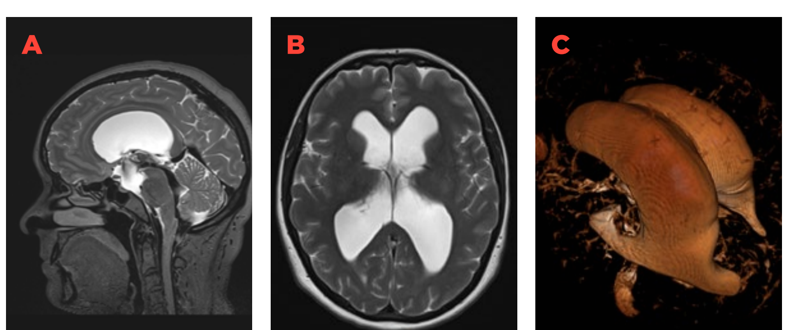


FIGURE 11

(A and B) show very prominent ventricles, the chambers within the brain that drain off the CSF. Figure (C) is a volumetric reconstruction of these structures.

FIGURE 12

(A) shows the white 'plaques' associated with multiple sclerosis. Figures (B and C) show how newer MRI techniques such as double inversion recovery (DIR) can help show these more easily.

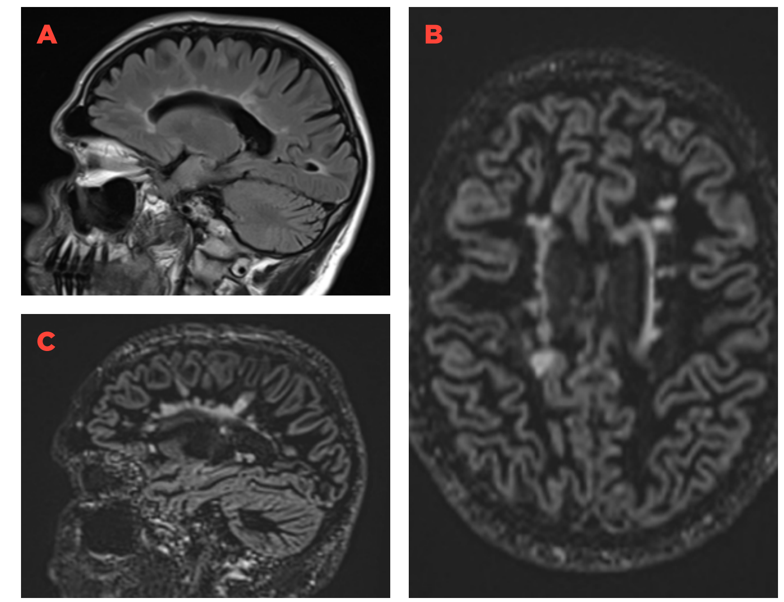
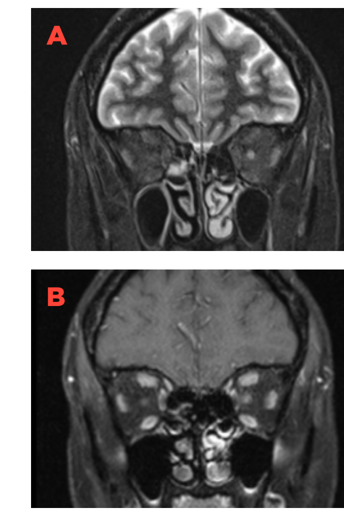


FIGURE 13

(A and B) are examples of optic neuritis, where the main visual nerve swells, with the left nerve here (on the right of the image) being bright in comparison to the other nerve.



steroids. This condition can present several times in a patient, so-called 'relapsing and remitting' MS, and imaging on these occasions can help establish if the patient requires escalation of treatment to one of the newer disease modifying therapies (DMTs) such as Tecfidera, Fingolimod or Tysabri. It may also present with a visual disturbance when the optic nerves are involved, called optic neuritis, which can cause blurring of vision or loss of colour vision, as well as pain when the eyes are moved. MRI can be used to evaluate the optic nerves in this situation, showing the swelling of the nerves (Figures 12 and 13).

Other conditions that cause the immune system to be weakened, and therefore make the patient more susceptible to organisms which would otherwise not be pathogenic, can cause severe infections within the brain. These 'opportunistic infections' can be devastating to the patient and difficult to treat. The Human Immunodeficiency Virus was first discovered as the cause for Acquired Immune Deficiency Syndrome (AIDS) in 1984. This virus targets the CD4 cell surface receptor, which is present on several of the immune system components within the body, primarily the CD4+ lymphocyte, a

FIGURE 14

depicts the 'ring enhancing' lesions of toxoplasma gondii within the brain with their characteristic nodule inside the ring.

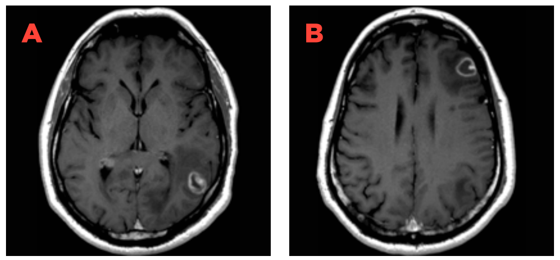


FIGURE 16

(A and B) evidence the nerve appearing bright due to damage (MRI).

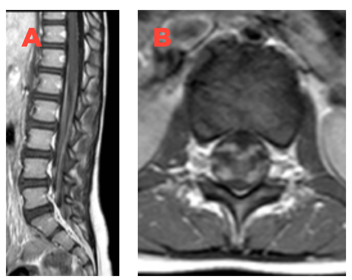
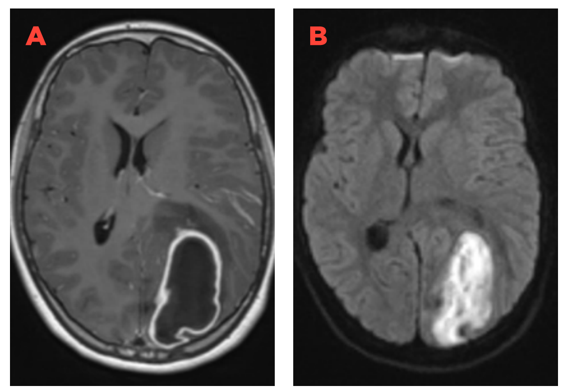


FIGURE 15

(A and B) show a more classical brain abscess, which also shows 'ring enhancement' on Figure (A). This could be confusing as it also looks like the tumour we saw in Figure 10. However, this mass is very bright on a specific sequence called diffusion weighted imaging (B). This sequence allows rapid diagnosis of the condition, which can then be drained of the thick pus contained within it through neurosurgery.



crucial white blood cell. The lack of a robust immune system in these patients leads them to be infected with unusual organisms that normally 'peacefully' exist inside the body or on the skin of many of us. These include fungal organisms such as Pneumocystis jirovecii (a fungus named after the Czech parasitologist Otto Jirovec), which causes a form of pneumonia. One of the main conditions to affect the brain includes infection by the parasite Toxoplasma gondii, which are known to thrive in domestic cats. When present in the brain, the associated lesions cause characteristic appearances after injection of gadolinium contrast known as 'ring enhancement', the presence of which guides the treating team to medicate using a combination of pyrimethamine (usually used for malaria), sulfadiazine (an antibiotic) and folinic acid (Figures 14 and 15).

Finally, imaging of the spinal cord is an essential part of the diagnosis of infections of the nervous system as it is directly connected to the brain. Infections in the brain directly communicate with the spinal cord, and the lower nerve roots extending from spinal cord called the cauda equina. A rare but potentially life-threatening condition that affects this region is called Guillan-Barre syndrome, and can affect all ages, including children, where the presentation of a progressive loss of movement, and potentially breathing, can be very frightening to both the child and their carer. This is another autoimmune condition where the body targets the peripheral nervous system. The disease either (and most commonly) involves the nerve sheath Schwann cells (Acute Inflammatory Demyelinating Polyneuropathy or AIDP) or the nerve cells themselves (Acute Motor Axonal Neuropathy – AMAN). The condition can be diagnosed with MRI, with characteristic appearances of the nerves enhancing after gadolinium contrast. This condition can be treated with intravenous immunoglobulin, which is manufactured from pooled human plasma, or plasmapheresis, which involves removing the patient's abnormal plasma and replacing it with unaffected plasma or a plasma substitute (Figure 16).

SUMMARY

The diagnosis of acute neurological conditions has provided a challenge for clinicians at the bedside for hundreds of years. In the current age of neuroimaging, the developments in CT, MRI and interventional neuroradiology have endowed those treating these complex conditions with an ability to peer into the anatomy of the brain and uncover pathologies that are potentially treatable, with preservation or restoration of the vital functions of day-to-day living the loss of which would otherwise be devastating.

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4

I CAN'T BREATHE!

I CAN'T BREATHE! IMAGING OF THORACIC EMERGENCIES

BY LORENZO BONOMO, DAVIDE COVIELLO, DAVIDE GEAT, ANNA RITA LARICI

Thoracic emergencies may be traumatic and non-traumatic.

Trauma is among the top ten causes of death worldwide (road injuries killed 1.3 million people in 2015, according to the World Health Organization), and the leading cause of death in persons under the age of 40. 20–25% of traumatic deaths of civilians annually result from chest trauma. Blunt thoracic injuries are more common than penetrating chest trauma with the most frequent causes being motor vehicle accidents, falls and crush injuries. The most frequent causes of penetrating traumatic injuries are stab and bullet wounds. Imaging plays a central role in the assessment of trauma patients.

IMAGING TECHNIQUES

The chest radiograph (CXR) is the oldest radiographic technique and remains the most common radiological examination performed in the world today. CXR is the most important imaging examination for the initial assessment of thoracic injuries and their management; it should be performed in any patient in whom chest trauma is suspected. Trauma patients are often unable to maintain a full-end inspiratory position because of pain, fatigue or unconsciousness. The supine position makes identification of mediastinal and pleural lesions more difficult and in these cases it is much better to obtain a computer tomography (CT) scan.

Multidetector CT (MDCT) is the most modern type of CT scanner. MDCT provides a 3D volumetric examination of the whole thorax within seconds and is well suited to examining the lungs, the thoracic vessels, the chest wall and the mediastinum. When indicated, an iodinated contrast agent may be injected intravenously to show cardiovascular injuries. MDCT is more frequently used as the first imaging test in emergency situations and especially in polytrauma patients.

Ultrasonography in thoracic trauma patients can be performed easily, quickly and safely with a small mobile ultrasound unit that can be carried to the bedside. The main use of ultrasound in the chest is the detection of soft tissue collections and of small pneumothoraces and pleural effusions not detectable on conventional chest x-rays and, at times, the detection of costal cartilage fractures. Occasionally it is used as a guide for aspiration of pleural fluid collection. Ultrasound with transthoracic and trans-oesophageal echocardiography is used for the identification of cardiac and aortic injuries.

FIGURE 1

Rib fractures. Chest radiograph of a 40-year-old man involved in a car accident; there are multiple rib fractures (blue circle); hyperlucency of the right apex suggests pneumothorax, a common complication of rib fractures.

Magnetic resonance imaging (MRI) is more complex than CXR or CT. Chest MRI is particularly challenging since the lung contains a large volume of air with no signal on MRI and only small amounts of liquid and tissue generating a low signal. This, in addition to a number of artefact sources, makes MRI not useful in the emergency of thoracic trauma.

TRAUMATIC INJURIES

Chest wall injuries and fractures of the ribs and sternum, are the most frequent lesions encountered in chest trauma; they affect the majority of chest trauma patients. Other injuries include pleural, pulmonary, mediastinal, cardiac and diaphragmatic lesions. Isolated chest injury is uncommon and this fact is confirmed in numerous statistics. Associated injuries are present in about 80% of the patients and they include cerebral, extremity, spinal, abdominal and pelvic injuries.

Rib fractures

Rib fractures are the most common skeletal injury in blunt chest trauma and occur in over 50% of chest trauma patients. They commonly affect elderly subjects and involve the lower ribs (4^{th}–10^{th} ribs); 1^{st}–3^{rd} rib trauma is less common, yet more dangerous because of the presence of important anatomical structures in the area: lung apex, aorta, subclavian vessels, and brachial nervous plexus. They are often associated with traumatic pleuro-pulmonary lesions, including pneumothorax (PNX) (Figure 1);

FIGURE 2

Tension pneumothorax. Chest radiograph (A) and CT (B) images show the pleural line (yellow arrow heads), the air accumulation between the parietal and the visceral pleura as hyperlucency above the pleural line (right blue circle), lung volume reduction and the contralateral dislocation of the mediastinum (red arrow).

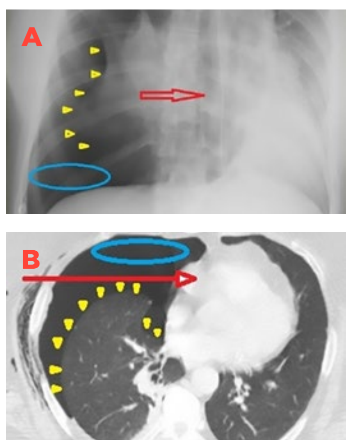


FIGURE 3

Radiographic follow-up after placement of a thoracic drainage (yellow arrow) to ensure proper lung re-expansion.

sometimes they even cause lesions to abdominal organs such as the spleen and liver, especially if the 9th to 12th ribs are involved. Clinical examination and imaging are both essential for a diagnosis. CXR is the first-line imaging study, but as many as 50% of rib fractures are not seen on initial radiographs; CT, because of its higher sensitivity, may be used to confirm the diagnosis in selected patients.

Fractures of the sternum

These occur in up to 4% of blunt chest trauma patients, mostly in high-speed deceleration accidents and are always the hallmark of severe trauma, and associated with a mortality of up to 22%. Although a sternal fracture can be detected on a true lateral chest radiograph, the diagnosis is made more often on CT. Other less frequent skeletal thoracic injuries include sternoclavicular dislocation and scapula-thoracic dissociation, which represent rare injuries always related to high energy trauma and most often encountered in motorcycle accidents.

Pneumothorax (PNX)

Pneumothorax refers to the presence of air in the pleural cavity, the space separating the lung from the chest wall. It affects approximately 60% of patients with severe thoracic trauma and can be rapidly fatal. Traumatic PNX is labelled *open* when it communicates with the external atmosphere through an open wound by gunshot, stabbing, etc. Conversely, in a closed PNX there is no such communication; instead, other mechanisms of injury are responsible, such as a fractured rib which lacerates the parietal pleural layer. Rarely, air is trapped in the pleural space and accumulates under pressure, leading ultimately to the compression of mediastinal structures: this condition is called tension pneumothorax and can be life-threatening. Tension PNX and massive PNX are medical emergencies and should be recognised and treated immediately. Because of the resulting impaired expansion of the lung, the main symptoms of traumatic PNX are shortness of breath and chest pain worsened by breathing. CXR or CT are always performed, often at the emergency department; CT is preferred in particular cases because of its diagnostic superiority. Both techniques show the air accumulation between the parietal and the visceral pleura; hyperlucency is observed above the 'pleural line' at the apex on an erect CXR, the lung volume is reduced and, in the case of tension pneumothorax, the mediastinum is shifted to the contralateral side (Figure 2). To ensure proper lung re-expansion, the patient must undergo thoracic drainage which will lead to a rapid improvement in clinical conditions (Figure 3).

Haemothorax

In polytraumatised patients with blunt chest trauma, pleural effusions are present in approximately 30–50% of cases. They are frequently haematic in nature and known as haemothorax. Common symptoms include chest pain, tachycardia, hypotension and pallor. On an erect CXR, a pleural effusion has a meniscal shape and obliterates the lateral costophrenic angles; the distinction between haematic and serous pleural effusion is quite clear on CT, due to the higher density of blood which ranges from 35 to 70 HU (Hounsfield units, the CT measure of density). The administration of iodinated contrast medium during CT allows direct visualisation of the injured vessel and a 'jet' within the haematoma in the case of active bleeding (Figure 4).

Pulmonary contusion and laceration

The impact of pulmonary contusion or laceration depends on the traumatic energy with which the pulmonary parenchyma is compressed against the chest wall or the other fixed anatomical parts like the trachea and the bronchi; contusions occur when a low energy impact damages the alveolar capillaries resulting in oedema and haemorrhagic focal deposits. High-energy trauma often causes parenchymal tears with destruction of the alveolar spaces, resulting in pulmonary laceration. Parenchymal contusion is the most common

FIGURE 4

Haemothorax. CT visualisation of the injured vessel and a 'jet' within the haematoma evidence active bleeding (red arrow).

FIGURE 5

Pulmonary contusion. Chest radiograph with multifocal areas of confluent 'ground-glass' opacities and consolidations in both lungs.

FIGURE 6

Pulmonary laceration. Traumatic cavitations in the lung can be seen ('Swiss cheese sign', white arrows). There is also right pneumothorax (P).

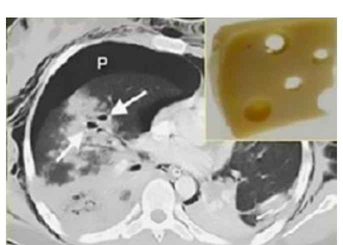


FIGURE 7

Aortic rupture. Circumferential transection of the aortic wall at the post-isthmic portion (yellow arrow). Blush of contrast medium indicates active bleeding from the aorta (yellow arrowhead) with associated haemothorax.

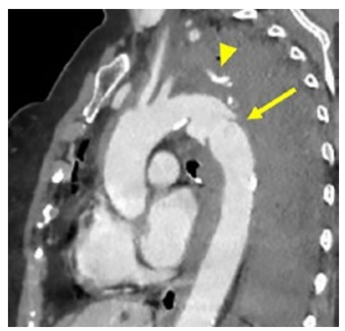


FIGURE 8

Aortic transection or rupture. CT image of aortic rupture shows extravasation of contrast medium (red arrow), and the resulting haematoma (yellow arrowheads) which widens the mediastinum.

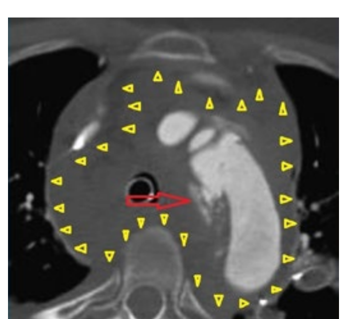


FIGURE 9

Thoracic aortic stent. This patient underwent endovascular treatment following thoracic aortic rupture.

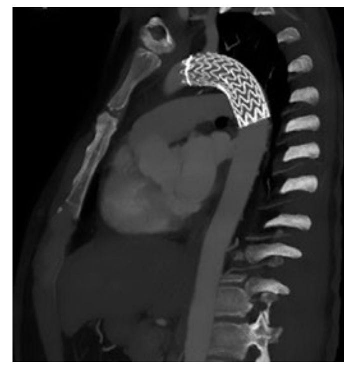
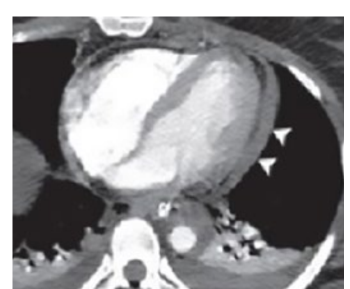


FIGURE 10

Haemopericardium. CT shows haematic effusion within the pericardial sac (white arrowheads).



cause of pulmonary opacity on CXR after blunt chest trauma. It appears as focal or multifocal areas of confluent 'ground-glass' opacities or consolidations, usually visible in the lung periphery adjacent to the area of direct trauma (Figure 5). Pulmonary lacerations are associated with heterogeneous opacities with evidence of cavitation giving a 'Swiss cheese sign' (Figure 6). Contusions improve considerably over 48 to 72 hours, while lacerations may persist for several months.

Injuries of the thoracic aorta

Thoracic aortic injuries are life-threatening, often fatal events. They result from either blunt or penetrating trauma. Approximately 80% of patients with thoracic aortic injury die at the trauma scene. In those who make it to hospital, clinical diagnosis is difficult. Aortic traumas may result in *aortic laceration:* a tear in the intima which may extend along the vessel wall; *aortic transection:* laceration of all three layers of the vessel wall, also known as aortic rupture (Figure 7); *aortic pseudoaneurysm:* aortic rupture contained by the external layer called adventitia; *aortic intramural haematoma:* haematoma within the aortic wall; or *aortic dissection:* a longitudinal tear in the aortic wall which is only rarely caused by trauma.

CXR remains the first examination to be performed on patients with low energy trauma. Mediastinal width greater than 8cm is considered pathologic; this finding is highly sensitive (90%) but nonspecific (10%), therefore further imaging investigations are needed to confirm the diagnosis. Other radiographic findings include right tracheal deviation and undefined aortic arc contour.

CT, performed on patients with high energy trauma or an abnormal chest radiograph, is the reference standard in aortic evaluation and allows differentiation between various traumatic aortic disorders. It ought to be performed before and after the administration of intravenous iodinated contrast and allows the visualisation both of *indirect* signs, such as mediastinal haematoma, and direct signs of aortic injury such as abnormal aortic contour in mural haematomas and extravasation of contrast in aortic rupture (Figure 8). Treatment consists of aortic stent grafting (Figure 9) or open surgical repair.

Cardiac injuries

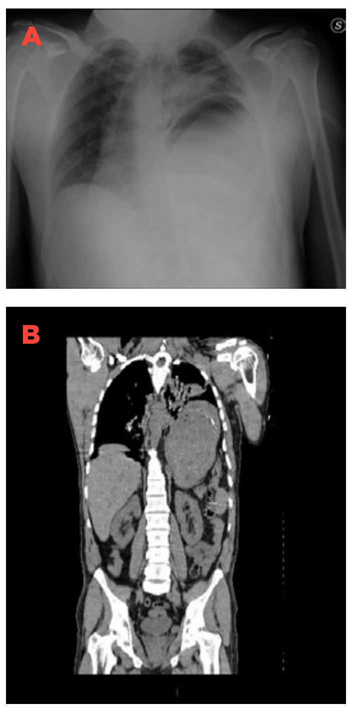
Cardiac trauma represents a serious, often fatal, emergency. They are classified as: penetrating, non-penetrating and iatrogenic. CXR shows the enlargement of the cardiac silhouette, a sign of pericardial effusion or cardiac tamponade. CT can detect the traumatic agent, a knife or a blade, visualises the exact location of the lesions and differentiates between serous effusions and haematic effusions (Figure 10).

Diaphragmatic injuries

These occur in 1–10% of blunt chest trauma patients and result from high speed deceleration and crush accidents. They include ruptures (which are the most frequent), tears and peripheral avulsions. CXR remains the most useful diagnostic tool for the diagnosis of diaphragmatic injuries, but a normal

FIGURE 11

Diaphragmatic rupture (A, B). Chest radiograph (A) demonstrates elevation of the left hemidiaphragm with contralateral displacement of the mediastinum. The coronal CT reformation (B) shows elevated abdominal organs within the left hemithorax. These findings are suggestive of diaphragmatic rupture which was confirmed at surgery.



CXR does not exclude the diagnosis of diaphragmatic lesion in cases involving the suggestive biomechanics of trauma. CT is required to rule out a diaphragmatic rupture (Figure 11).

NON-TRAUMATIC EMERGENCIES

Non-traumatic thoracic emergencies are very frequent in adults and even in children. Patients usually present with breathing difficulties and/or chest pain. Non-traumatic thoracic emergencies are less well defined than those with traumatic causes. They may have a cardiovascular or a non-cardiovascular origin. Cardiovascular diseases including acute pulmonary embolism, acute aortic dissection and acute coronary syndrome, make up the triad of high risk diseases.

Pulmonary embolism (PE)

PE is a common clinical problem that is associated with considerable morbidity and mortality.

PE is caused by a thrombus, a blood clot, which obstructs a portion of the pulmonary vasculature. 70% of patients with PE have deep vein thrombosis (DVT): clots form in the deep veins of the lower limbs and subsequently travel via the venous system through the heart to the lung vessels.

Several tests may be used to confirm the diagnosis including lab tests (D-dimer), CXR, CT, electrocardiogram (ECG) and cardiac ultrasound. A CXR may be entirely negative even in the presence of PE and is mainly useful in order to rule out other diseases, such as pneumonia and PNX, which can present with the same symptoms. CT angiography, on the other hand, is very sensitive: the clot is clearly visible as a filling defect within a pulmonary vessel (Figure 12). CT angiography is the modality of choice to detect or exclude PE because of its very high accuracy, availability, rapidity and low cost compared to other imaging modalities.

Aortic dissection

Dissection of the aorta is a life-threatening condition requiring immediate diagnosis and treatment. Thoracic aortic dissection has an incidence of 3–4 cases per 100,000 people per year worldwide, and it is more common in elderly hypertensive men. It is also associated with genetic syndromes such as Marfan's syndrome and also with trauma, including from surgery and intra-vascular procedures. The most common symptom is stabbing chest pain related to the dissection itself; devastating complications are possible, including aortic rupture and reduced blood supply resulting in ischaemia to vital organs such as the brain and the heart. CXR has a low sensitivity and specificity and cannot rule out dissection. CT angiography (CTA) has a sensitivity and specificity of nearly 100% and is needed to confirm the diagnosis. CTA provides crucial information on the extension of the dissection and therefore guides its management (Figure 13). Aortic dissection together with intramural haematoma and penetrating atherosclerotic ulcer are three closely related entities affecting

FIGURE 12

Pulmonary embolism. (A) A clot obstructing a pulmonary artery is seen as a filling defect (yellow arrow); (B) distal lung ischaemia is well visualised on perfusion map.

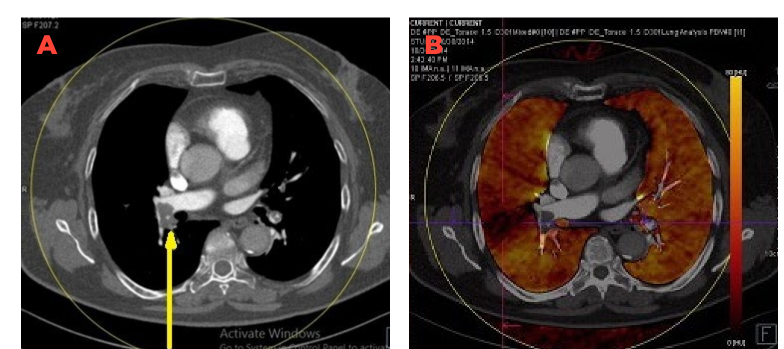
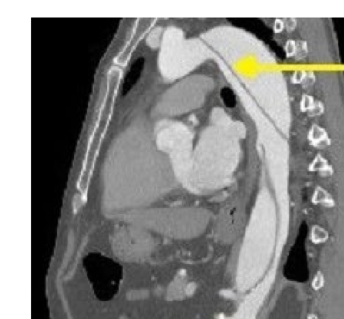


FIGURE 13

Aortic dissection. CT angiography shows a thin flap (yellow arrow) representing the most inner layer of the aortic wall (intima).



HELP Emergency Medical Imaging

the thoracic aorta, clinically indistinguishable, which are gathered under the label Acute Aortic Syndrome.

Acute Coronary Syndrome (ACS)

The clinical scenarios of unstable angina, non-ST-segment elevated myocardial ischaemia and ST-segment elevated myocardial ischaemia on ECG make up Acute Coronary Syndrome. These entities encompass the most significant and potentially lethal causes of chest pain in the emergency department. Acute chest pain is one of the most common complaints in patients presenting to the emergency department. Pulmonary embolism and acute aortic syndrome are other potentially life-threatening diagnoses that can manifest primarily as chest pain. On initial presentation to the emergency department, all such patients undergo initial evaluation including history, physical examination, ECG and CXR to identify or exclude coronary syndrome and to identify non-cardiovascular illnesses. Immediate cardiac and pulmonary biomarker analysis plays a central role (troponin and D-dimer).

Pleural and parenchymal lung disease

These diseases commonly manifest with symptoms of chest pain. Usually a typical history and clinical findings can discriminate pleuro-pulmonary entities from cardiac or vascular pathology.

Pleural diseases are common and represent a significant contribution to the workload of the emergency department. CXR remains the initial investigation of choice in the detection of pleural disease. Ultrasound is an easily applicable, cheap and radiation-free technique used to assess pleural disease; it can be performed at bedside and may be used to guide aspiration.

Spontaneous pneumothorax

Spontaneous detachment of the pleural layers from the chest wall occurs in the absence of trauma and is classified as primary or secondary depending on the precipitating cause. Primary spontaneous pneumothorax is a relatively common cause of thoracic pain in young, thin, tall males without pre-existent lung diseases, although it is known that its occurrence is due to the rupture of small subpleural bullae at the lung apices. Secondary causes include chronic obstructive pulmonary disease, infectious aetiologies and cystic lung diseases. The classic radiographic sign is identification of the pleural line separated from the chest wall which leaves an area of lucency absent of parenchymal vessels. Whereas small (< 2cm) asymptomatic pneumothoraces need no treatment and undergo radiological follow-up until resolution, in larger pneumothoraces a tube is placed to drain air. Secondary forms of spontaneous pneumothorax are a complication of a pre-existing lung disease, such as emphysema, asthma, cystic fibrosis or interstitial lung disease. CT may be useful to better evaluate the underlying pulmonary disease, as well as the pneumothorax. Fast and readily available, CXR and CT are most helpful in the acute setting to establish the diagnosis of pneumothorax, as well as in the subsequent follow-up, to guide the treatment.

Acute pulmonary oedema

Pulmonary oedema is defined as presence of excess extravascular fluid in the lungs. The more common type of acute pulmonary oedema is hydrostatic pulmonary oedema and is due to acute cardiac failure or to cardiac fluid overload caused by overhydration or renal failure. CXR is the classical radiological examination for the diagnosis of pulmonary oedema while lung ultrasonography is an emerging technique. CT is not performed for suspected pulmonary oedema but pulmonary oedema is a frequent finding in CT examinations performed for other acute purposes. CXR in one such patient (Figure 14) shows bilateral wool-like opacities representing fluid accumulating inside the lung. Note that the failing heart of these patients looks much larger than usual. CXR is also particularly useful in the follow-up after treatment (Figure 15).

Pneumonia

Pneumonia is an acute inflammation of the lung caused by an infection. It is the main cause of death among infectious diseases in the world and has high mortality rates among elderly people, when acquired in underdeveloped countries or during hospitalisation. Most commonly, however, pneumonia is acquired outside the hospital and is known as community acquired pneumonia or (CAP). CAP incidence ranges between 1.6 and 12 cases per 1,000 people. It is caused by aggressive bacteria, like streptococcus pneumonia, that proliferate inside the lung and elicit an extensive inflammatory response: air sacs or alveoli become filled with fluid and white blood cells are recruited to fight the infection: the process interests a vast area, usually an entire lobe of the lung. CXR can be used to confirm the diagnosis: fluid-filled alveoli in the left lower lobe appear as a 'white' area of consolidation

FIGURE 14

Acute pulmonary oedema. The silhouette of the failing heart is markedly enlarged and bilateral wool-like opacities are present.

FIGURE 15

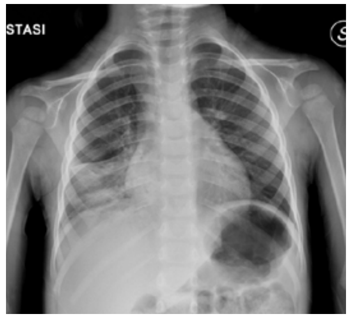
Pulmonary oedema and follow-up after medical treatment, which led to a significant improvement of the radiographic and clinical findings.

FIGURE 16

Lobar pneumonia. Lung parenchymal consolidation in the right upper lung.

FIGURE 17

Inhaled foreign body. This 3-year-old boy was brought to the emergency department after inhaling a nut. The density of the nut is not sufficiently high to be directly identified on the chest radiograph, but there is an indirect sign of bronchial obstruction (right lower lobe atelectasis).



(Figure 16). Because some of the symptoms of pneumonia may be caused by other diseases, CXR is sometimes necessary in order to differentiate. CT better evaluates pneumonia and may suggest the involved pathogen, yet, due to the higher radiation exposure to the patient, it is reserved for particular circumstances such as severe pneumonia, immunocompromised patients, or patients with strong suspicion of pneumonia but negative CXR.

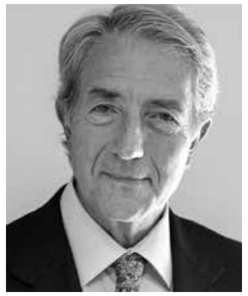
PAEDIATRIC NON-TRAUMATIC THORACIC EMERGENCIES

In children such emergencies are very frequent and they usually present with breathing difficulties. These emergencies always require a rapid diagnosis to establish a medical or surgical intervention plan and radiological imaging often plays a key role. Radiation safety must always be considered when imaging children. There are many different causes of thoracic emergencies in children, some specific to certain age groups. A wide variety of different conditions may lead to thoracic emergencies in children; the most urgent and important ones involve the airways and may be life-threatening. CXR is still the most important tool and can be supplemented with ultrasound, CT and MRI.

One of the most common household accidents, most frequent in the youngest children, is foreign body aspiration. Pre-school children are particularly at risk of aspirating foreign bodies, for example seeds, nuts or coins. Generally, inhaled foreign bodies tend to reach the right lung because the right bronchus is more vertical than the left one; depending on where exactly the obstruction is, symptoms vary greatly. While impaction in the larynx or main bronchus causes sudden-onset choking and may be fatal, a small foreign body obstructing a peripheral bronchus may not result in acute symptoms; sometimes the only hints are recurrent pneumonia, chronic wheezing or breathlessness because of the partial collapse, atelectasis, of the lung where the obstruction is located. In stable patients, CXR is the first imaging modality: high-density radiopaque foreign bodies, such as coins, are easy to see. Nonetheless, even when the foreign body is not visible, indirect signs caused by the obstruction such as atelectasis, pneumonia, or air trapping in expiratory CXR, can suggest the diagnosis (Figure 17). If the presence of a foreign body is suspected on CXR, flexible bronchoscopy using a fibre-optic cylindrical scope can visualise the airways, confirm the diagnosis and successfully remove the foreign body.

SUMMARY

Thoracic emergencies include a number of life-threatening conditions. Because there is great overlapping in the symptoms patients complain of, differentiating between them is of pivotal importance. Radiological examination, particularly CXR and CT, are readily-available rapid modalities that, within a few minutes, allow for differential diagnosis and treatment planning. In recent years, much research has focused on radiation dose reduction and new CT scanners have been developed which deliver to the patients a lower dose without compromising the very high diagnostic quality of the studies.



PROF. LORENZO BONOMO

is professor of radiology at the Catholic University of Rome.

He graduated from the Medical School of the Catholic University of Rome in 1970 and began his residency in radiology there where he became a certified radiologist in 1975. In 1976 he moved to the University of Chieti and was promoted to professor of radiology in 1983. He served there as chairman and professor of radiology from 1986 to 2003.

Prof. Bonomo moved back to the Catholic University of Rome in 2003 and served as chairman and professor of radiology from 2003 to 2016 when he retired. From 2008 to 2016 he was director of the training programme in radiology at the Catholic University of Rome.

His main field of interest is thoracic radiology and he has published over 400 scientific papers. He served as President of the European Society of Thoracic Imaging (ESTI) from 2000 to 2001.

From 2002 to 2004, as President of the Italian Society of Radiology (SIRM), he supported international cooperation and actively contributed to the founding of the European Society of Radiology (ESR).

An active member of the ESR for many years, Prof. Bonomo served as President of the European Congress of Radiology (ECR) 2012 and the ESR from March 2014 to March 2015.

He has received widespread recognition for his work and has been awarded honorary memberships by the Italian, Argentinian, Bulgarian, French, German, Greek, Romanian, Serbian and Spanish radiological societies as well as the RSNA and ESTRO. He received honorary membership to ESTI and the gold medal of the European Society of Emergency Radiology (ESER).

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5

CARDIAC AND CORONARY EMERGENCIES

CARDIAC AND CORONARY EMERGENCIES: THE GROWTH OF CROSS-SECTION IMAGING

BY **MATTHIAS GUTBERLET**

HISTORY OF CORONARY ARTERY IMAGING

The history of imaging in cardiac and coronary emergencies started almost one hundred years ago with a self-experiment in Berlin by Werner Forßmann 1929 – less than 40 years after Wilhelm Conrad Röntgen's discovery of x-rays in 1895. In 1929 Werner Forßmann was a physician in further training at the department of surgery in Eberswalde, Brandenburg and later worked with the famous Prof. Ferdinand Sauerbruch at the Charité in Berlin. He finally received the Nobel Prize in Medicine in 1956 for his invention. This involved using a urinary catheter, which he introduced via his antecubital vein, to access the right side of his heart under x-ray fluoroscopy guidance. Finally, he used x-rays to visualise the catheter tip at the right atrium.

It was some time before the first left heart catheterisation and especially coronary artery visualisation in humans was unintentionally performed by F. Mason Sones, a paediatric cardiologist at the Cleveland Clinic, in 1958. Melvin Judkins introduced the percutaneous transfemoral access for selective coronary angiography which facilitated the procedure dramatically. Charles Dotter, a pioneering interventional radiologist, also called the 'Father of Intervention', performed the first percutaneous transluminal angioplasty in a femoral artery, this was subsequently performed in the coronary arteries in 1977 by Andreas Grüntzig, a German physician born and raised in Saxony.

From that time on several minimal-invasive procedures to treat occlusive coronary artery as well as valve disease have been developed. But the coronary arteries themselves could only be visualised by invasive selective coronary angiograms in the 1980s.

With the invention of computed tomography (CT) in the early seventies (1971) by the English engineer Godfrey N. Hounsfield working at EMI industries (Electric and Musical Industries), which also included EMI records, non-invasive visualisation of the coronary arteries became possible. This was improved upon by the quicker electron beam tomography (EBT) in 1983.

In the late 1970s and early 1980s magnetic resonance imaging (MRI) was invented and the introduction of the first clinical MR systems started in 1983. Therefore, in the late 1980s and early 1990s, imaging of the coronaries without radiation exposure became feasible, but with a much longer acquisition time, lower spatial resolution, and, therefore, lower reliability compared to CT.

However, a fast, robust, reliable and cost-effective method to exclude occlusive coronary artery disease also in an acute setting was not available until the introduction of the first spiral CT in 1989 and finally multislice CT in 1998 with the introduction of the first 4-row CT. Nowadays, the guidelines recommend at least a 64-row CT for coronary artery imaging, which was first introduced in 2004, over ten years ago.

These days cardiac CT is the non-invasive method of choice to visualise the coronary arteries and cardiac MR is preferred for further functional and especially myocardial perfusion studies and myocardial tissue characterisation.

THE ROLE OF CT IN CARDIAC AND CORONARY EMERGENCIES

For almost two decades CT has been the non-invasive modality of choice for acute vascular emergencies including aortic dissection or pulmonary embolism and has replaced invasive diagnostic procedures or lung perfusion scintigraphy.

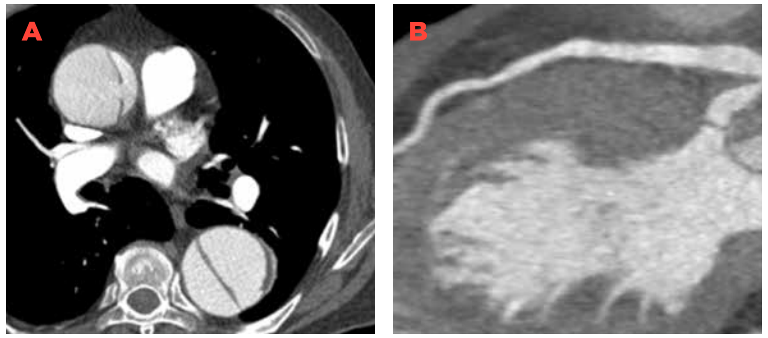
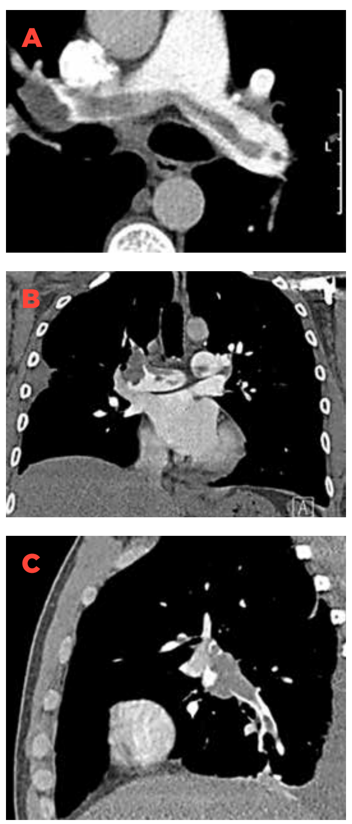


FIGURE 1

CT of a type A and type B aortic dissection in an 83-year-old male. Tear of the dissected vessel wall (arrow) of the ascending aorta (A). Involvement of the left coronary artery (arrows) with its main stem in another patient (B).

FIGURE 2

CT with contrast agent of a severe pulmonary embolism (white arrows) in a 38-year-old male with deep vein thrombosis (DVT) of the left leg after a transatlantic flight at the pulmonary artery (PA) bifurcation (A) and especially the main right branch (B, C).
A: transverse, B: coronal and C: sagittal reconstruction.
The ‘filling defects’ of the thrombi (dark) in this contrast-enhanced CT are clearly visible.



Aortic dissection is a tear of one or more layers of a large trunk artery’s vessel wall, which could lead to aortic rupture and therefore can also be lethal. The most dangerous form of aortic dissection is type A dissection (Figure 1), in which the entry of the tear is located in the aortic root, ascending aorta or the aortic arch up to the outlet of the left subclavian artery. The ostia or orifices of the coronary arteries may become occluded during aortic dissection, the aortic valve insufficient and a rupture of the aorta into the pericardial sac can occur: all are life threatening complications. An acute type A dissection is an emergency and has to be treated by open surgery as quickly as possible. Up to 24% of patients with type A dissection die within 24 hours. If the entry of the aortic dissection is located distally to the origin of the left subclavian artery it is defined as a type B dissection and is less severe.

Along with transthoracic and/or transoesophageal echocardiography, CT is the imaging modality of choice, which can be performed within seconds. Due to cardiac motion of the aortic root close to the left ventricle, ECG gating is recommended to perform this scan and for this reason usually also allows for the assessment of the coronary arteries, at least at their origin at the aortic root. Possible involvement of the coronary arteries by the dissection membrane can also be assessed by CT. The symptoms of an acute aortic dissection as well as pulmonary embolism (Figure 2) include acute chest pain and are therefore an important differential diagnosis of acute coronary syndrome (ACS). Both can usually only be excluded by CT.

In pulmonary embolism one or more blood clots, e.g. from a deep venous thrombosis, embolise via the right heart to the pulmonary arteries and obstruct larger or smaller branches of the pulmonary vasculature depending on the size of the clots. With a special technique known as ‘Dual-Energy’ the reduced lung perfusion in more distally located parts can also be assessed (Figure 3). The symptoms include acute chest pain, but of course more often shortness of breath or dyspnoea. Depending on the size of the embolised clots and the obstructed pulmonary artery, acute right heart failure could occur. CT is the fastest method to diagnose or exclude pulmonary embolism as the cause of acute chest pain.

According to recent European guidelines of the European Society of Cardiology (ESC) on the management of stable coronary artery disease (CAD), several national guidelines, including the German Disease Management Guideline on chronic CAD, recommend coronary artery computed tomography (CTA) in suspected CAD especially for patients with a low to intermediate probability of CAD.

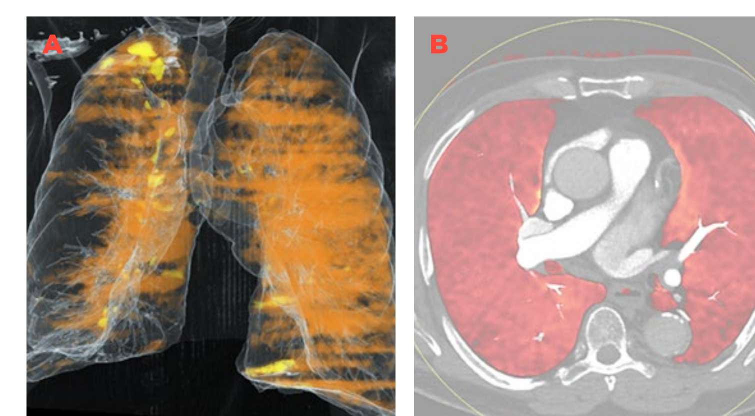
Coronary CTA has shown in several clinical trials over the last decade very high sensitivity and especially very high negative predictive value to exclude CAD, when at least a 64-slice CT was used, in comparison to the ‘gold standard’: invasive coronary catheterisation. That means that, especially in the group of patients with low to intermediate likelihood of CAD, after coronary CTA, patients can be discharged frequently without the need for further diagnostic procedures or invasive treatment, when CTA has excluded relevant CAD.

So far no guidelines recommend CTA as the first-line method in ACS. But the updated British NICE-Guidelines (National Institute for Clinical Excellence) from November 2016 recommend indirectly making use of CT coronary angiography in patients with acute chest pain, e.g. when the *“… clinical assessment indicates non-anginal chest pain but 12 lead resting ECG has been done and indicates ST T changes or Q waves …”*

Therefore, it can be expected that in the near future, alongside the evaluation of the

FIGURE 3

CT with the use of the ‘Dual Energy’ technique in a patient (A) with severe pulmonary embolism and reduced ‘perfusion’ (white arrows), especially of the right lung and a patient (B) with normal ‘perfusion’ (orange) of the lungs.



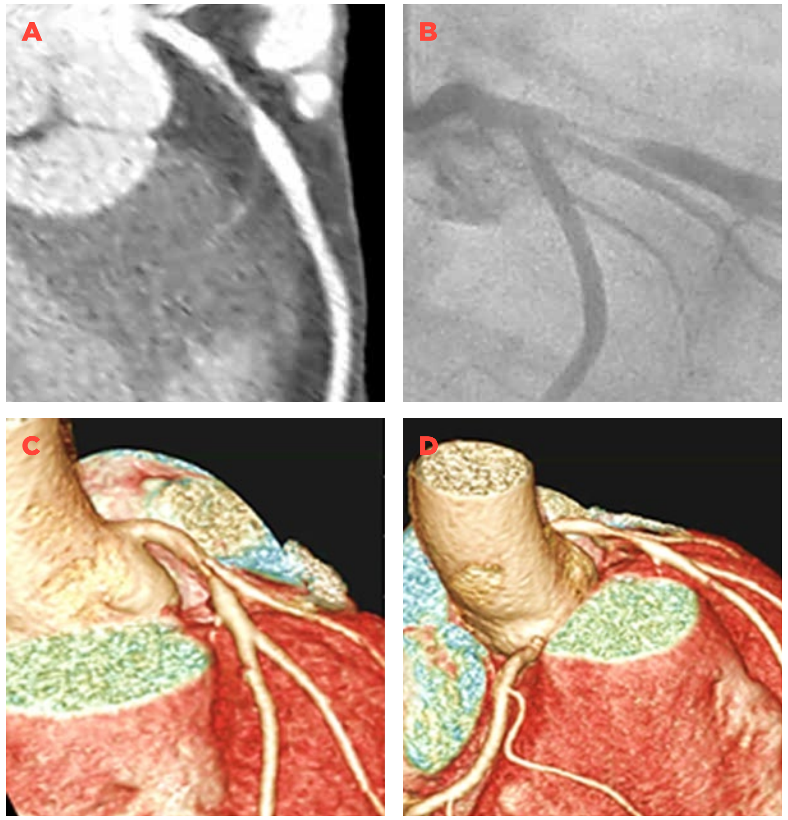


FIGURE 4

Coronary CT in a 48-year-old male presenting at the ER with acute chest pain and no clinical, lab and ECG findings for acute myocardial infarction and a low to intermediate likelihood of CAD demonstrates a high-degree stenosis of the left coronary artery (arrows) due to non-calcified, potentially 'vulnerable' plaque (A, C, D). The stenosis was verified by invasive catheterisation (B) and treated by PCI and stent placement.

differential diagnoses in acute chest pain and in stable coronary artery disease, CTA may also play an emerging role in the emergency room to explicitly rule out CAD, e.g. in instable angina (Figure 4).

THE ROLE OF CARDIAC MAGNETIC RESONANCE (CMR) IMAGING IN CARDIAC AND CORONARY EMERGENCIES

From the above-mentioned it might be clear that CMR with its much longer acquisition times compared to CT may not be the first-line method for emergencies. However it can be used to exclude aortic dissection and pulmonary embolism, if CT cannot be used due to contraindications or if CMR is used as a follow-up method. Nevertheless, due to the unique capabilities of CMR, especially in tissue characterisation, it is mainly used for risk stratification in CAD and differential diagnosis in acute chest pain, if CAD has already been excluded invasively.

After acute myocardial infarction and revascularisation of an obstructed coronary artery, the unique features of CMR can be used for risk stratification. From the very beginning of clinical MRI it was known that, with MR contrast agents, the area of necrosis in acute myocardial infarction can be visualised by an increased delayed-contrast enhancement of Gadolinium-based contrast agents. However, the image quality was not good enough to use it frequently. In the mid-1990s, special inversion recovery sequences were introduced with which the contrast between scar tissue and non-diseased myocardium could be intensified. This technique of viability assessment is also known as the 'late-Gadolinium-enhancement' (LGE) technique. In these LGE images bright signal indicates dead tissue (Figure 5). Therefore, from that time on, LGE has been used to predict functional recovery after revascularisation by bypass surgery. Due to the high spatial resolution of CMR compared to other methods such as Single-Photon Emission CT (SPECT) or Fluoro-Deoxy-Glucose-Positron Emission Tomography (FDG-PET), the extent of scar formation, the transmurality, can be more precisely assessed. A segmental extent of scar between 75–100% of the myocardium makes a functional recovery after revascularisation less likely as compared to a patient with only 25% transmurality. Therefore, risk-benefit assessments of further treatment can be performed with LGE.

With additional sequences, such as water sensitive sequences, myocardial oedema can be assessed. Myocardial infarction can then be classified as acute or chronic by using these CMR techniques. Myocardial inflammation can also be detected by using that same CMR sequence. Furthermore, myocardial haemorrhage as a result of reperfusion injury or microvascular obstruction (MVO) can be assessed by CMR. Both myocardial

FIGURE 5

Cardiac magnetic resonance imaging (CMR) of a 58-year-old male after an occlusion of the circumflex coronary artery with a corresponding transmural myocardial infarction of the lateral wall of the left ventricle (LV) using the 'late Gadolinium enhancement' (LGE) technique. (A) 4-chamber view, (B) short axis of the LV demonstrates a 'bright area' indicating transmural scar formation including the posterior papillary muscle. With a transmurality of the lateral segment of almost 100%, functional recovery after revascularisation is very unlikely.

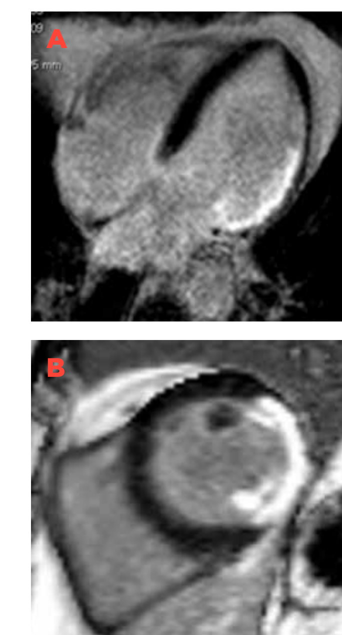


FIGURE 6

Cardiac magnetic resonance imaging (CMR) of a 40-year-old male with acute myocarditis with infarct-like symptoms and cell damage (troponin elevation) demonstrates the typical 'late Gadolinium enhancement' pattern with mainly subepicardially and intramyocardially located 'patchwork'-like bright areas.

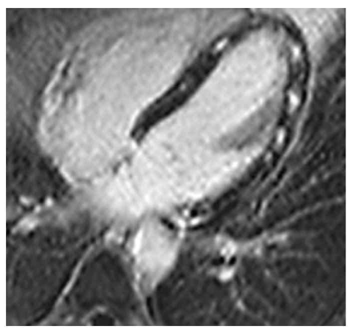
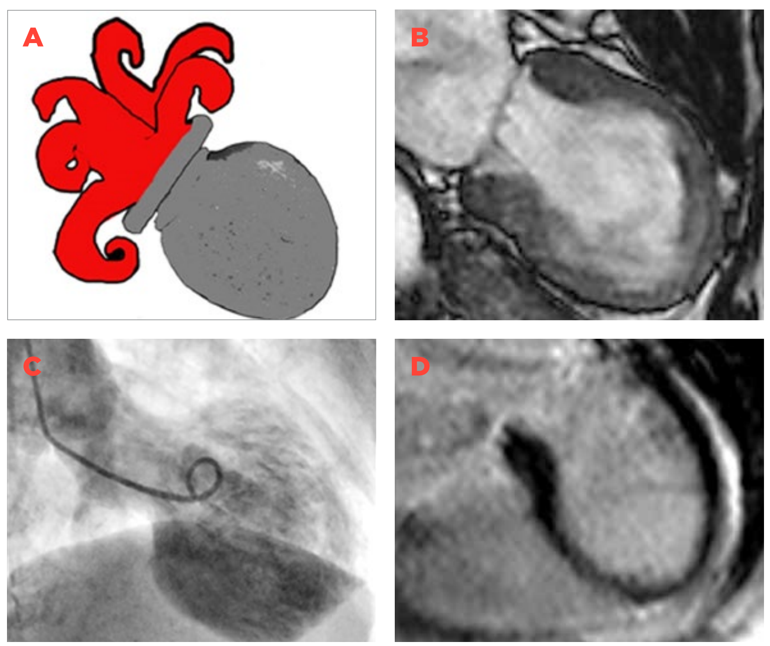


FIGURE 7

Schematic (A) of a takotsubo (Japanese for octopus trap) and CMR of an 83-year-old female with infarct-like symptoms after emotional stress (B, D). (B–D) The images demonstrate the typical 'apical ballooning' morphology of the left ventricle (LV) in takotsubo cardiomyopathy (TTC), which is also known as 'Broken Heart Syndrome' or stress cardiomyopathy. (B) CINE-MRI in the vertical long axis during systole showing no systolic inward motion of the ventricular wall as well as the corresponding image from invasive catheterisation (C). (D) LGE-image shows only viable (black) myocardium, no bright scar formation.



haemorrhage as well as MVO has a negative influence on the individual prognosis of the patient.

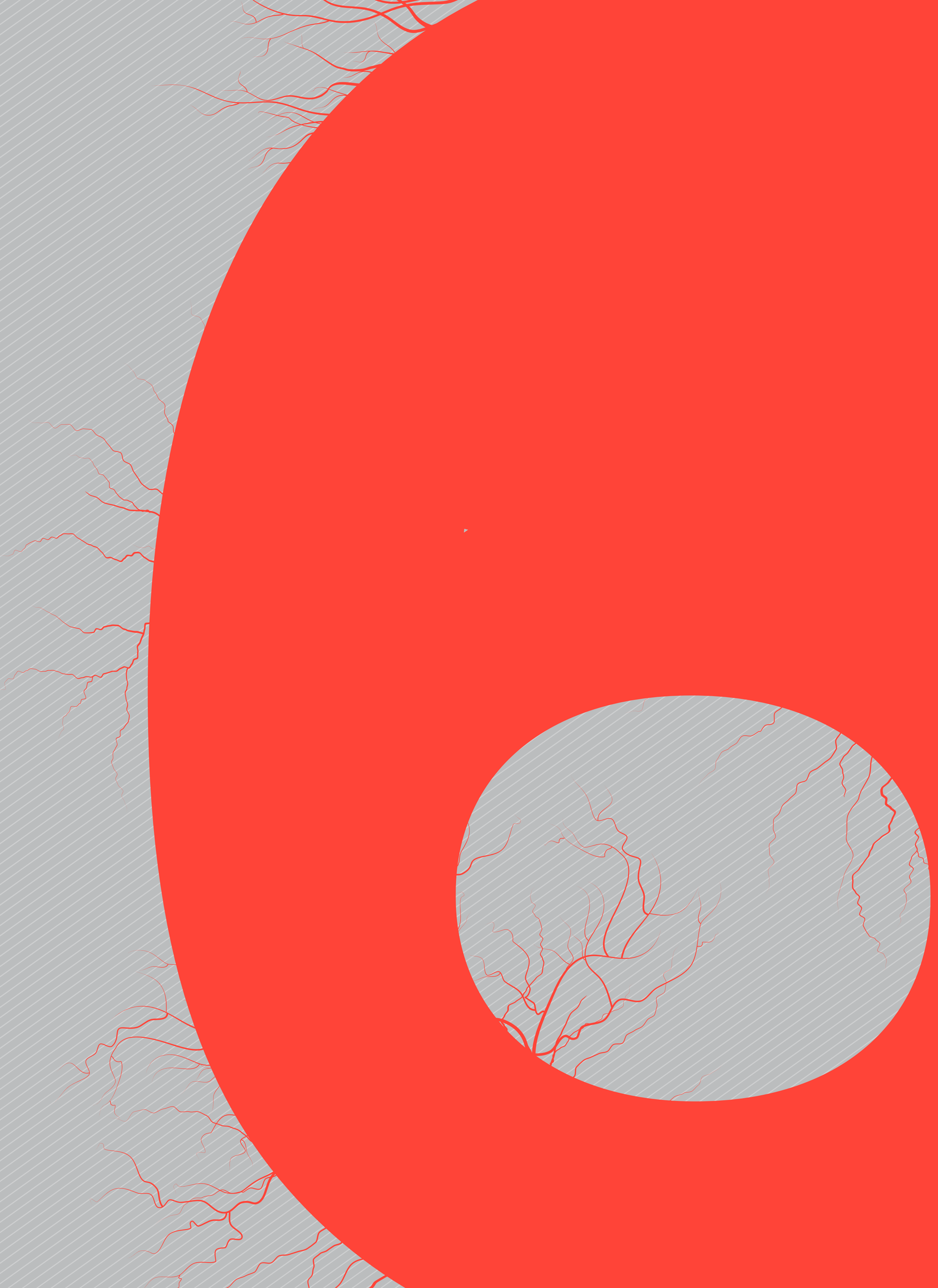
Beside acute myocardial infarction, several other cardiac diseases may present with infarct-like symptoms. Two of the most common ones are acute myocarditis and takotsubo cardiomyopathy (TTC). Myocarditis is an inflammatory disease of the myocardium with various causes. Due to inflammation, myocardial cell death can occur, similar to myocardial infarction, and can be visualised with LGE (Figure 6). However, myocarditis can also occur without any visible cell damage or functional impairment. CMR helps to further characterise the afflicted myocardium according to local, global, or diffuse inflammation or fibrous tissue. TTC is also known as the broken-heart syndrome in the lay press. Takotsubo is Japanese for an octopus trap, which the left ventricle resembles with this disease (Figure 7). Usually the apex of the left heart chamber shows an 'apical ballooning' meaning that the apex does not contract.

The morphologic appearance is similar to a patient with myocardial infarction of the anterior wall. But in contrary to myocardial infarction the wall motion abnormality is usually fully reversible in TTC. TTC is triggered by stressful events, e.g. death of a loved one, but also by positive emotional stress.

Broken heart syndrome or stress cardiomyopathy may be caused by the heart's reaction to a surge of stress hormones. However, the exact mechanisms which lead to the disease are still not fully understood. When the symptoms of TTC are treated, the wall motion abnormality usually reverses itself within day or weeks. CMR helps to differentiate between acute myocardial infarction, myocarditis and TTC by using different sequences to examine for LGE, oedema and function. TTC usually includes a local oedema at the site of the wall motion abnormality, but no scar tissue formation, whereas in myocardial infarction scar tissue and oedema may be present similar to myocarditis, but the LGE pattern is different. The LGE in myocardial infarction usually starts subendocardially at the inner border of the heart chamber and in myocarditis usually subendocardially at the outer border of the heart (Figure 6).

PROF. MATTHIAS GUTBERLET

had his education in medicine at Philipps-University, Medical School, Marburg, Germany, from 1985–1992. He defended his dissertation in orthopaedics in 1993 and underwent a residency training in cardiology at the German Heart Institute, Berlin (DHZB) from 1992–1995. Prof. Gutberlet continued with a research fellowship and residency training in diagnostic radiology at Charité, Berlin, from 1995–2000. He trained in nuclear medicine during a research fellowship at Charité from 2000–2002. Prof. Gutberlet was a consultant in diagnostic radiology in 2002 and received his Habilitation *(post-doctoral teaching qualification) as Assistant Professor of Radiology in 2002. He was certified as a specialist in nuclear medicine in 2003. Since 2007, Prof. Gutberlet has been Head of the Department of Diagnostic and Interventional Radiology at the Heart Centre of the University of Leipzig and has a professorship for cardiovascular imaging at the University of Leipzig, where he is involved in clinical and research activities using PET/MR. Prof. Gutberlet has mostly been involved in research projects dealing with Doppler-ultrasound, contrast agents, MDCT and MRI of the cardiovascular system. He has been one of the project leaders of the German Competence Network for Congenital Heart Diseases since 2003 and has gathered first-hand experience in cardiac PET/MR and interventional MRI. Prof. Gutberlet was President of the European Society of Cardiovascular Radiology from 2015–2017, President of the Working Group of Cardiovascular Imaging of the German Röntgen Society (DRG) from 2014–2016, and Congress President of the European Society of Cardiovascular Radiology in 2009. He has been a member of the European Board of Cardiac Radiology and Q3-Adviser Cardiac CT and Cardiac MR of the German Röntgen Society (DRG), since 2011. Prof. Gutberlet has authored more than 200 publications in peer-reviewed scientific journals.*



6

CHANGING THE PARADIGM OF HEPATOBILIARY EMERGENCIES

HOW MODERN IMAGING CHANGES THE PARADIGM OF HEPATO-BILIARY EMERGENCIES

BY **YVES MENU**

Acute diseases of the liver and bile ducts commonly present as abdominal emergencies.

Most are related to infection, inflammation or bleeding. Treatment of hepato-biliary emergencies largely varies according to the identified cause, but it is obvious that imaging has revolutionised the management of these emergencies. For diagnostic purposes, ultrasound (US) and/or computed tomography (CT) are almost always performed as first-line examinations and magnetic resonance imaging (MRI) is also playing an increasingly important role for the diagnosis of biliary diseases. Imaging is not only crucial for the confirmation of the presence of a clinically suspected disease, it also contributes guidance in selecting between conservative treatment, interventional radiologic procedures, or surgery, and contributes in deciding when treatment should be applied during the course of disease, taking into account a patient's clinical and biological background. The role of imaging is most significant in solving problematic emergency situations. As clinical presentation is often misleading, emergency physicians may have trouble correlating a patient's atypical symptoms to a liver or bile duct disease. When a first clinical impression suggests there is probably no significant disease, the need for imaging for confirmation before discharging the patient is clear. In this common clinical setting, a normal abdominal ultrasound and/or CT examination, including the base of the thorax, allows for confident decision-making by the treating physician. Imaging should be readily available round-the-clock at the emergency department and radiologists should be able to manage urgent examinations and should join in the discussion of treatment options, based in part on imaging. In other instances, it might be useful to obtain follow-up imaging examinations, in order to determine if the patient's anatomical condition has improved, or conversely to decide if a radiological interventional procedure or surgery should replace inefficient conservative treatment.

IMAGING MODALITIES

Ultrasound

Ultrasound is certainly the preferred initial method for many reasons: it is widely available and important information can be obtained rapidly without the requirement of sophisticated equipment. In feeble patients, ultrasound can be performed at the patient's bedside. Depending on the local hospital organisation, emergency physicians sometimes perform ultrasound examinations on their own in order to collect basic information, such as gallbladder and bile duct dilatation, presence of intraperitoneal fluid, or of an intrahepatic mass. Results obtained depend on the operator's skills and expertise as well as knowledge of potential traps and pitfalls. If present or suspected, uncertain diagnoses should be clarified by the diagnostic team, in order to rule out false-negative diagnoses. For instance, detection of common bile duct stones by ultrasound is typically difficult, and, therefore, this diagnosis cannot be discarded by ultrasound alone. According to the policy adopted by the emergency and radiology department, ultrasound could collect sufficient information for the patient's management, but some policies demand further investigation, either with more advanced ultrasound, including Doppler imaging, or more commonly by CT and sometimes MRI.

Computed tomography

CT is widely available round-the-clock in many institutions. The number of CT examinations performed for abdominal emergencies is constantly growing. The main advantage of CT is the complete all-organ encompassing demonstration of the abdomen without any limitations related to anatomical display. The images obtained can be double read, possibly by a remote reader when a specialised opinion is necessary. One important limitation is radiation exposure, especially in children and young adults, however modern equipment allows high quality examination with reduced radiation doses. Compared with CT performed a decade ago, the overall radiation dose delivered to the patient has dramatically decreased. Radiologists also adapt the examination technique to the clinical situation, for instance acquiring only diagnostically relevant images and not necessarily always demanding plain and contrast-enhanced series automatically for all cases. In addition dual-energy CT allows reconstructing virtual non-enhanced images from post-injection acquisitions, rendering

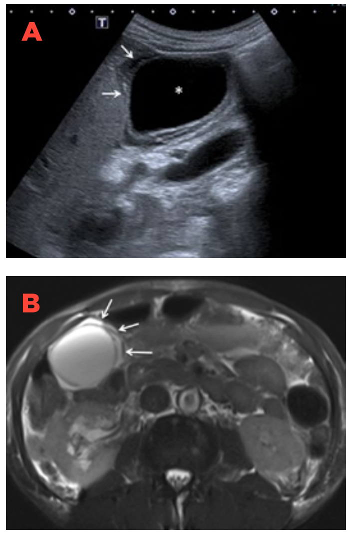


FIGURE 1

A 68-year-old male under medical treatment for myeloma who developed right upper-quadrant abdominal pain and fever. Ultrasound (A) showed a distended gallbladder (star) with wall thickening (arrows). CT was not performed, as iodinated contrast medium injection is contraindicated in this setting. MRI (B) confirmed presence of distended gallbladder and wall thickening with pseudo-membranes (arrows). The patient was rapidly operated thereafter. Acalculous cholecystitis was found with gangrenous wall and early wall perforation.

direct acquisition unnecessary. CT has, however, some limitations. For example, iodinated contrast medium injection should not be performed in patients with renal insufficiency or with a previous intolerance to iodine. In haemodynamically unstable patients, who need to undergo laparotomy without delay, the CT examination should not be performed, unless the equipment is installed in the shock room and resuscitation of the patient goes on during image acquisition. Concerning bile ducts, CT has limited capability in the detection of poorly calcified gallstones.

Magnetic resonance imaging

Although MRI is still uncommonly applied in emergency situations, its role in the evaluation of hepatobiliary diseases is increasing, mainly for the evaluation of bile duct pathologies. MRI should be performed exclusively on stable patients, as acquisition time, even when only basic sequences are obtained, is much longer than for CT. Moreover, ferromagnetic resuscitation equipment may not be compatible with the strong magnetic field and cannot accompany the critically ill patient inside the examination area. Minimal cooperation from the patient is also necessary, for instance to obtain breath hold images. Basic contra-indications of MRI, such as ferromagnetic implants including pacemakers, should be meticulously searched for and located, despite the emergency situation. The dominant advantage of MRI over ultrasound and CT is its reliable ability to examine the bile ducts. In combination with ultrasound, MRI might be limited to fast acquisition of cholangio-pancreatography sequences (MRCP) with breath-hold T1 and T2 weighted sequences, for an examination time of the patient inside the MRI tunnel not exceeding 10–15 minutes. Thus emergency MRI examinations might become more feasible in daily use. In the future, MRI will become more and more part of a decision tree of diagnostic modality

options in hepato-biliary emergency cases and will be more readily available, as is already the case for patients with cerebral ischaemia or spinal cord compression.

Other diagnostic modalities

Conventional radiography is no longer performed for hepato-biliary emergencies. Angiography has no indication for diagnosis and has largely been replaced by CT; however it is essential for demonstration of a focal bleeding source and allows control of acute haemorrhage during diagnostic investigation by using one of many vessel embolisation procedures. Similarly, percutaneous or endoscopic opacification of the bile ducts and biliary drainage procedures are part of the therapeutic armamentarium in an acute setting.

ACUTE CHOLECYSTITIS

Acute cholecystitis is one of the most common abdominal emergencies. Ultrasound is the method of choice for detection and diagnostic confirmation. However, CT may be useful in addition, especially in the case of complicated cholecystitis, as well as MRI, for cases which are not so straight forward (Figure 1).

Calculous cholecystitis

Fortunately, cholecystitis develops only in a minority (5–20%) of patients with gallstones, and, for this reason, there is no room for preventive treatment of gallstones in asymptomatic patients. Most patients with acute cholecystitis had previous episodes of biliary colic and only a minority has no clinical background. Obstruction of the cystic duct by a stone causes inflammation and distension of the gallbladder and consequently promotes gallbladder infection. Clinical symptoms are commonly suggestive: right upper quadrant pain and fever of 38–39°. At physical examination, local guarding may be found and Murphy's manoeuvre is positive, which is pain caused by palpation of the gallbladder area that limits breathing. In some cases, symptoms might be less typical: vague epigastric pain and doubtful Murphy's manoeuvre. In all cases ultrasound is the method of choice, showing the association of intraluminal gallstones, wall thickening over 3mm and a positive ultrasound-guided Murphy's manoeuvre, when the gallbladder fossa is screened with the ultrasound probe. Associated signs are sludge of the bile contained in the gallbladder and gallbladder wall distension.

Of note is the fact that the association of gallstones and thickened gallbladder wall is not necessarily indicative of acute cholecystitis, as stones are extremely common, and thickening of the gallbladder wall as an isolated finding is not pathognomonic. The latter can also be found in patients with acute hepatitis, portal hypertension, hypoalbuminemia or cardiac failure. Important traps are an empty gallbladder and the existence of an asymptomatic chronic cholecystitis. Murphy's sign is in itself not specific either, as it could be observed in the case of peritoneal inflammation or acute hepatitis.

Therefore, the diagnosis of acute cholecystitis relies on the association of signs, together with clinical symptoms. This underlines that imaging findings should always be put into perspective with the clinical background.

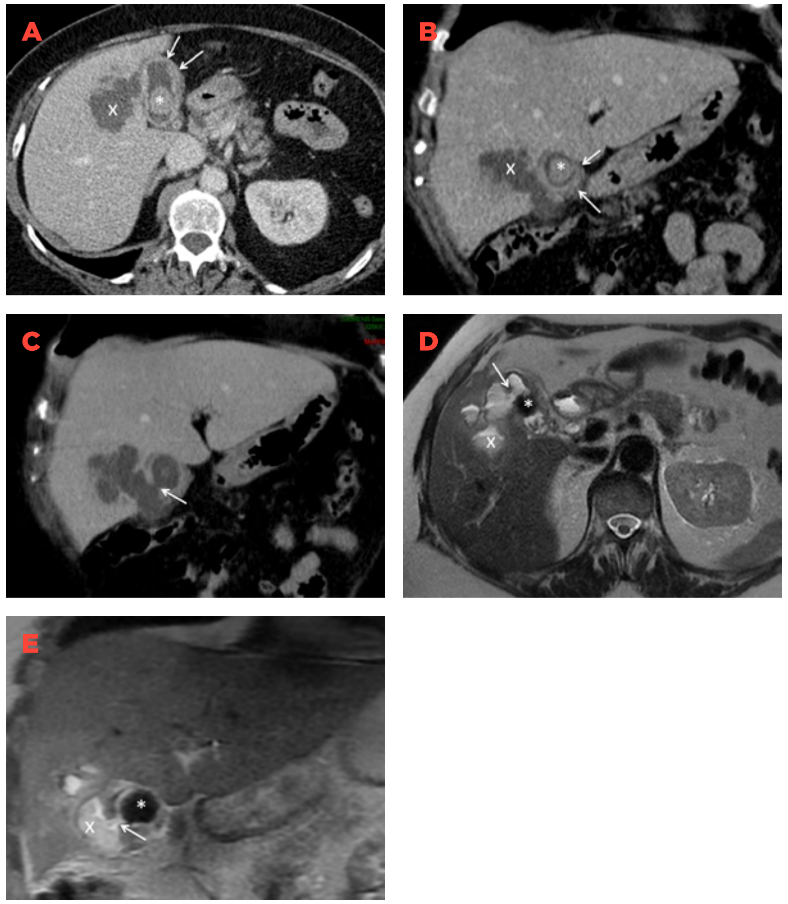


FIGURE 2

A 72-year-old female presented with right upper-quadrant abdominal pain and fever. Ultrasound disclosed a gallbladder stone and thickened gallbladder wall. Following conservative treatment with antibiotics, fever did not subside. CT with axial (A) and coronal reformatted images (B) evidenced cholecystitis, a gallbladder stone (star) and thickened gallbladder wall (arrows). Within the liver, a hypoattenuated area with irregular margins represented liver abscess (x). Minimum Intensity Projection CT (C) showed communication between the gallbladder and the abscess (arrow). MRI in axial (D) and coronal (E) planes showed the stone (star), abscess (x) and communication (arrow).

Conversely, a normal ultrasound examination of the gallbladder is an excellent indicator of absence of cholecystitis. In rare cases, ultrasound examination fails to demonstrate the entire panel of signs and may even have difficulties locating the gallbladder, for instance in the case of massive calcification of the gallbladder wall, called 'porcelain gallbladder', that might escape ultrasound demonstration due to signal blackout. CT rescues the diagnosis showing either intensive calcification of the gallbladder wall or in other situations its unusual heterotopic location.

Complications

A major role of imaging is to detect complications of acute cholecystitis. Uncomplicated presentation is usually treated conservatively followed by delayed surgery after resolution or significant improvement of local inflammation. Conversely, complications such as gangrenous cholecystitis and gallbladder perforation may require immediate additional treatment. In gangrenous cholecystitis, the gallbladder wall is fragilised by ischaemia, leading to rupture in the peritoneal cavity. A fatal outcome is possible if left untreated. Diagnosis is difficult

as clinical signs may be misleading: gallbladder wall thickening and positive Murphy's sign may be missing. CT is useful, showing absence of contrast enhancement of the gallbladder wall, possibly intramural gas bubbles, haemorrhage, and internal membranes. Immuno-compromised patients or those with vascular risk factors are especially vulnerable. Imaging offers key elements for unequivocal immediate diagnosis and allows for appropriate treatment.

Another common complication of acute cholecystitis is perforation, which may stay locally limited due to peritoneal inflammation and adhesions. A so called cholecystic phlegmon is sometimes difficult to assess with ultrasound and is much better seen on CT. Usually, this pathology is controlled by medical treatment, as peritoneal adhesions would make surgery difficult in the emergency setting. A further complication is represented by abscess formation within the liver parenchyma (Figure 2). This occurs in up to 10% of cases, by local spread of infection. Although ultrasound is able to detect a hepatic abscess, CT is more accurate in delineating the exact location and extent and allows for a more confident comparison of follow-up examinations.

Lastly, fistulisation of the acutely inflamed gallbladder in the duodenum can occur. Gallbladder stones that pass through the fistulous communication migrate through the duodenum to the small intestine and, when large enough, might become blocked in the ileum, causing small bowel obstruction. Association of aerobilia, or pneumobilia, which is the presence of gas in the gallbladder or bile ducts, and small bowel obstruction is highly suggestive, particularly when the calcified stone itself is also depicted (Figure 3).

FIGURE 3

A 79-year-old female presented with previous episodes of mild biliary colic related to known gallstone. She suddenly experienced severe epigastric pain and vomiting. Non-enhanced CT (A) showed aerobilia (arrows) and minimum intensity projection (B) showed a fistula (arrow) between the duodenum and air-filled gallbladder (star) whereas the gallstone was no longer visible. Axial slices covering the lower abdomen (C) revealed the stone located in the small bowel and causing intestinal obstruction.

Acalculous cholecystitis

Acute cholecystitis developing without the presence of gallbladder stones is a challenging diagnosis (Figure 1) and occurs in less than 10% of the cases of acute cholecystitis. Specific subgroups of patients are involved: patients in the posttraumatic phase, those admitted to the intensive care unit, and diabetic patients are some of the typical patient profiles. Patients recently treated with hepatic chemo-embolisation are similarly exposed to an onset of acalculous cholecystitis. Despite the absence of gallstones, imaging is usually able to provide a reliable diagnosis, showing the signs of gallbladder wall inflammation, while it is sometimes necessary to perform percutaneous puncture and/or drainage of the gallbladder to assess the diagnosis and at the same time treat the patient.

Percutaneous cholecystostomy

Directed image-guided puncture of the gallbladder is performed for two reasons. One is the difficulty of assessing the diagnosis, for instance in the case of acalculous cholecystitis, another is to perform an emergency treatment for critical patients who are unfit or at high risk for surgery. Needle puncture and catheter drainage of the gallbladder can be performed at the patient's bedside, under ultrasound guidance. Although a transhepatic approach is recommended, traversing the liver parenchyma for safety reasons and avoiding direct emptying of infected bile into the peritoneal cavity, recent studies showed no real difference in terms of complication with a direct subhepatic approach.

It is largely accepted that this treatment is not definitively curative but gains time for preparation of the patient for subsequent surgery. However, large studies have demonstrated that percutaneous cholecystostomy may well be efficient in the long-term, even in the absence of delayed surgery. Some particularly frail patients could be considered eligible for conservative management without surgery after percutaneous cholecystostomy.

ACUTE CHOLANGITIS

Jaundice rarely represents an emergency situation, as in most cases, when bile duct obstruction is caused by tumour, compression of the bile duct is slowly progressive. However, there is a specific clinical situation, commonly associated with jaundice which requires emergency management. Acute cholangitis might evolve as a severe condition and be potentially life-threatening. The most common cause for acute cholangitis is common bile duct obstruction by gallstone. Other causes are iatrogenic, especially after endoscopic retrograde cannulation and contrast medium injection in the biliary system. Clinically, the diagnosis is evident, based on the sequence of pain-fever-jaundice. Because bile duct stones favour biliary stasis and consequently bile duct infection, septicaemia might ensue, with dramatic consequences such as septic shock and acute renal failure.

Imaging is the cornerstone of diagnosis. Ultrasound is the first method performed,

and may show dilation of the common bile duct and intrahepatic ducts. However, as this is a finding far from being constantly present, the stone located in the common bile duct may act as a check valve causing only intermittent biliary obstruction. Moreover, identification of common bile duct stones is sometimes difficult, due to the anatomical location of the distal segment of the common bile duct, where most obstructive stones are located, and the fact that it is hidden by gas contained in the digestive tract. Therefore, whenever clinical symptoms are suggestive of acute cholangitis, an apparently negative or inconclusive ultrasound examination should not be considered to rule out acute cholangitis.

CT obtained in an axial plane and with 3D reformatting depicts more clearly the common bile duct and detects thickening and enhancement of the bile duct wall which influences the inflammatory process. Unfortunately common bile duct stones are not or poorly calcified in the vast majority of cases and may not be detected regularly, as their attenuation values on CT may be similar to that of bile or environmental tissue. Obtaining non-enhanced and enhanced acquisitions is recommended as slight hyperattenuation of stones might become better visible, when comparing both.

However, despite acceptable diagnostic capability of CT, MRI is more commonly used for detection of common bile duct stones (Figure 4), even when they are small (Figure 5). MRCP is recognised as a robust imaging technique, quick and non-invasive for assessment of biliary obstruction. There is no doubt that MRI will have an increasingly important role in the evaluation of emergencies related to bile duct pathology. Acute cholangitis may be complicated by abscess formation within the liver. CT and MRI are well-adapted to the detection of abscesses.

LIVER ABSCESS

Liver abscesses occur commonly. Because treatment differs, pyogenic and amoebic abscesses are considered separately. In the case of pyogenic, or bacterial, infection, treatment is a combination of antibiotics, cure of the origin of infection and sometimes abscess aspiration or drainage. In case of amoebic abscess, specific treatment by Metronidazole is provided and drainage is only performed in selected cases, to prevent rupture if it is a large abscess. Surgical drainage is no longer a first option for treatment of liver abscesses.

Pyogenic abscess

Most pyogenic or bacterial abscesses originate from the digestive tract, from conditions such as acute diverticulitis of the sigmoid colon, from the bile ducts (Figure 6), from septicaemia, or spread to the liver by direct contact. Specific causes are iatrogenic, after tumour ablation, or chemoembolisation of a liver tumour. In 10% of cases, no origin is found. In the past, acute appendicitis was the main cause of liver abscess.

Ultrasound is commonly the first imaging modality to be used. Although diagnosis is

FIGURE 4

A 56-year-old female presented with sudden onset of epigastric pain, followed by fever and jaundice. Ultrasound depicted bile duct and gallbladder dilatation and the distal segment of the common bile duct remained obscured. CT (A) confirmed dilatation of the common bile duct (arrows) and (B) of the gallbladder (star) but was unable to detect the cause of bile duct obstruction. The arrow points to the stone that was demonstrated by MRI. Axial MRI (C) confirmed gallbladder distension (star), sludge within the common bile duct (long arrow) and in the gallbladder (arrowhead), together with wall thickening. Notice the inflammatory changes of the peritoneum in front of the gallbladder (short arrows). MRCP (D) showed the stone causing biliary obstruction and located in the distal common bile duct (arrow).

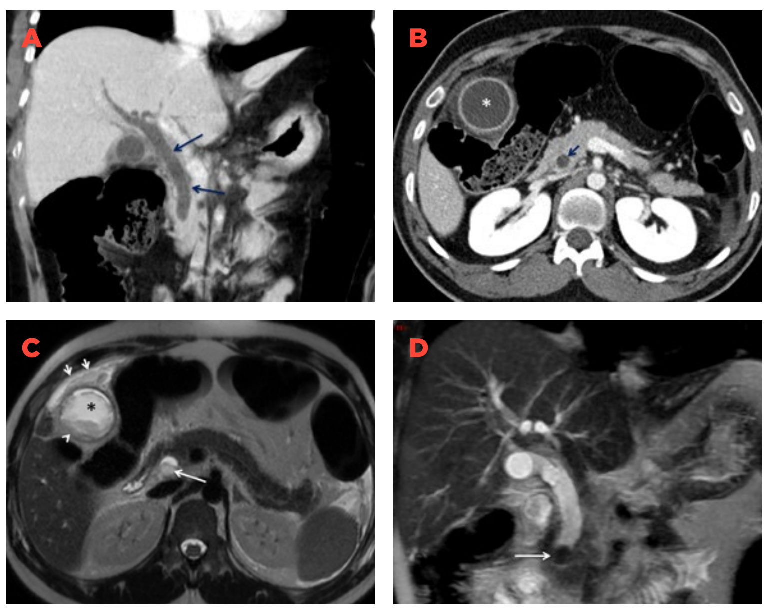
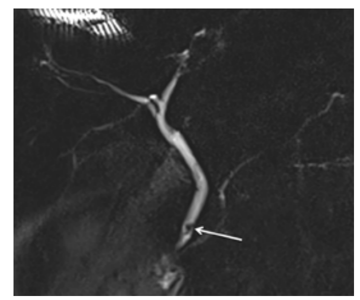


FIGURE 5

A 42-year-old female with epigastric pain and fever. Ultrasound and CT were normal. MRCP showed a small stone as a hypointense defect within the common bile duct (arrow).



easily established when pus has collected and one or more hypoechoic processes containing more or less strong internal echoes are seen, diagnosis might be difficult at the early presuppurative phase, when pus has not yet collected. Its misleading appearance may even mimic a solid tumour.

CT is the most reliable imaging modality; it shows the precise extent of the fluid collection, with inflammatory enhancement of the limiting pseudocapsule, septations, and an absence of enhancement of the centre. Pyogenic abscesses are commonly multiple whatever their cause and CT is able to make a precise

map of all collections even including those of small dimensions. CT also can be used to check the perihepatic anatomical environment and the entire abdominal cavity to search for the cause of infection, or for any other abscess location: pulmonary, renal or splenic, in the case of septicaemia.

MRI is mainly useful when a biliary origin of infection is suspected. Many abscesses will resolve following treatment of the origin and administration of antibiotics (Figure 7). However, if the abscess origin is unclear, performing a needle puncture and aspiration of pus content for bacteriological culture may be indicated before antibiotics are given. Image-guided insertion of a drainage catheter can be useful for large abscesses or those located subcapsularly, prone to extrahepatic rupture, or if medical treatment alone is not followed by rapid improvement of the patient. Sufficiently large-bore catheters should be used in order to empty the abscess as it usually contains thick fluid and debris (Figure 6).

Amoebic abscess

Amoebic abscess differs from pyogenic abscess clinically and treatment is different. The diagnosis is sustained by epidemiological information regarding the contact of the patient with an endemic spread of the amoebic parasite in infested regions. It may take up to five months for the abscess to develop after initial contamination. The patient may present with associated inconstant diarrhoea. Ultrasound shows a hypoechoic intrahepatic lesion, usually well demarcated and with homogenous content. At the early phase, however, ultrasound can be normal. CT shows the non-enhancing abscess content, with a possible

FIGURE 6

A 61-year-old female with recently detected pancreatic cancer. CT (A) demonstrated bile duct dilatation (arrows). Endoscopic stenting was performed to relieve biliary obstruction. Reformatted CT (B) confirmed the correct position of the stent (arrows). Fever and pain developed thereafter. Follow-up CT showed cholecystitis as well as a hypoattenuating mass next to the gallbladder (arrows) with gas (arrowheads) suggesting liver abscess. Percutaneous drainage of the abscess (C) was carried out. Upon abscess resolution, the patient underwent resection of pancreatic cancer.

peripheral enhanced rim. Amoebic abscesses are multiple in one-third of cases (Figure 8). Imaging is most useful to evaluate the risk of rupture and for selection of candidates for percutaneous abscess drainage. Abscesses larger than 10cm in diameter, abutting the liver capsule, especially when located in the smaller left liver lobe or close to the diaphragm, may be considered for preventive drainage. However, only a minority of patients are concerned, given the efficiency of medical treatment.

Hydatid cyst

Although echinococcal hydatid cysts are a rather common parasitic liver disease in certain areas, they rarely present as an emergency. Only cases with rupture in the bile ducts may be complicated by biliary obstruction and/or cholangitis. The diagnosis is usually easily established by ultrasound, CT or MRI. Biliary rupture might be suspected if bile duct dilatation is seen in association with hepatic hydatid cyst.

LIVER BLEEDING

The most common cause for hepatic haemorrhage is penetrating or blunt abdominal trauma. However, in some cases, non-traumatic bleeding can occur, mostly related to liver tumours.

Liver injury

In abdominal trauma, the liver is the most commonly involved organ, followed closely by the spleen. Approximately 25% of patients

FIGURE 7

A 48-year-old male was treated for multiple liver abscesses. CT showed multiple hypoattenuating hepatic nodules, without internal enhancement (A). After medical treatment, follow-up CT obtained two months later (B) showed almost complete remission.

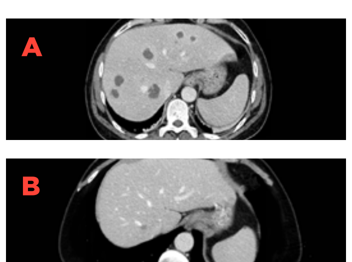
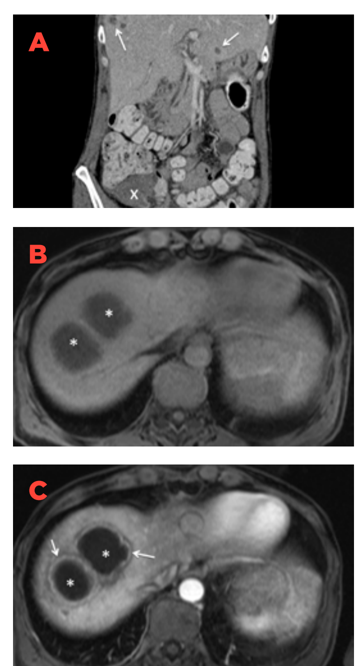


FIGURE 8

A 52-year-old female presented with diarrhoea, fever and right upper-quadrant abdominal pain. She had travelled to India two months previous. Amoebiasis was suspected and later confirmed by specific blood tests. Coronal CT (A) showed multiple hypoattenuating areas in the liver (arrows) as well as marked thickening of the caecum (x). MRI before (B) and after (C) Gadolinium chelate injection confirmed hypointense amoebic liver abscesses (star) with marked enhancement of a pseudo-capsule (arrows).



with abdominal trauma have liver injury. In blunt abdominal trauma, the entire abdomen has to be imaged and in polytrauma victims, a diagnostic check from top to bottom is required. Ultrasound and CT are used with different goals.

Ultrasound is not faster to perform than CT and has a limited potential for detection and staging of liver injuries and associated trauma to other structures, such as the digestive tract or the diaphragm. However, ultrasound may still be useful, when performed at the patient's bedside, to evidence intraperitoneal bleeding, when the unstable patient is being taken to the operating theatre.

CT is the gold standard for evaluation of both blunt and penetrating trauma. The patient is scanned faster than with ultrasound. In trauma centres, CT equipment is installed in the shock room and CT examination and resuscitation of the patient can take place simultaneously. When CT is not available in the emergency department environment and patient transport to a remotely located CT unit is necessary, only haemodynamically stable patients can be considered. When performed, CT shows the type of liver injury: contusion, laceration or fracture or presence of haematoma and shows the extent of the injury including any large vessel injury involved. In addition, CT detects ongoing bleeding on iodinated contrast enhanced scans, which is indicated by extravascular contrast accumulation or pseudoaneurysm or arteriovenous fistulas which may prompt either endovascular haemostatic catheter-directed arterial embolisation or surgery (Figure 9).

FIGURE 9

A 20-year-old patient was admitted in haemodynamic shock and with abdominal distension through an increasing amount of peritoneal fluid following a car accident. After initial resuscitation of the patient, CT was obtained. Non-enhanced images (A) showed a heterogeneous mass in the quadrate lobe of the liver (short arrows) with a less hypodense central area (long arrow) representing post-traumatic haematoma containing an internal clot. Images obtained at the phase of arterial enhancement and maximum intensity projection reformatting in the axial (B) and sagittal plane (C), showed extravasation of contrast (arrows) representing ongoing haemorrhage. Images obtained at the portal phase of enhancement (D) showed the accumulation of extravasated iodinated contrast within the haematoma. Outcome was uneventful after segmental liver resection.

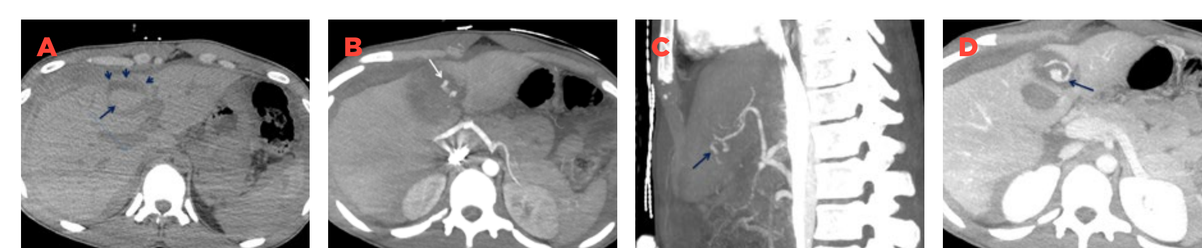


FIGURE 10

A 21-year-old female was admitted following a car accident. Emergency CT (A) showed laceration of the right liver lobe. As no peritoneal fluid or ongoing bleeding was observed, conservative treatment was the option. Follow-up CT obtained two months later (B) showed complete resolution of liver injury.

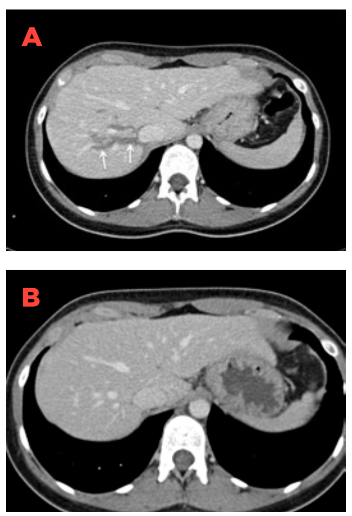
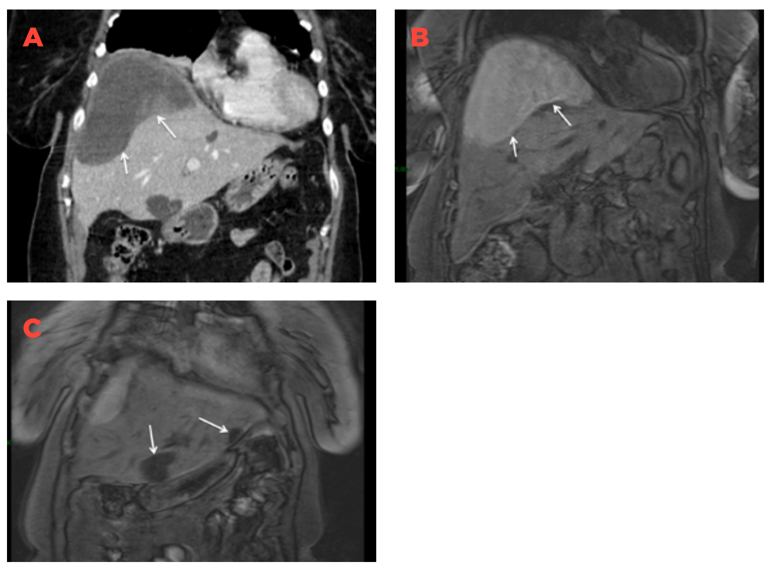


FIGURE 11

An 82-year-old female with known asymptomatic large biliary cysts in the liver. She suddenly complained of right upper-abdominal pain irradiating to the right shoulder. CT (A) showed a heterogeneous mass in the subdiaphragmatic right liver lobe. MRI (B) confirmed a blood filled lesion on hyperintense T1 weighted images. (C) Notice other biliary cysts (arrows) with a normal hypointense appearance on T1 weighted images. Comparison with previous images confirmed that bleeding had occurred in a pre-existing cyst. The patient was treated conservatively and symptoms resolved rapidly.



Information gained by CT has reduced the need for surgery in most cases of liver trauma and hepatic debridement or resection are rarely performed, surgery being limited to suturing of peripheral capsular tears. Even in a limited penetrating injury, surgical revision is not required in all cases, as the cross-sectional images demonstrate the pathway of penetration of a stab wound. Treatment of liver contusion has become more conservative, in the majority of cases, even including some high grades. Urgent surgery at admission is reserved for cases where haemostasis is not obtained or for large vein injury or other extrahepatic-associated injuries which need surgical repair. CT and/or MRI are optimal for the follow-up of these patients, in order to assess the progressive resolution of injury or pick up delayed complications (Figure 10).

Liver tumour

Although any liver tumour can potentially bleed, haemorrhage is most often a complication of hepatocellular carcinoma or liver cell adenoma. Intraperitoneal bleeding can be life-threatening and might require emergency arterial embolisation, while intrahepatic or subcapsular haemorrhage might be managed conservatively. Ultrasound may have difficulties differentiating haematoma from tumour, while contrast-enhanced CT delineates the tumoural components and concomitant haematoma with more precision. A common situation is intraluminal bleeding of biliary cysts, occurring spontaneously or after a limited upper-abdominal contusion, but it often remains asymptomatic and conservative management is adequate, despite seemingly alarming images seen on CT. MRI is especially useful in demonstrating, with a particular MR signal, blood content within the lesion, which is usually more difficult to assess with CT (Figure 11).

SUMMARY

In summary, cross-sectional imaging has revolutionised the management of hepato-biliary emergencies. The combination of ultrasound, CT and MRI offers a wide spectrum of specific information for the diagnosis of virtually all clinical situations. These examinations are complementary for the detection and characterisation of disease, and provide unique information for the selection of treatment options, monitoring the treatment and guiding intervention.

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is professor of radiology and chairman of the department of radiology at Saint Antoine Hospital, Pierre & Marie Curie University in Paris, France. Originally from Dijon in the east of France, Prof. Menu graduated from the University of Paris VI Medical School in 1976, and began his residency in neurosurgery, endocrinology and radiology at the Assistance Publique Hôpitaux de Paris and University of Paris in 1977. He became a board certified radiologist in 1981 and then a fellow at Beaujon Hospital's department of radiology in Clichy. At Beaujon Hospital, he was promoted to professor of radiology, and in 1990 he was appointed chairman of the department of radiology at Bichat Hospital in Paris. He returned to Beaujon Hospital in 1993 and served as chairman of the radiology department until 2003, when he assumed until 2008 the post of chairman of Bicêtre Hospital's department of radiology as well as professor of radiology at the University of Paris XI.

Prof. Menu's main areas of interest are in the fields of gastrointestinal radiology, oncologic imaging and emergency radiology. He has published 191 peer-reviewed scientific articles, 19 book chapters and a book. He has also delivered 290 lectures, presentations and invited talks around the world. A long-time and active member of the ESR, Prof. Menu has been committed to advancing the profession and science of radiology. He served as president of ECR 2011 and on many of ECR's Programme Planning Committees. From January 2018 Prof. Menu will be Editor-in-Chief of European Radiology, *the ESR's scientific journal.*

7

ACUTE PANCREATITIS

ACUTE PANCREATITIS: IMAGING EVIDENCES DISASTROUS COMPLICATIONS FROM INFLAMMATION

BY **MIRKO D'ONOFRIO, ALESSANDRO SARNO, RICCARDO DE ROBERTIS**

Non-traumatic pancreatic emergencies can be a consequence of pancreatic pathologies or secondary to pancreatic interventions.

Acute pancreatic conditions include inflammatory involvement of the gland, pancreatic infections, pancreatic pathologies extending to adjacent organs, or vascular complications as well as acute clinical manifestations of pancreatic tumour.

ACUTE PANCREATITIS

Acute pancreatitis is an inflammatory disorder of the pancreas with abnormal activation of digestive enzymes leading to self-digestion of the pancreas and the surrounding tissue. The process consists of local inflammation and systemic inflammatory response syndrome (SIRS), which may result in multisystem organ failure. Causes include alcohol intoxication or small biliary stones that have migrated to obstruct the main pancreatic excretory duct and less often include other toxins, auto-immune reactions, pancreatic trauma or tumour. Another complication is that the distal bile duct becomes easily compressed when the pancreatic head swells because it traverses the pancreatic head. Fortunately, about 80 to 85% of patients suffer only from a mild form of pancreatitis, whereas approximately 15 to 20% develop a severe form with potential life threatening complications. The main reason for the severity of acute pancreatitis is that the pancreas is not limited by a strong protecting capsule. In the case of small ductal rupture, aggressive enzymes, protease and lipase, which attack proteins and fat, are released into the abdominal cavity. Furthermore, the pancreas sits at the anatomical frontier of the peritoneal cavity and the retroperitoneal space. All abdominal compartments can therefore become involved when severe acute pancreatitis develops, leading to a major crisis.

In 2012, the Atlanta Classification of acute pancreatitis in adults was revised in order to incorporate modern concepts of the disease, to improve clinical assessment of severity, to enable standardised reporting of data and to facilitate communication among physicians and between institutions. In particular, this classification defines criteria for the diagnosis of acute pancreatitis, differentiates the two types of acute pancreatitis (interstitial oedematous or necrotising), classifies the severity of acute pancreatitis into three categories, and defines the anatomical changes that are observed on imaging in the gland itself and the areas around it. The clinical diagnosis of acute pancreatitis is based on the acute onset of highly suggestive central abdominal pain, often radiating to the back, and serum lipase or amylase activity at least 3 times above the upper limits of normal. Characteristic features of acute pancreatitis are described on computed tomography (CT) and less commonly on magnetic resonance imaging (MRI) or ultrasound. When the levels of serum lipase and amylase are not abnormally elevated, but clinical symptoms strongly suggest acute pancreatitis, imaging is required to confirm the diagnosis. Imaging is usually not required in the emergency department or on the first day of admission.

Interstitial oedematous pancreatitis

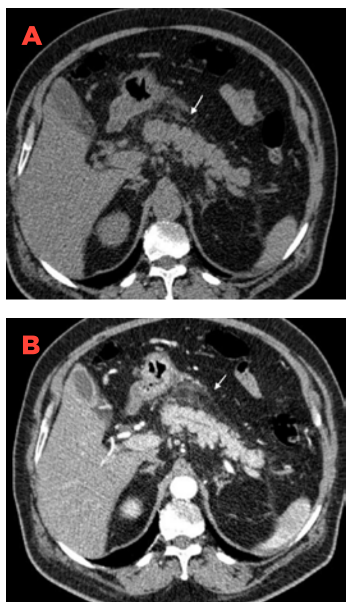
The majority of patients with acute pancreatitis have a diffuse or occasionally localised enlargement of the pancreas due to inflammatory oedema. On contrast-enhanced CT, the pancreatic parenchyma is enlarged and enhancement shows a homogeneous or slightly heterogeneous gland. Fat planes around the pancreas may appear normal, particularly in mild cases, but minimally obscured peripancreatic fat is a more frequent observation (Figure 1). The clinical symptoms of interstitial oedematous pancreatitis usually resolve within the first week and no further imaging control is needed.

Necrotising pancreatitis

This represents the most severe form of acute pancreatitis. Isolated necrosis of the pancreatic parenchyma is the least common form of necrotising pancreatitis (<5%). Due to the impairment of pancreatic perfusion and

FIGURE 1

Non-enhanced CT (A) and contrast-enhanced CT on the arterial phase (B) in a 44-year-old female with interstitial oedematous pancreatitis. Notice normal pancreatic parenchymal enhancement surrounded by mild stranding of the peripancreatic fat (arrow).



peripancreatic tissue necrosis evolving over several days, imaging can underestimate the eventual extent of pancreatic necrosis and the pattern of perfusion of the pancreatic parenchyma during the first days of the course of the disease. Glandular contrast enhancement may appear patchy. After one week of evolution, a non-enhancing area of the pancreas should be considered to represent parenchymal necrosis. The changes seen on contrast-enhanced CT are caused by the presence of nonviable tissue and liquefying surrounding fat.

Isolated peripancreatic necrosis is the second-most common form of necrotising pancreatitis and may be seen in approximately 20% of patients. It is important to recognise this type of necrosis, because these patients have a better prognosis than patients with pancreatic parenchymal necrosis. On contrast-enhanced CT, the pancreas enhances normally similar to interstitial oedematous pancreatitis, but necrosis develops in peripancreatic tissue. Non-enhancing areas of heterogeneous attenuation values are demonstrated in the lesser sac or in the retroperitoneal space, showing liquid as well as non-liquefied components.

The most common form of acute necrotising pancreatitis is represented by a combination of pancreatic parenchymal and peripancreatic fat necrosis. This appearance can be noticed in 75 to 80% of patients. On contrast-enhanced CT, a combination of the imaging findings described above for pancreatic parenchymal necrosis and peripancreatic necrosis can be seen (Figure 2). The course of the disease is variable, as necrotic changes may remain solid or liquefy, stay sterile or become infected,

persist or be resorbed over a longer or shorter time span.

According to the revised Atlanta classification, the severity of acute pancreatitis can be divided into three stages that are treated differently: mild, moderately severe, and severe. Mild acute pancreatitis is characterised by the absence of organ failure and local or systemic complications. Patients with mild acute pancreatitis will usually not require pancreatic imaging. Moderately severe acute pancreatitis is characterised by the presence of transient organ failure or local or systemic complications in the absence of persistent organ failure. Severe acute pancreatitis is defined by persistent organ failure. Patients with persistent organ failure usually have one or more local complications. The local complications defined in the revised Atlanta classification are pancreatic and peripancreatic fluid collections. Here, imaging is essential for a diagnosis.

Acute peripancreatic fluid collection (APFC) is defined as an exudate originating from the inflamed pancreas and occurring alongside interstitial oedematous pancreatitis – within the first four weeks after onset – with no associated peripancreatic necrosis and without the features of an organised pseudocyst. On contrast-enhanced CT, one or more homogeneous collections containing fluid densities, and confined by normal peripancreatic fat planes, without intrapancreatic extension, are evidenced. No definable wall encapsulating the collection is present. Most acute fluid collections remain sterile and usually resolve spontaneously without intervention.

Pancreatic pseudocyst (PC) is a specific fluid collection surrounded by a well-defined

FIGURE 2

Non-enhanced CT (A) and contrast-enhanced CT in the arterial phase (B) in a 52-year-old male with necrotising acute pancreatitis and necrosis involving both pancreatic and peripancreatic tissue. Notice the presence of nonviable non-enhanced pancreatic tissue in the head of the pancreas consisting predominantly of necrotic pancreatic parenchyma (arrow).

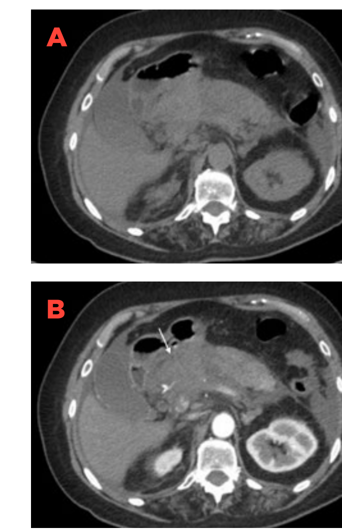


FIGURE 3

Pseudocyst on contrast-enhanced CT in the portal venous phase in axial (A) and coronal (B) plane in a 60-year-old male, 4 weeks after a first episode of acute pancreatitis. The pseudocyst (star) appears as a well circumscribed fluid collection, completely encapsulated, oval in shape, with homogeneous fluid densities and without any non-liquid component.

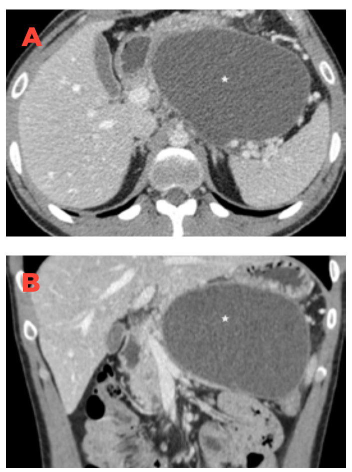
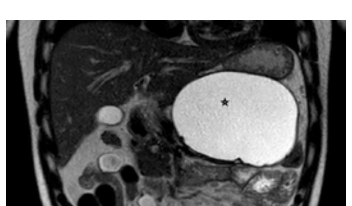


FIGURE 4

Coronal plane MRI of a pancreatic pseudocyst (star) on T2 HASTE shows the homogeneously fluid content of the collection.



inflammatory wall, located in the peripancreatic tissue or occasionally partly or totally intra-pancreatic. PC usually arises four weeks or later after the clinical onset of acute interstitial oedematous pancreatitis. PC is thought to arise from disruption of the main excretory pancreatic duct or its intrapancreatic branches without recognisable pancreatic parenchymal necrosis. According to the Atlanta classification, PC does not result from an acute necrotic collection (ANC) as defined below. PC may also arise in the setting of acute necrotising pancreatitis as a result of a disconnected duct syndrome, whereby pancreatic parenchymal necrosis of the neck or body of the gland isolates a still viable distal pancreatic remnant. Moreover, PC may be evident several weeks after operative removal of the necrotised tissue or necrosectomy, due to localised leakage of the disconnected duct.

On contrast-enhanced CT, PC appears as a well circumscribed fluid collection, completely encapsulated, usually round or oval in shape, with homogeneous fluid densities inside the lesion and with no or only minimal non-liquid component (Figure 3). Although contrast-enhanced CT is the imaging modality used most commonly to characterise PC, MRI or ultrasound may be required to confirm the absence of solid content in the collection (Figure 4).

Acute necrotic collection (ANC) may occur with all three types of necrotising pancreatitis and represents a combination of parenchymal and fat necrosis mixed with exudates extending from the pancreas due to the release of activated pancreatic enzymes into the pancreatic tissue and around it. Although within the first week of evolution it may be difficult to differentiate APFC from ANC, after the

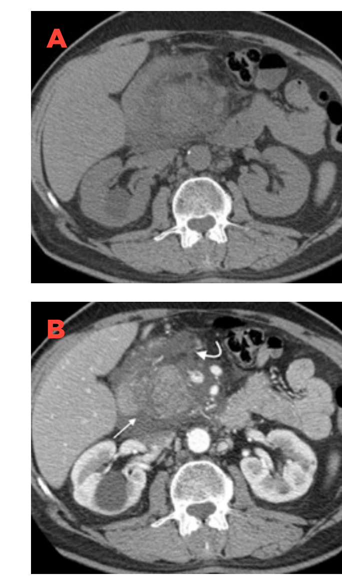
first week the distinction between these two types of collections becomes clear. ANC may appear homogeneous early in its course, but generally heterogeneous changes due to the necrotising process appear, with non-liquid densities of varying degrees and in various locations (Figure 5). ANC does not have a definable wall; it may be loculated on multiple sites, and intrapancreatic and/or extrapancreatic. The necrotic components can be missed by CT. When there is clinical suspicion, MRI or ultrasound are able to confirm the presence or absence of such necrotic material with more confidence, if considered relevant for treatment. Interventional treatment is based on the clinical presentation. ANC resolves spontaneously in 20% of patients, becomes superinfected in another 20%, and develops into sterile walled-off necrosis in approximately 60%.

Walled-off necrosis (WON) consists of a mature, encapsulated collection of pancreatic and/or peripancreatic necrosis and has a well-defined inflammatory wall, which defines the interface between the viable fat and the necrosis. Usually this maturation occurs in the subacute phase of necrotising pancreatitis, after around four weeks of evolution of acute pancreatitis. It represents the mature stage of an ANC. WON may become infected, it can be single or multiple and can involve the pancreas alone, the peripancreatic fat alone, or, most commonly, both, similar to ANC. On contrast-enhanced CT, WON appears heterogeneous with liquid and non-liquid densities (Figures 6 and 7).

All four types of pancreatic fluid collections can become superinfected, but, overall, infection of APFC and PC is rare. Infection of

FIGURE 5

Non-enhanced CT (A) and contrast-enhanced CT in the arterial (B) phase in a 45-year-old male with necrotising pancreatitis. Heterogeneous enhancement of the pancreatic head due to pancreatic necrosis (arrow). ANC appears heterogeneous due to the necrotising process, with non-liquid densities. It does not have a definable wall encapsulating the collection and is intra-pancreatic and extra-pancreatic in extent (curved arrow).



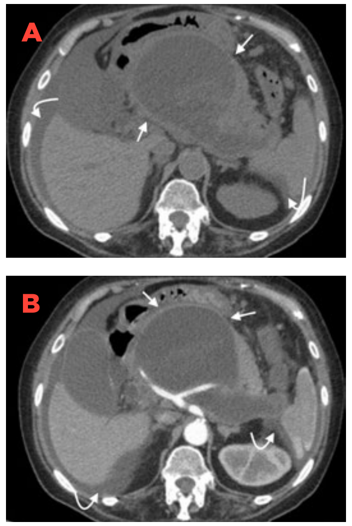


FIGURE 6

Non-enhanced CT (A) and contrast-enhanced CT in the arterial phase (B) show the evolution of ANC in WON. Heterogeneous lesion with liquid and non-liquid densities and completely encapsulated by a well-defined wall (arrow). Notice the presence of ascites (curved arrow).

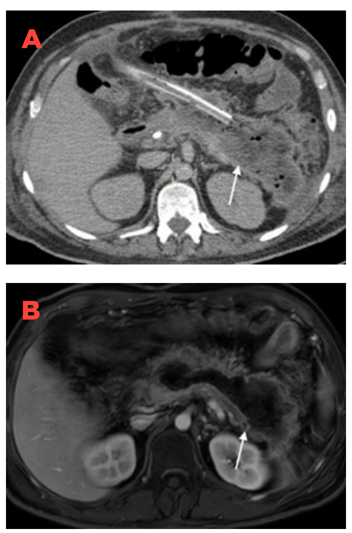


FIGURE 7

Non-enhanced CT (A) and T1 GRE FS MRI after administration of gadolinium in the arterial phase (B) during follow up of WON (arrow), in a young adult after placement of a large-bore drainage catheter and progressive clearing of the fluid collection in the pancreatic compartment.

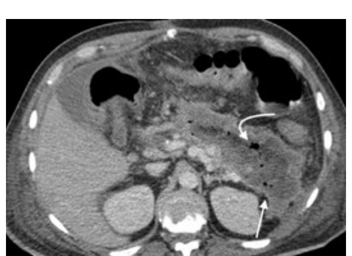


FIGURE 8

Contrast-enhanced CT in the portal venous phase 10 days after onset of acute necrotising pancreatitis; superinfection of ANC was clinically suspected. CT confirms the presence of gas bubbles (curved arrow) within the fluid collection (arrow).

pancreatic necrosis occurs in about 20% of patients, usually between the second to fourth weeks from the onset of symptoms. Superinfection of a pancreatic fluid collection can be diagnosed on CT when gas bubbles are present within the fluid collection but pitfalls are caused by spontaneous perforation into the gastro-intestinal tract (Figure 8).

OPTIONS FOR IMAGING IN ACUTE PANCREATITIS

CT plays a primary role in the management of pancreatitis, helping in confirmation of the clinical diagnosis, assessing severity and detecting complications, and is clearly the method of choice for imaging the pancreas. MRI or ultrasound is used for clarification of the content of fluid collections, for evidencing biliary stones, or when CT is contraindicated. Imaging usually is not required in the initial phase of acute pancreatitis or in patients with acute pancreatitis who are rapidly improving clinically. However, imaging is recommended during the initial course, when the diagnosis is indeterminate clinically. Unless contraindicated, contrast-enhanced CT should be used, particularly in patients with SIRS, organ failure, or other clinical or biochemical predictors of severe acute pancreatitis as well as in patients who are suspected of developing local complications of acute pancreatitis. The optimal time for scanning these patients is 72 hours, or later, after the onset of symptoms. Re-examination is indicated when the clinical picture drastically changes or for guidance of percutaneous catheter placement to drain fluid collections, for follow-up after large-bore catheter drainage or surgical debridement, and to establish a specific cause of acute pancreatitis (Figure 7A).

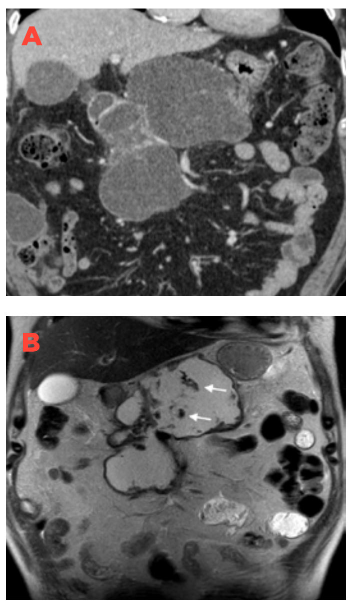
In assessing acute pancreatitis, following initial scout images, the upper abdomen is scanned with a low-dose technique to evidence stones, calcifications, and possible haemorrhage. Then, intravenous iodinated contrast is given because CT diagnosis of pancreatic necrosis relies on a lack of enhancement in the necrotic areas of the pancreas. MRI could be useful in patients with impaired renal function or allergies to iodinated contrast, in young or pregnant patients, in patients with suspected biliary stones for better evaluation or when not detected on CT, and for more precise assessment of the composition of a pancreatic fluid collection (Figure 9). MRI is more sensitive than CT for detecting haemorrhage and for demonstrating communication of a collection with the pancreatic duct. Ultrasound has no distinct role in acute presentation of pancreatitis. Moreover, the pancreas may appear completely normal in mild cases of acute pancreatitis. The principal role of ultrasound is to clarify the presence or absence of solid components within a fluid collection or for detection of gallstones not seen on CT, or when CT is contraindicated.

INVOLVEMENT OF ADJACENT ORGANS

Anatomical structures that are located close to the pancreas from head to tail are: the duodenum, common bile duct, transverse colon, splenic flexure of the colon, splenic vessels and hilum of the spleen. The intimate relationship

FIGURE 9

Contrast-enhanced CT in portal venous (A) phase and T2 HASTE MRI in a coronal plane (B) in a 62-year-old male in the assessment of the components of a pancreatic fluid collection: MRI shows more precisely the presence of non-liquefied material or necrotic debris (arrow).



of the pancreas with these structures explains their possible involvement in acute pancreatitis, which may cause gastro-intestinal obstruction, splenic involvement and formation of fistulas in the digestive tract.

Bowel involvement can occur as a late complication of a severe acute pancreatitis by compression, when a large collection or pseudocyst is present, or due to fibrous reaction of the viscus during resorption of a fluid collection. The transverse mesocolon or the left anterior pararenal space are most often involved. An acute intestinal obstruction is rare in pancreatic diseases. However, stenosis of the digestive tract is more common.

Involvement of the spleen is also a rare complication of pancreatic inflammatory disease and occurs in 1 to 5% of cases. Two different mechanisms of splenic damage are defined: indirect and direct. Indirect involvement of the spleen may occur either due to damaged splenic vessels, with consequent splenic haemorrhage and haematoma, or by destructive or lytic action of necrotic haemorrhagic collections on the peritoneal layer of the spleen, with consequent splenic rupture and haemoperitoneum. Direct involvement of the spleen is less common and is caused by penetration of acute pancreatic inflammation into the spleen through the splenic-pancreatic ligament, resulting in an intrasplenic pseudocyst or abscess (Figure 10).

Pancreatic fistulas can be separated in two different groups: internal and external. The most commonly encountered internal pancreatic fistulas are the pancreatic-digestive fistulas, in which the activated pancreatic enzymes spreading from a disrupted duct or

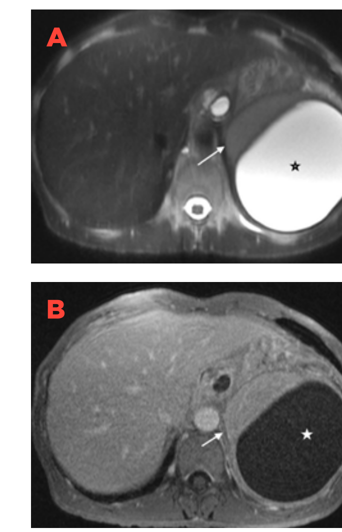
a peripancreatic collection directly erode the intestinal wall. In intra-peritoneal fistulas, the pancreatic juice collects in the peritoneal cavity and presents as pancreatic ascites. Sometimes the fistula can develop in the retroperitoneal space, involving the kidney, the ureter or the psoas muscle; it can also progress into the thorax by infiltrating the mediastinal space through the oesophageal/aortic hiatus or can erode the parietal pleura, in the case of pancreaticopleural fistula. A self-limited abscess can arise in any location at any time. External pancreatic fistulas are more common, as a complication of surgery or pancreatic needle puncture. In most cases, it is caused by the dehiscence of a surgical pancreatico-digestive anastomosis or leakage at the residual pancreatic stump. An external fistula may be simple, with direct communication of the main pancreatic duct, or duct of Wirsung, with the skin, or it can be complicated by the involvement of other structures of the digestive tract.

Imaging

In the past, diagnosis of digestive tract stenosis or obstruction was obtained by abdominal radiographs, looking for signs of intestinal blockage, a distended sentinel loop sign and/or by oral opacification of the digestive tract. A large mass effect in the upper abdomen and the nature of the stenosis of the digestive tract, fibrotic or neoplastic, could thus be evidenced. Nowadays the examination of choice is CT, which demonstrates the cause of obstruction and the relationship with the involved organs. Whereas ultrasound can identify an intrasplenic or perisplenic fluid collection, CT and MRI demonstrate the content of the collection, which is fluid, in the case of intrasplenic or perisplenic pseudocyst, and haemorrhagic,

FIGURE 10

MRI in a 40 year-old male patient with a complication of acute pancreatitis represented by an intrasplenic pseudocyst (star): (A) T2-weighted axial imaging; (B): T1-weighted axial post-contrast imaging in the delayed portal phase enhancement.



in the case of splenic haematoma. These imaging modalities also better identify laceration, capsular disruption, and haemoperitoneum that may occur as a consequence later.

Although small splenic parenchymal lesions, such as intra-splenic pseudocysts or subcapsular haematomas, probably heal spontaneously, the risk of splenic rupture remains. CT is helpful in early detection and evaluation of the extent and course of direct splenic involvement.

Internal pancreatic fistulas are often an incidental finding after repeated imaging, even though they can signify serious clinical symptoms. Demonstration of a pancreatic-digestive fistula is obtained by oral contrast study of the digestive tract or by CT when gas is recognised in the pancreatic collection in the absence of sepsis. On imaging, the drastic and sudden volume reduction of an intrapancreatic or peripancreatic pseudocyst, in the presence of ascites, should raise the suspicion of an intraperitoneal fistula. Small retroperitoneal fistulas can be found incidentally on CT examination that was required to elucidate the cause of acute pain. Diagnostic confirmation of an internal fistula can be made with magnetic resonance cholangiopancreatography (MRCP), which locates the site of the ductal rupture and perhaps also the fluid collection or the viscus involved.

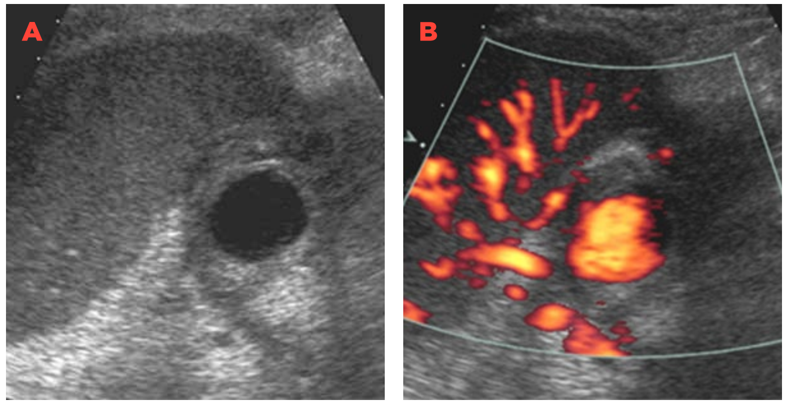
External pancreatic fistulas can be diagnosed by analysis of the fluid and imaging is required to define the extent of fistulous tracts. Fistulography or opacification of the fistulous tract is the primary investigation to show the structures involved and should be considered in cases of complex fistulas. In selected cases, CT examination combined with opacification of the fistulous tract may be useful to delineate more precisely all fistulous ramifications.

VASCULAR INVOLVEMENT

Pancreatitis may cause a spectrum of vascular complications, ranging from incidentally discovered pseudoaneurysms to acute life-threatening arterial haemorrhage and from asymptomatic venous thrombosis to catastrophic variceal haemorrhage. Major severe haemorrhagic arterial complications in pancreatitis are infrequent but life-threatening conditions can arise. Massive bleeding may be due to pseudoaneurysmal disruption. Usually it occurs late in the course of the disease or in post-operative patients. The splenic artery is the most commonly involved (60–65%), due to its contiguity with the pancreas, followed, in decreasing order of frequency, by gastroduodenal (20–25%), pancreaticoduodenal (10–15%), hepatic (5–10%), and left gastric arteries (2–5%). The true incidence of pseudoaneurysm formation from pancreatitis is not well established, although generally estimated low at a range from 1.3 to 10%. A pseudoaneurysm is defined as an encapsulated haematoma in communication with the lumen of the ruptured vessel, where the external wall consists of adventitia, perivascular tissue, fibrosis, or clot. Leakage of pancreatic enzymes from an inflamed pancreas may result in enzymatic auto-digestion of the vascular wall, arterial wall maceration and diffuse bleeding in association with extensive necrosis, or pseudoaneurysm formation.

FIGURE 11

(A) Ultrasound examination evidences a round well-delineated hypoechoic intrasplenic lesion. Its vascular nature is confirmed by bright signal on colour-Doppler, (B) which highlights intrasplenic vascular structures containing flow. Signal brightness is correlated to intensity of flow.



Pseudoaneurysms usually occur in the proximity of pseudocysts. The pseudocyst, through the action of proteolytic enzymes, erodes into and communicates with the vessel lumen. Haemorrhagic complications are expected in 6–31% of patients with pancreatic pseudocyst and in 7–14% of those suffering from chronic pancreatitis. Arterial disruption is one of the most serious emergency conditions in pancreatic pathology. It is an uncommon complication of inflammatory pancreatic disease, but mortality is higher than 50% in the absence of appropriate and preventive therapy. Arterial embolisation techniques play a significant role in minimally invasive vascular therapy and are applied systematically when pseudoaneurysm is detected.

Venous complications are less commonly reported and are often confined to thrombosis of a large vein; the splenic vein being the most often affected. A surge in procoagulant inflammatory mediators, blood stasis by external compression from the surrounding inflamed pancreas, and vessel spasm can cause venous thrombosis in acute pancreatitis. Proteolytic damage or inflammation of the vessel wall may also contribute. Acute pancreatitis also causes a systemic inflammatory response that has effects on an endothelium-dependent relaxing response for acetylcholine. However, chronic pancreatitis, especially when calcified, is the most common cause of splenic vein thrombosis with 5–37% of patients affected. Compression and/or venous involvement induce thrombosis that leads to formation of oesophageal or gastric varices, which can, in turn, be responsible for acute bleeding. Thrombophlebitis of the peripancreatic tributaries of the portal vein is an acute infection of the portal venous system associated with hepatic involvement. It can arise from the extension of infected pancreatic necrosis along the sheath of the portal vein followed by hepatic involvement with hepatic abscess formation.

Imaging

Non-invasive vascular imaging, Doppler ultrasound, CT, and MRI, are almost as sensitive as angiography and should be the first choice in asymptomatic patients (Figure 11).

Asymptomatic pseudoaneurysm is occasionally reported in the course of an ultrasound examination using Doppler. CT angiography (CTA) is a fast modality that is less operator-dependent, has a shorter acquisition time, and demonstrates high accuracy in diagnosing arterial injuries. CTA also can demonstrate the full extent of a pseudoaneurysm if partially thrombosed and its effect on the adjacent viscera. Image post-processing with maximum intensity projections and 3-D reformatted reconstructions allowing for accurate vessel analysis can prove valuable in pre-procedural planning, regardless of whether treatment involves angiographic embolisation or surgery. Most pseudoaneurysms are saccular in shape, with the enhancing component possibly surrounded by thrombus. When the patient is in haemorrhagic shock, CT is the optimal imaging technique: it detects perivascular haemorrhagic collections and often, if present, demonstrates the ongoing bleeding source.

For venous involvement, ultrasound and CT can demonstrate the presence of varices but diagnosis of minimal venous bleeding is problematic. Upper gastro-intestinal endoscopy is mandatory, combined with either variceal sclerotherapy or variceal ligation or banding. Ultrasound would demonstrate thrombus within a larger vein and absence of flow at Doppler examination. Contrast-enhanced CT perfectly demonstrates thrombus as low attenuation values, and depicts the extent of thrombus in the branches of the portal venous system.

ACUTE PRESENTATION OF PANCREATIC NEOPLASM

Pancreatic cancer may present with acute clinical symptoms such as bleeding or pancreatitis caused by acute ductal obstruction. Haemorrhagic complications may be caused by tumour proliferation and invasion of surrounding tissues. Most frequently, the patient presents with melena due to bleeding in the digestive tract or secondary to rupture of perigastric varices that have developed after splenic vein occlusion caused by tumour compression. Acute pancreatitis occasionally occurs as a consequence of pancreatic neoplasms. While chronic pancreatitis more often coexists with a pancreatic mass, a tumour is revealed in only 1–2% of cases of acute pancreatitis (Figure 12).

FIGURE 12

Contrast-enhanced CT images in the arterial phase (A, C) and venous (B) phase in a patient with sudden onset of abdominal pain and melena. There is evidence of a lesion in the duodenal lumen (arrow), and intralesional haemorrhagic foci (curved arrow).

Imaging

Accurate diagnosis of haemorrhagic pancreatic conditions is best made based on unenhanced CT and MRI. In particular, MRI offers a higher soft-tissue contrast in the detection of haemorrhage. Optimal sequences for the evaluation of haemorrhage are fat-suppressed T1-weighted imaging and T2-weighted imaging, thanks to their sensitiveness to the paramagnetic effect of the blood component methaemoglobin. The imaging appearances of haemorrhage depend on the time elapsed from the onset of bleeding. Typically, acute haemorrhage has a high attenuation signal on unenhanced CT scans, but as time passes, attenuation values decrease. On MRI the appearance of blood is highly variable depending on the age of the haematoma and the imaging sequence used. These different appearances are due to the physiological evolution of haemoglobin over time.

In the case of acute pancreatitis secondary to pancreatic tumour, inflammatory changes predominate in the clinical and radiological setting and may hide the underlying tumour, resulting in possible delay of diagnosis. Findings that are useful to suggesting the presence of an underlying pancreatic malignancy include involvement of only a portion of the pancreas, associated significant dilatation of the pancreatic duct, vascular infiltration, and distant metastases. Other imaging modalities, such as MRI and endoscopic ultrasonography may be used to confirm the diagnosis in such a case.

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8

MY BELLY HURTS

MY BELLY HURTS: DIAGNOSTIC MANAGEMENT OF DIGESTIVE TRACT EMERGENCIES

BY PATRICE TAOUREL, CELINE ORLIAC, INGRID MILLET

Acute abdominal pain is a common presentation in the ambulatory setting.

It accounts for about 1.5% of all medical consultations and 8% of all emergency department visits in the United States in 2010. Although the differential diagnosis of acute abdominal pain is considerable, including hepatobiliary, urologic, gynaecologic, vascular and musculoskeletal conditions, gastro-intestinal diseases constitute both the most frequent and the most serious causes of acute abdominal pain.

Forty years ago, exploratory laparotomy was the standard for both diagnosis and treatment of gastro-intestinal causes of acute abdomen, but invasive emergency surgery without a hint of diagnosis is often useless. Twenty years ago, multiple studies showed the reliability of computed tomography (CT) for the primary diagnosis of virtually all causes of acute abdominal pain with the exception of acute cholecystitis and some gynaecologic emergencies, such as pelvic inflammatory disease and ectopic pregnancy. The benefit of CT in comparison to other imaging examinations was particularly significant in gastro-intestinal emergencies. Plain abdominal radiographs, which were traditionally considered the first-line diagnostic modality in gastro-intestinal emergencies, are of little value. CT gives much more information for little added cost.

Today, CT is considered the 'all-in-one' emergency diagnosis and triage for the acute abdomen. But the role of CT extends beyond its ability to diagnose causes of acute abdominal pain. By showing accurately the stage, the anatomic extension, and the potential resolution of disease without surgical treatment, CT has dramatically changed the management of gastro-intestinal emergencies. We will illustrate this significant progress regarding five common gastro-intestinal emergencies: appendicitis, bowel obstruction, diverticulitis, bowel perforation and acute mesenteric ischaemia. We will not deal with gastrointestinal bleeding for which the clinical presentation is specific.

ULTRASOUND, CT, OR NO IMAGING FOR THE DIAGNOSIS OF APPENDICITIS: COMPLEMENTARITY OR COMPETITION?

Acute appendicitis, or inflammation of the appendix, is currently the most frequent cause of acute abdominal emergency requiring surgery. It affects about 250,000 people per year in the USA and represents about three-quarters of paediatric surgical emergencies. The diagnosis is usually performed based on clinical symptoms including tenderness at McBurney's point, migratory abdominal pain and on blood analysis: C-reactive protein (CRP) correlates with the severity of the disease and white cell count (leucocytosis) is more sensitive for the detection of early-stage appendicitis. However, the clinical diagnosis is not always straightforward when clinical presentation is atypical, as is the case in about 50% of patients. This is particularly true in young children unable to verbalise symptoms, in old patients for whom clinical presentation may be sub-acute despite advanced disease, and in childbearing-age women because of the high rate of alternative gynaecologic diagnoses including pelvic inflammatory disease, complication of an ovarian cyst, or adnexal torsion.

These difficulties explain the risk of a strategy only based on clinical and biological data: to operate patients at the slightest suspicion results in a negative appendectomy rate of 15–25%, and up to 40% in young women. It is preferable to clinically monitor patients with an increased risk of perforation, which can lead to potentially life-threatening complications such as abscess, peritonitis and sepsis, since there is a correlation between duration of symptoms and the rate of complications. Extensive use of imaging for the diagnosis of appendicitis has allowed a decrease in the rate of negative appendectomy and is optimistically known as prophylactic appendectomy leading to bands and adhesions and delayed surgery.

Ultrasound (US) and CT have been largely assessed for the diagnosis of appendicitis and, more recently, magnetic resonance imaging (MRI) has also been evaluated in dedicated populations such as pregnant women and children. The diagnostic signs are well known. Ultrasound shows an enlarged, non-compressible and painful appendix measuring more than 6mm in diameter (Figure 1) and less useful ancillary

FIGURE 1

Ultrasound shows enlarged (>6mm), non-compressible appendix with hyperechogenecity of the surrounding fat, reflecting periappendiceal inflammation.

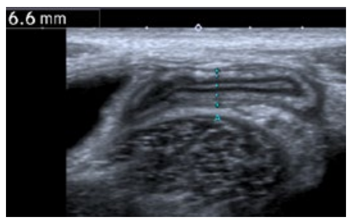


FIGURE 2

CT coronal reconstruction shows increased thickness and enhancement of the appendiceal wall (arrows) suggestive of appendicitis.

findings such as calcification in the appendix lumen or appendicolith, a fluid-filled appendix, hypervascularisation of the appendiceal wall, pericaecal fluid or inflammation of the surrounding fat. CT shows increased transverse diameter of the appendix, increased thickness of the appendiceal wall, periappendiceal haziness (Figure 2) and in some cases an appendicolith, caecal wall thickening or the presence of a focal defect in the appendiceal wall or gas bubbles outside the digestive tract when the appendix is perforated. MRI shows an increased enhancement of the appendiceal wall after intravenous injection of contrast and oedema, particularly well demonstrated by T2 signal hyperintensity within the wall or surrounding the appendix.

If there were a competition between ultrasound and CT in terms of accuracy, CT is the winner, at least in adult patients. CT has better sensitivity and it is more accurate for the diagnosis of appendix perforation, which remains challenging at ultrasound. It also allows for diagnosis of appendiceal plastron represented by an agglutination of small bowel loops. This may lead to a change of treatment using antibiotherapy, percutaneous drainage of an abscess, when necessary (Figure 3), and delayed rather than immediate surgery. CT delineates a wide field of view permitting easier identification of the location of the appendix when atypical, since its location within the abdomen is highly variable. CT is more accurate for depicting most of the alternative diagnoses, which include mesenteric lymphadenitis, Crohn's disease, colon diverticulitis, caecal cancer, epiploic appendagitis (Figure 4), or gynaecologic or urologic diseases, the latter comprising renal colic or pyelonephritis. CT can rule out

appendicitis and may shorten the hospital stay. By preventing unnecessary operation and patient observation and by permitting early recognition of alternative diagnoses, CT saves healthcare costs, up to almost 500 dollars per patient, despite the cost of CT examination, as reported in a study published 20 years ago.

Conversely, when radiation exposure is a concern, particularly in pregnant, paediatric, or young adult patients, ultrasound, despite its slightly inferior performance to CT, is often used as the first-line diagnostic modality. CT, and, following that, MRI, are advised if ultrasound is non-diagnostic. What is surprising for such a common disease is that there is no consensus in the imaging options for the diagnosis of appendicitis in children. There is greater use of CT in the USA, whereas ultrasound remains the first imaging modality elsewhere.

In the same way, although one million CT examinations are performed each year around the world for acute right lower abdominal pain, it is surprising that no consensus exists on the recommended CT technique. All do agree though that thin slices increase spatial resolution, which allows multiplanar and notably coronal reformatting, and thereby accuracy of the diagnosis of appendicitis.

Controversies also exist about the use of oral, rectal, and intravenous contrast and about the size of the field of view. Should the examination be focused on the appendiceal area or performed on the entire abdomen in order to make alternative diagnoses? Such controversies are illustrated by the

FIGURE 3

CT coronal reformatting of an abscess located in the right iliac fossa (arrows), illustrates a complicated appendicitis. An endoluminal calcification or appendicolith is seen within the abscess (arrowhead).

FIGURE 4

CT axial view of epiploic appendagitis: a fat-density ovoid structure adjacent to the colon (arrow). The differential diagnosis is appendicitis.

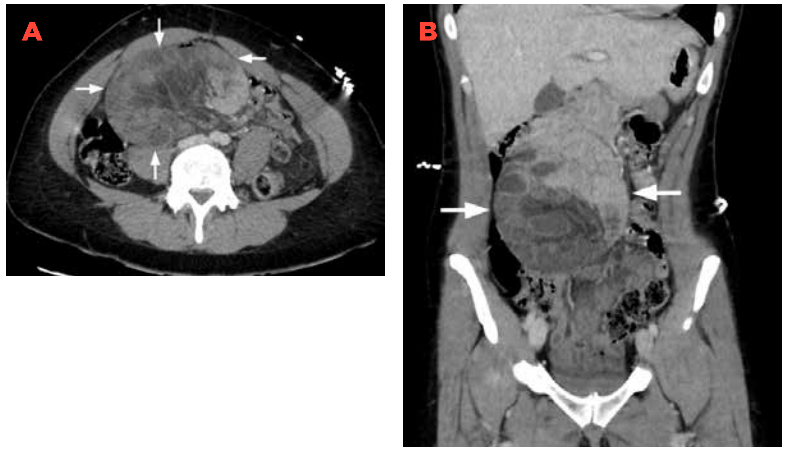


FIGURE 5

CT (A) axial and (B) coronal view of a paraduodenal hernia, the most common type of internal hernia, which has resulted in a closed-loop bowel obstruction. Note the sac-like cluster of small bowel loops in an atypical position (arrows).

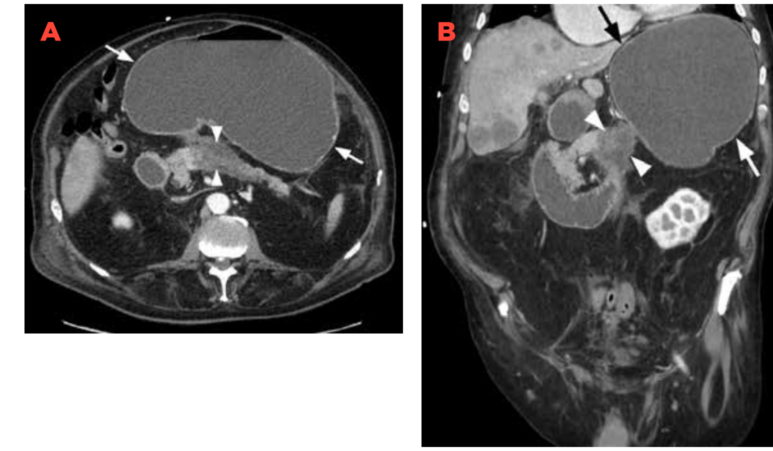
recommendations of the American College of Radiology, which conclude that the use of oral or rectal contrast should depend on institutional preferences. Despite this there are important points of agreement for the diagnosis of appendicitis. Imaging is helpful and permits a decrease in the rate of negative appendectomy and easier identification of complicated appendicitis, identifying patients who would benefit from surgery and those who would need clinical observation. Ultrasound and CT are both accurate but CT is still slightly superior, particularly for the diagnosis of complicated appendicitis and making alternative diagnoses. However, there are still some controversies left open: is imaging recommended for all suspected appendicitis or should surgery be performed without imaging when the clinical suspicion is high? In young patients, and particularly in children, for whom radiation is a concern, should the strategy of CT as the all-in-one examination be adopted or be replaced by a more restrictive approach with CT performed only if ultrasound is inconclusive?

BOWEL OBSTRUCTION: SURGERY IS NOT THE RULE

At the end of the last century, surgery was considered the standard of care in management of patients with bowel obstruction with the adage 'never let the sun set or rise on a suspicion of small bowel obstruction'. The clinical diagnosis of small bowel obstruction classically depends on four cardinal findings: abdominal pain, vomiting, constipation and abdominal distension. However, the clinical observations vary with the degree and level of bowel obstruction and with the vascular status of the obstructed segment, making even a positive diagnosis difficult. By contrast, the presence of dilated bowel proximal to a transition zone and a collapsed distal small bowel indicates with confidence the diagnosis of intestinal obstruction and shows precisely the level of the obstruction: stomach, duodenum, small bowel, or colon. Preferential causes are associated with each location.

FIGURE 6

CT (A) axial and (B) coronal view of gastro-duodenal obstruction. Note dilated stomach and duodenum (arrows) caused by pancreatic cancer: a hypodense pancreatic lesion can be identified (arrowheads).



Today, the management of suspected bowel obstruction is adapted to the level, the cause and whether ischaemia is present or not. All this information is given by CT. More than 50% of small bowel obstructions are due to adhesion, the most common cause of bowel obstruction, and treated without surgery. CT has permitted a significant change in management by solving the key issues in patients with suspected bowel obstruction: differentiation between mechanical obstruction and paralytic ileus, localising the level of obstruction; evaluating high-grade versus incomplete obstruction; showing the cause of obstruction and identifying intestinal loop strangulation. The complete diagnostic work-up, based on the information gained from CT, either medical or surgical therapy will be adopted.

The pattern of major causes of intestinal obstruction has changed over the past five decades. The most common cause was originally external hernia. Now, adhesions comprise 60–80% of all causes in industrialised countries; the other main causes include inflammatory bowel disease, internal (Figures 5A, 5B) and external hernias, primary tumours, peritoneal carcinomatosis, acute focal inflammatory disease entities such as appendicitis or diverticulitis and intussusception. CT diagnosis of adhesion in the past was considered difficult because it was based on negative findings, ruling out any other pathology. Thin slices and multiplanar reformatting have improved the diagnosis of peritoneal adhesion. The transition zone is depicted with more confidence, and the adhesive band itself can be shown.

Gastro-duodenal obstruction accounts for about 1% of bowel obstruction; malignant tumour and peptic ulcer disease are the two main causes. Gastric cancer is usually responsible for gastric obstruction, whereas duodenal obstruction is caused by pancreatic cancer (Figures 6A, 6B). In gastro-duodenal obstruction secondary to peptic ulcer, the stenosis is often short and may be

FIGURE 7

CT coronal view of sigmoid volvulus: large gas and stercoral content-filled loop (arrows) with sigmoid transition zone and twisting of mesenteric vessels 'whirl sign' (arrowhead).

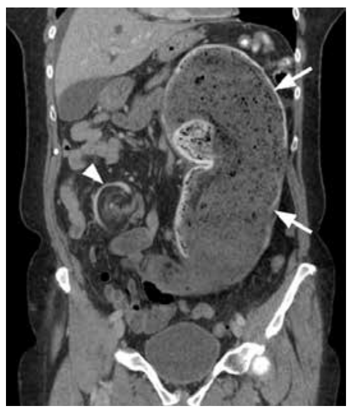
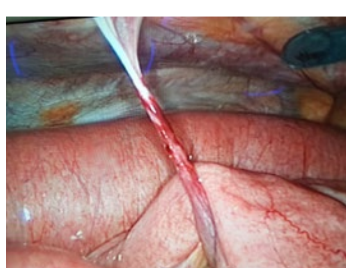


FIGURE 8

Laparoscopic view of small bowel obstruction resulting from a band.



difficult to identify at CT, obscuring differentiation between obstruction related to peptic ulcer and gastroparesis.

Since surgery is not considered first-line treatment in small bowel obstruction due to adhesions, it is important to search for complications, which may make emergency surgery mandatory. Closed-loop or incarcerated intestinal obstruction is defined by an obstruction of a loop of bowel at two or more adjacent locations, the obstruction could be an adhesive band or the neck of a hernia. CT features include a 'U' or 'C' appearance of the bowel loop pointing to the site of obstruction or a radial arrangement of the bowel loops. The adjacent vessels often show a swirled configuration reflecting the twist in the mesentery. The complication of a closed loop obstruction is strangulation with intestinal ischaemia. The severity and duration of intestinal and mesenteric obstruction determines the grade of ischaemia. At first, venous return from the involved bowel segment is compromised because intraluminal pressure exceeds venous pressure and congestion affects the bowel wall and the mesentery, while the influx of arterial blood still continues. Ischaemia is resolved with emergent surgical treatment. Increased bowel distension predisposes the closed loop to rotate around the mesentery. Consequently, arterial ischaemia ensues, which aggravates bowel hypoxia and further accelerates rapid development of bowel wall gangrene and perforation. CT findings of strangulation include lack of enhancement of the incarcerated bowel wall after intravenous administration of iodinated contrast, which is the most specific finding of strangulation. Spontaneous hyperdensity of the bowel wall before contrast is the most specific finding of irreversible ischaemia and localised infiltration of the mesenteric fat is the most sensitive finding of ischaemia.

Large bowel obstruction accounts for about 25% of all bowel obstruction and the two main causes are colon cancer and sigmoid volvulus (Figure 7). One of the advantages of CT in comparison with contrast enema, classically considered the gold standard imaging method in large bowel obstruction, is improved characterisation of the thickened bowel wall responsible for stenosis and to differentiate tumour from other causes. Furthermore, right-sided colon obstruction is difficult to characterise and, in cases of caecal volvulus, abdominal plain film and contrast enema may fail to identify the cause of obstruction. Consequently, CT has become the standard examination in the assessment of large bowel obstruction.

The management of bowel obstruction depends on cause and severity of obstruction. Nowadays, most surgeons recommend surgery without delay when strangulation is suspected: open laparotomy is recommended when bowel wall necrosis is suspected, whereas laparoscopy may be sufficient in patients when no bowel resection is required (Figure 8). Delayed surgery is recommended in case of malignant tumour, whereas medical management is generally advised in most cases of peritoneal carcinomatosis, radiation enteritis or jejunal haematoma. Conservative management is recommended with Crohn's disease when an acute flare causes bowel obstruction, whereas obstruction caused by a chronic fibrotic narrowing may, in some cases, necessitate surgical resection. Lastly, small bowel obstruction due to adhesion without strangulation is generally treated medically with diet and placement of a nasogastric tube; surgery is performed only in case of failure of medical management.

ACUTE SIGMOID DIVERTICULITIS: CT DIAGNOSIS IS NOT SUFFICIENT

Colon diverticula are acquired herniations of the mucosa and parts of the submucosa through the muscularis propria of the colon wall. Colon diverticulosis is a clinically silent disease resulting from the development of multiple diverticula on the colonic wall. Diverticulosis is the most common colonic disease in the Western population, with an estimated incidence of 30% in people over 50 years of age and up to 60% over the age of 70. When diverticula become diseased, they result in acute inflammation, or diverticulitis, and further complications or even diverticular haemorrhage. Diverticulitis occurs in 10 to 35% of patients with diverticulosis and 30% of these patients will have complicated diverticulitis.

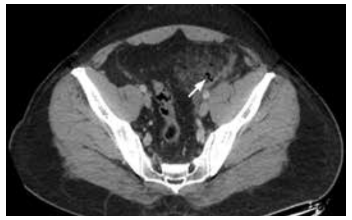
Although CT is definitively considered the best tool to diagnose acute diverticulitis, a majority of outpatients with clinical and biological findings consistent with acute uncomplicated diverticulitis of predominantly the sigmoid colon will not be investigated by CT. This may have harmful consequences, since in patients with left lower quadrant pain, alternative diagnoses should be considered including colon carcinoma, colitis, either infectious, inflammatory or ischaemic in origin, epiploic appendagitis, functional colonic disorders and

FIGURE 9

CT axial view of diverticulitis: bowel wall thickening (arrows) and inflammatory changes in the surrounding fat (arrowhead).

FIGURE 10

Complicated diverticulitis in the same patient as Figure 9: bubbles of extra-luminal gas are an indication for perforation (arrow).



non-gastro-intestinal disease, such as pyelonephritis or gynaecologic pathologies. Main CT findings for the diagnosis of acute colonic diverticulitis were already described twenty years ago and associate both intramural patterns: diverticula and bowel wall thickening as well as extramural patterns consisting of inflammatory changes of the pericolic and mesocolic fat (Figure 9).

However, CT has some difficulties in noting the difference between sigmoid diverticulitis and sigmoid cancer. One of the most helpful findings in differentiation is multiple pericolic lymph nodes measuring 1cm or more in the short axis that are more frequent in carcinoma. Another is a combination of a mild circumferential thickening of the colonic wall longer than 10cm with a progressive transition zone and the non-narrowed proximal and distal colon associated with inflammatory changes of the mesocolon, which are suggestive of diverticulitis. A specific ring or double ring pattern of the colon wall enhancement can also be suggestive of diverticulitis. However, because these findings can lack specificity, guidelines advise performing colonoscopy after an episode of diverticulitis, particularly in patients over 50.

CT is particularly able to differentiate uncomplicated from complicated diverticulitis. Complicated diverticulitis must be investigated in depth. Indeed, treatment options for diverticulitis depend on CT evaluation with a recent change towards less invasive therapy. The classical surgical classification by Hinchey is now outdated. This classification divided complicated diverticulitis into moderate and severe: peridiverticular abscess (stage 1–2) being managed with medical treatment including CT-guided percutaneous drainage and purulent or faecal peritonitis (stage 3–4) requiring surgical treatment. Nowadays, therapeutic options for haemodynamically stable patients include colectomy, laparoscopic lavage or medical treatment. Consequently, the radiologist's report should specify the presence of phlegmon in uncomplicated diverticulitis or the presence of an abscess; should describe the location and extent, and recognise the presence of extra-luminal gas (Figure 10), or pericolic, mesocolic or free fluid in the peritoneal cavity and the extent of diverticulitis in the descending colon.

BOWEL PERFORATION: WHY MAKE IT SIMPLE WHEN WE CAN MAKE IT COMPLICATED?

Bowel perforation accounts for 1 to 3% of acute abdominal syndrome and represents a medical emergency. It can affect any segment of the digestive tract and complicate any alteration of the bowel wall, whether the cause is tumoural, inflammatory, ischaemic, from radiation, or from ulcer. Nevertheless, the list of most frequent causes can be shortened to gastro-duodenal ulcer or sigmoid colon diverticulitis.

Gas in the peritoneal cavity or pneumoperitoneum is the most characteristic sign of digestive perforation. Plain films of the abdomen were the first radiographic examination to diagnose bowel perforation. However, although experimental studies show that as little as 1ml of gas can theoretically be detected on an erect chest radiograph beneath the diaphragm, abdominal radiographs miss about half of the pneumoperitoneum in clinical practice, and the site of the perforation is ignored. This stresses the role of CT in the diagnosis of bowel perforation, which is able to identify the site and cause of perforation. In France, taking abdominal radiographs is no longer recommended.

Abnormalities demonstrated on CT in bowel perforation depend on site and cause of bowel perforation. In oesophageal perforation, fluid collection located in the posterior mediastinum pointing to focal mediastinitis and pneumomediastinum is observed. In gastroduodenal perforation a rupture of the intestinal wall, most commonly located in the duodenal bulb or pre-pyloric region, is a direct sign of a perforated gastroduodenal ulcer (Figures 11, 12). In small bowel perforation, CT shows gas bubbles and localised fatty infiltration in the mesentery. Potential causes of perforation are small bowel obstruction, acute

FIGURE 11

Rupture of bowel wall (arrowheads) in the pyloric region as result of perforated ulcer. CT patterns of associated peritonitis are free peritoneal fluid and enhancement of peritoneal reflections (arrows).

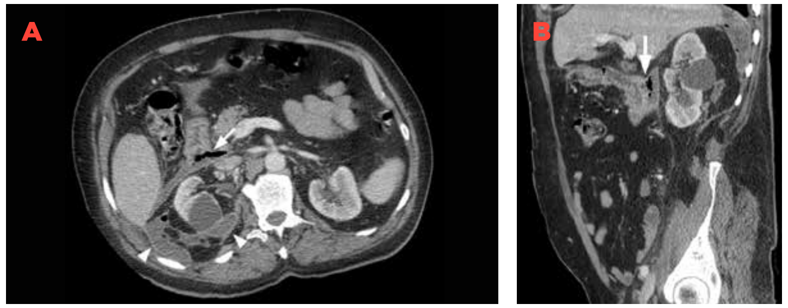


FIGURE 12

Perforation of posterior aspect of the duodenum (arrow) resulting in retroperitoneal abscess (arrowheads): (A) axial scans and (B) reformatted sagittal views.

ischaemia of the mesentery, Crohn's disease, lymphoma, small bowel diverticulitis, tuberculosis, jejunal ulcer, foreign body or vasculitis. In appendiceal perforation, CT differentiates complicated from uncomplicated appendicitis based on the presence of abscess, phlegmon, extraluminal air, extra-appendiceal calcification or stercolith, a defect in enhancement of the appendiceal wall and ileus. All these observations are indications of a perforated appendicitis. Free pneumoperitoneum occurs rarely in appendicular perforation.

The two main causes of perforation are diverticulitis and neoplasia. The tumour growth itself can perforate the bowel wall; otherwise, the mechanism is diastatic perforation (Figure 13). Rarely, perforation complicates an ischaemic colitis or a stercoral colitis. The question is: does the site of perforation need to be identified with absolute precision, as emergency surgery will be necessary anyway? The answer is yes: the type of surgery to be performed is influenced by the site and cause of perforation. In gastroduodenal ulcer perforation of the anterior or lateral wall, laparoscopy is the preferred option as shown in a number of randomised studies, whereas perforation of the posterior aspect is easier managed by open surgery because laparoscopic access to the posterior wall remains cumbersome. Selected patients could be managed non-operatively or with novel endoscopic approaches such as endoscopic clips or stents. Unlike gastroduodenal ulcer perforation, small bowel perforation is best treated by laparotomy. Colon perforation or tumour-related perforation must be repaired by open surgery. In contrast, management of perforation from sigmoid diverticulitis depends on the stage of the disease, as well as on the preferences of the surgical team.

ACUTE MESENTERIC ISCHAEMIA: CT IS THE FIRST STEP TOWARDS SAVING GUTS AND EVEN LIVES

Nearly a century ago, Cokkinis stated that "occlusion of the mesenteric vessels is apt to be regarded as one of those conditions of which diagnosis is impossible, the prognosis hopeless and the treatment almost useless". Prognosis cannot significantly be changed if the delay in diagnosis and treatment of acute mesenteric ischaemia is not decreased. Diagnostic delay is partly due to the relative infrequency of the event and partly to its

FIGURE 13

(A) CT views of perforated sigmoid cancer: focal, irregular thickening of the bowel wall (arrows). (B) Pericolic enlarged lymph nodes, and extraluminal gas bubbles (arrow).

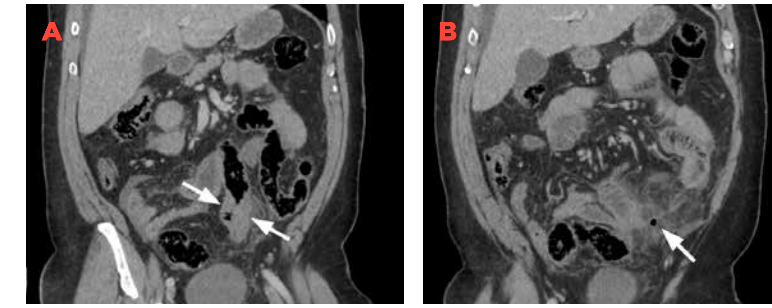
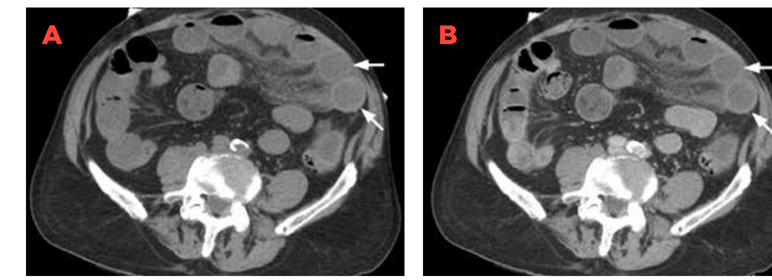


FIGURE 14

Small bowel ischaemia. (A) Absence of bowel wall enhancement on pre-contrast scan and (B) on post-contrast CT images.



non-specific clinical presentation. Until now, acute mesenteric ischaemia has always been considered an abdominal emergency associated with a high mortality rate and often intestinal failure in survivors. An improvement of prognosis requires a prompt diagnosis, established as early as possible from the onset of symptoms and multidisciplinary, multimodal management.

Diagnosis is based on CT findings depending on the stage of the disease. At the very early stage, the neurogenic reaction of the intestine to ischaemia is spastic reflex ileus, which leads to a collapsed bowel with no endoluminal content. In this case, bowel wall enhancement is normal or in some cases appears brighter than usual. Precise scrutiny of the splanchnic vessels can lead to a discovery of the cause of ischaemia. In the next stage, the lumen of the small intestine will be distended by fluid, the wall appears thinner than normal, and accurate evaluation of bowel wall enhancement is mandatory (Figure 14). At a late stage intestinal infarction, necrosis of the involved bowel is announced by the absence of intestinal wall enhancement, intra-parietal, mesenteric, portal vein gas or pneumatosis and free intraperitoneal air if bowel wall perforation has occurred. Splanchnic vessels must be analysed in detail to identify the cause of ischaemia, which can include arterial emboli, arterial local thrombosis, arterial dissection, vasculitis, mesenteric low flow in a suggestive clinical setting, or finally other rare causes of vascular obstruction such as trauma, tumour, or extrinsic vascular compression. Another cause can be mesenteric venous thrombosis, in which acute mesenteric ischaemia is often associated with a mesenteric arterial spasm.

The identification of vascular abnormalities, even if isolated, is a key issue for therapy since recognition of ischaemia before the onset of bowel wall necrosis permits an adapted treatment avoiding extended bowel resection. Multidisciplinary and multimodal management of acute mesenteric ischaemia, including gastroenterologists, diagnostic and interventional radiologists and vascular and digestive surgeons in an intestinal stroke centre, may avoid large intestinal resection, permanent intestinal failure and patient death. The differentiation between ischaemia as a potentially reversible affliction and infarction as an irreversible affliction with necrosis of the involved intestinal segment has a therapeutic impact since the former can benefit from radiological endoluminal catheter-directed revascularisation whereas the latter will need surgical revascularisation and intestinal resection.

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9

ACUTE LUMBAR PAIN

ACUTE LUMBAR PAIN: CROSS-SECTION IMAGING GIVES THE ANSWER

BY **RAYMOND H. OYEN**

Pathologies of the urinary tract are common in patients referred in emergency settings.

The appropriate use of imaging in suspected renal and ureteral pathologies, and the familiarity with the appearance of common pathologic conditions is crucial for prompt diagnosis and further therapeutic management.

Ultrasound is readily available in the emergency setting, but diagnostic accuracy is largely operator-dependent. Recent advances in radiation-dose reduction have resulted in high-quality CT images with relatively low radiation doses. CT has become the primary and quickest imaging modality for the assessment of suspected urinary tract pathologies in the acute setting providing a definitive diagnosis and enabling appropriate treatment.

The most common emergency conditions of the kidneys and ureters are related to urinary tract obstruction. Although various intrinsic or extrinsic processes along the urinary tract may result in obstruction, by far the most common cause is stone disease. Other conditions with different degrees of severity such as infection, haemorrhage, acute ischaemic disease, and traumatic injuries also occur.

RENAL COLIC AND STONE DISEASE

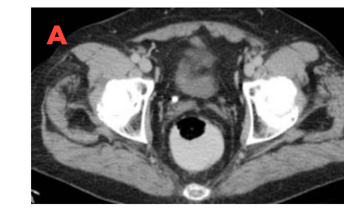
Renal colic caused by ureteral stones is a common condition and is increasing in prevalence. Most stones (approximately 80%) are calcium based (calcium oxalate or phosphate, or a mixture). Other types of stones include struvite and uric acid stones. Unenhanced low-dose CT of the abdomen has become the preferred method for the evaluation of urolithiasis, signs of obstruction and related complications. Nearly all stones are easily visible on CT, with the exception of uncommon matrix stones and incrustations related to indinavir therapy. Stone size (and total stone load), location, and composition are factors considered when determining treatment; these features should be part of the CT report.

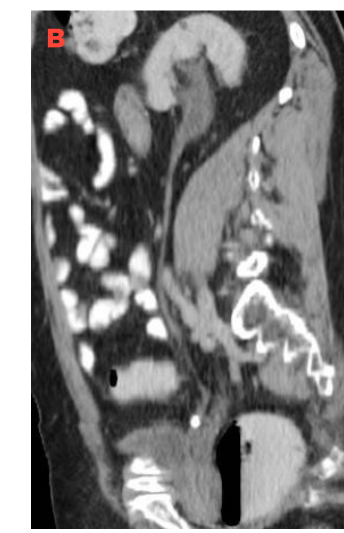
Reliable differentiation between stone types is not possible using conventional CT. The CT attenuation value can be used to suggest the diagnosis of pure uric acid stones, which have an attenuation of < 400 Hounsfield units (HU), but there is a large overlap with attenuation values of non-uric acid stones. Dual-energy CT has been propagated to determine the composition of stones. The attenuation of stones differs at different energy levels, and with appropriate post-processing tools, this attenuation difference can be used to characterise stone composition.

Although ureteral stones can rather easily be diagnosed by following the course of the ureter, differentiating between a stone and an extraureteral calcification, i.e. a phlebolith can occasionally be difficult to distinguish especially in slender patients and/or when the ureter is not dilated. Phleboliths are unlikely

FIGURE 1

Patient with right renal coli. Distal ureteral stone on the right (A). Reformatted image demonstrating the stone on the course of the ureter (B).





to have an attenuation greater than 300 HU, unlike most stones. Additional signs including the 'soft-tissue rim sign' (smaller ureteral stones) and the 'comet-tail sign' (phleboliths) can be helpful in making such a distinction in some cases.

The main complication of urolithiasis is urinary tract obstruction. CT findings of acute obstruction include dilatation of the collecting system, unilateral renal enlargement, perinephric and/or periureteric stranding. The probability of spontaneous stone evacuation depends on the size and location of the obstructing stone. The most common locations for stone impaction are sites of anatomic narrowing of the collecting system, i.e. the ureteropelvic junction (UPJ), the cross-over of the iliac vessels, and the ureterovesical junction (UVJ). Obstructing proximal calculi are typically larger than obstructing distal calculi, with the average diameter of distal ureteral stones being 4mm. Nearly 90% of stones measuring 1mm will spontaneously pass, the rate decreasing to 25% for stones >9mm. Spontaneous stone passage increases with distal location of the stone, with almost 80% of the stones at the UVJ passing spontaneously compared to only approximately half of the stones in the proximal ureter.

Increased pressure in the renal pelvis results in leakage of urine from a renal fornix. The cause of obstruction is generally a ureteral stone (usually in the distal ureter), although other intrinsic or extrinsic causes can cause leakage. Forniceal rupture indicates higher pressure, leads to perirenal fluid infiltration and accumulation, reduces the grade of dilatation of the collecting system, and is usually more painful. With forniceal ruptures, the grade of obstruction is not necessarily correlated with the grade of dilatation of the collecting system.

Following lithotripsy, urinary tract obstruction may occur due to passage of stone fragments in the ureter, occasionally by a chain of multiple small stone fragments.

In selected cases of clinical uncertainty, patients with stone disease may need contrast-enhanced CT (CECT) to document obstruction or to differentiate a stone from an extraureteral calcification (usually phlebolith). CECT can be useful for the evaluation of nonopaque indinavir stones or matrix calculi, seen as soft tissue attenuation causing filling defects. CECT should also be performed in cases of suspected infectious or vascular aetiology (pyelonephritis, renal infarct).

OTHER CAUSES OF OBSTRUCTION

There are multiple other pathologic conditions that may result in obstruction. Lesions within the urinary tract (blood clots and urothelial tumours) and outside of the urinary tract may cause obstruction due to extrinsic compression: vascular aneurysms, retroperitoneal fibrosis, retroperitoneal lymphadenopathy, or fibrosis of the ureters due to prior surgery or radiation therapy. Delayed imaging in the excretory phase is essential for accurate depiction of the level of ureteral obstruction.

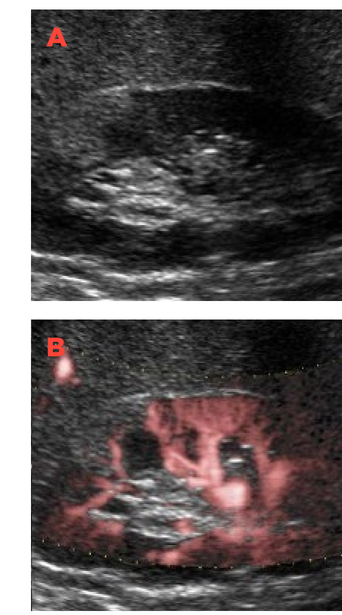
Urothelial transitional cell carcinoma accounts for approximately 10% of malignant tumours of the upper urinary tract. It can only be considered to be a 'systemic disease' (collecting system), and is frequently multifocal in the upper tract and bladder. Haematuria is the most common presentation. Imaging plays an important role; careful evaluation of the entire urinary tract is mandatory.

INFECTION – ACUTE PYELONEPHRITIS (APN)

Infection of the urinary tract usually ascends from the bladder to involve the kidneys. Infection of the kidney can also originate via the haematogenous route. APN is a clinical diagnosis; when imaging is considered necessary to evaluate patients with suspected APN (elderly patients, persisting fever under appropriate treatment, immune-suppressed patients), CECT is the preferred modality. Typical CECT-findings include wedge-shaped or patchy areas of decreased cortical enhancement with a 'striated' appearance during the nephrographic phase. Persistent striations on delayed scans (4–6 hours after IV contrast administration) are seen due to slow transit and prolonged accumulation of contrast in the affected renal areas and are highly suggestive of APN. This feature is useful in selected patients to confirm the diagnosis of APN or to differentiate from other pathologies (infarction, tumour). Interestingly and surprisingly ultrasound is (false) negative in approximately 50% of cases of CT-confirmed pyelonephritis in native kidneys. In some cases wedge-shaped or rounded hypo- or hyperechoic parenchymal areas may be seen; at colour-Doppler ultrasound these areas are less vascularised compared to the surrounding unaffected parenchyma.

FIGURE 2

Ultrasound study in a young female with clinical symptoms of acute pyelonephritis. Ultrasound showing a slightly hyperechoic area in the upper pole of the right kidney (A) with decreased vascularity of the affected area at colour-Doppler study (B).



HELP Emergency Medical Imaging

FIGURE 3

CECT of abscess in the right kidney, showing a thick walled rounded cavity, and some perirenal inflammation. Axial (A) and coronal reformatted (B).

Focal bacterial nephritis is a form of localised renal infection more likely to be a result of haematogenous spread of infection. On CT, this focal inflammation appears as a round or wedge-shaped hypodense area with patchy hypoenhancement on CECT. Such inflammatory areas may have a pseudotumoural appearance, and correlation with clinical symptoms and laboratory findings are crucial.

INFECTION – RENAL ABSCESS

Renal abscess is a complication and more advanced stage of focal renal infection. Abscesses are rare with appropriate antibiotic treatment. Abscesses may be located within the kidney and/or in the perirenal space and is more common in diabetic or immune suppressed patients. On CECT, abscesses are usually well delineated with thick walls, central low density, and with an enhancing peripheral surrounding rim. Percutaneous image-guided aspiration may be indicated in larger abscesses (> 3cm in diameter). Appropriate needle thickness is required for swift aspiration of the thick and viscous purulent content.

Cyst infection or any other pre-existing cavity may cause abscesses as well. There is a higher incidence of cyst infection in the setting of polycystic kidney disease. These infected cysts may be difficult to diagnose. Comparison with previous imaging, when available, and a subtle search for 'secondary' signs (thick wall, perilesional stranding, fascial thickening) may be helpful for final diagnosis. Percutaneous image-guided aspiration may be contributive toward diagnosis and speed up response to antibiotic therapy.

INFECTION – PYONEPHROSIS

Pyonephrosis refers to the presence of pus in a dilated collecting system, whatever the obstructing cause (most often obstructing stone), and is considered to be a urological emergency. This condition is rapidly progressive and should be suspected if a patient has fever and flank pain in the context of urinary tract obstruction. On CT, hydronephrosis and perirenal inflammatory changes are seen. Distinguishing between uncomplicated hydronephrosis and pyonephrosis, though, is difficult. On ultrasound, reflections may be seen in the collecting system, at times with a fluid-fluid level (urine/pus). The absence of internal reflections/fluid levels however does not exclude pyonephrosis. CT-features suggestive of pyonephrosis include more severe perinephric inflammatory changes and increased pelvic wall thickness. Urgent drainage is needed in cases of pyonephrosis (percutaneous nephrostomy).

INFECTION – EMPHYSEMATOUS RENAL INFECTION

Emphysematous pyelonephritis, usually caused by E. Coli, is considered to be a severe necrotising renal infection that may be rapidly progressive. It is seen predominantly in female diabetic patients and may occur secondary to urinary tract obstruction irrespective of the obstructing cause. Emphysematous renal infections are best diagnosed on CT, which can clearly demonstrate the presence and extent of renal and extrarenal gas accumulation. Several classification systems have been proposed depending on the presence of renal and/or perirenal fluid collections and with differences in mortality rates. Treatment for this condition ranges from medical management to percutaneous drainage and nephrectomy.

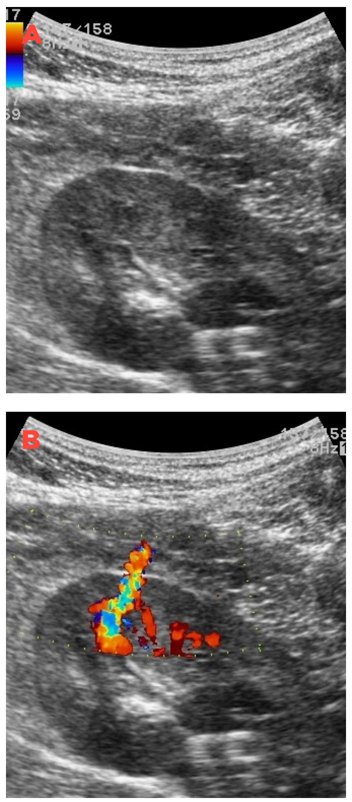
In emphysematous pyelitis, gas accumulation is limited to the collecting system, without associated parenchymal destruction or collection. This condition is considered benign with a favourable outcome and is treated medically.

VASCULAR – RENAL INFARCT

Renal infarct is most commonly due to thromboembolic disease, with atrial fibrillation being the leading underlying cause. Other aetiologies include atherosclerosis, septic emboli from bacterial endocarditis, aortic dissection, vasculitis, and trauma. Patients present with symptoms mimicking renal colic, i.e. abdominal or flank pain, haematuria, nausea and vomiting, and elevated white blood cell count and, contrary to renal colic, elevated lactate dehydrogenase levels. The CECT appearance of a renal infarct is a wedge-shaped hypodensity or a patchy hypodense appearance of the renal cortex, and may resemble features of APN. There may be a thin peripheral rim of enhancement

FIGURE 4

Active haemorrhage after renal biopsy: perirenal haematoma (A), with active bleeding only visible at colour-Doppler (B).



seen on the nephrographic phase, referred to as the cortical or nephrographic rim sign. This viable rim of renal cortical tissue is due to a separate capsular vascular supply and is often only first seen several days after the infarct occurs. Treatment may include anticoagulation, thrombolysis, and angioplasty.

VASCULAR – RENAL VEIN THROMBOSIS

Renal vein thrombosis occurs more commonly on the left side, most likely related to the longer renal vein. Presentation includes flank pain and haematuria. Renal vein thrombosis may be caused by hypercoagulable states, nephrotic syndrome, invasion by neoplasm, trauma, extension of thrombus from left ovarian vein, and, in infants, dehydration. On CECT, clotting will be recognised in the affected renal vein. (Partial) clot enhancement is expected in tumour thrombus. Enlargement of the kidney and perinephric stranding due to congestion and oedema are frequent. Imaging evaluation should include accurate extent of clotting (into the inferior vena cava, below/above diaphragm) and careful analysis of eventual underlying disease. Treatment of renal vein thrombosis usually involves anticoagulation.

RENAL TRAUMA

Most renal injuries are due to blunt trauma, and kidneys with pre-existing abnormalities (unique hypertrophic kidney, renal ectopy, UPJ-stenosis ...) are at increased risk of injury.

CECT is the preferred imaging modality in cases of suspected renal trauma. Imaging in both the corticomedullary phase and the excretory phase is required to fully assess renal trauma. Delayed scanning may be required for diagnosis/exclusion or urinary leakage.

Currently, the American Association for the Surgery of Trauma grading system, based on surgical findings, is most commonly used. Grade I injuries are most common and may not have any imaging findings or may present with contusions (focal areas of decreased enhancement) or small subcapsular haematomas. Grade II injuries include perinephric haematomas and superficial cortical lacerations <1cm, whereas in grade III injuries, the laceration is >1cm without collecting system injury. Grade IV injuries include lacerations extending to the collecting system, segmental infarcts, or involvement of the main renal artery or vein. Involvement of the vasculature or collecting system with grade IV injuries may be demonstrated by the presence of active extravasation of enhanced blood on the initial or delayed phase of imaging, and extravasation of enhanced urine on the delayed phase, respectively. Grade V injuries include shattered kidney and avulsion or thrombosis of the main renal artery or vein, or avulsion of the UPJ. Management of renal trauma is typically conservative except in selected cases of grade IV and grade V injuries. Input from an interventional radiologist is required.

On CECT, active haemorrhage will appear on the corticomedullary phase as a dense area in or around the kidney in a linear or irregular appearance, and often surrounded by a clot. Contrast outside the confines of the kidney or ureter on the excretory phase attests to urinary extravasation. Full evaluation of presence/absence of urine extravasation may require an additional scan phase after 10–15 minutes, or even later.

Ureteral trauma is less common than renal trauma and most commonly occurs at the fixation points of the ureteropelvic or ureterovesical junctions. The most common mechanism of injury is sudden deceleration, which results in laceration of the ureter. Haematuria is present in many patients, but not always. CECT with appropriate timing will demonstrate contrast extravasation from the ureter. Differentiation between partial and complete tears of the ureter is based on the presence of contrast in the distal ureter in the case of a partial tear, and the absence of distal opacification of the ureter with a complete tear. Complete tear of the ureter requires surgical repair, while stenting can often be successful for partial tears.

SPONTANEOUS HAEMORRHAGE – RENAL HAEMORRHAGE

The most common cause of spontaneous renal haemorrhage is underlying neoplasm, most frequently angiomyolipoma (AML), followed by renal cell carcinoma. Non-neoplastic causes include vascular disease (polyarteritis nodosa or other vasculitis, renal artery aneurysm, AV malformation or fistula, or renal vein thrombosis), nephritis, renal infection, and stone disease.

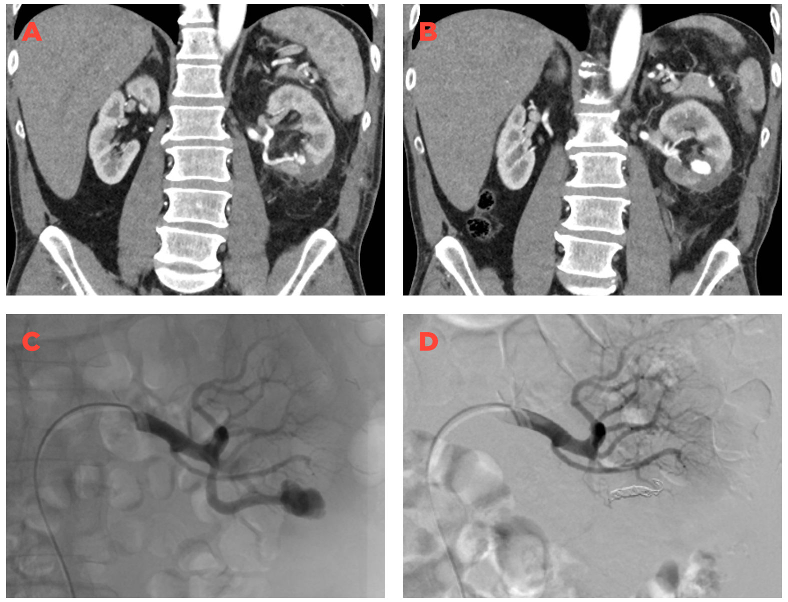


FIGURE 5

60-year-old male with massive haematuria after partial nephrectomy for renal cell carcinoma at the lower pole of the left kidney. CECT showing a pseudoaneurysm at the lower pole. Coronal reformatted CT (A) and (B). Treated with selective embolisation with coils (C) and (D).

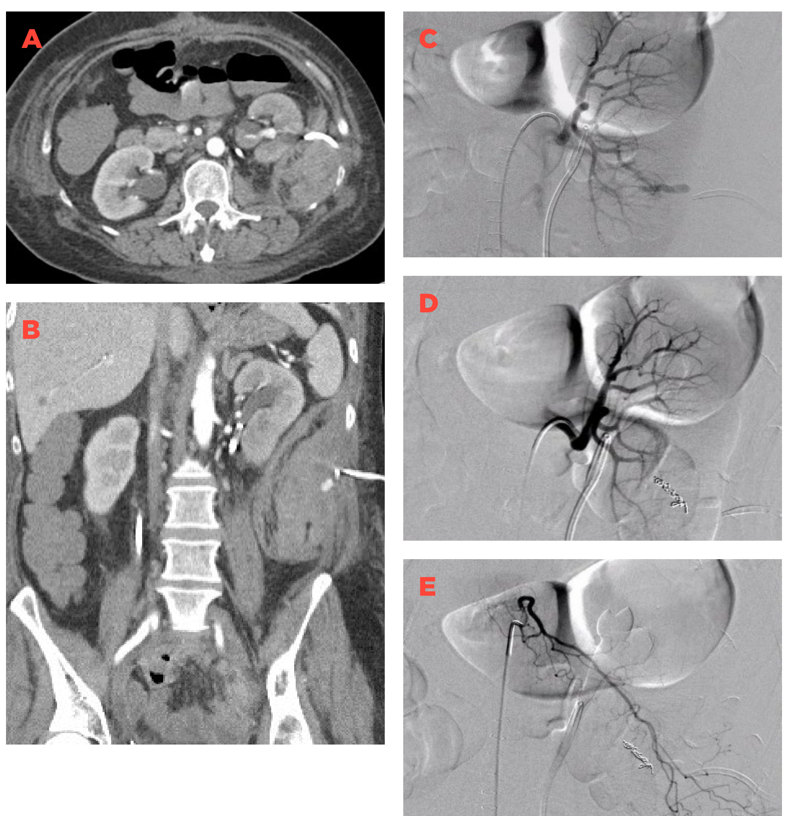


FIGURE 6

Massive haematuria and hypotension after percutaneous nephrostomy. Active haemorrhage. Intrarenal haemorrhage extending to the renal pelvis (A) and in addition active bleeding in the abdominal wall from a branch of a lumbar artery (B). Both bleeding sites successfully treated by selective embolisation using intrarenal coils (C) and (D) and microspheres in the lumbar artery (E).

Presentation is typically with acute-onset flank pain in the absence of haematuria.

If renal haemorrhage is caused by a mass, CT will usually be able to demonstrate this.

AMLs may spontaneously haemorrhage, most likely due to rupture of an aneurysm or after mild abdominal trauma, exercise or during pregnancy. Selective embolisation is the preferred treatment option. As the risk of haemorrhage increases with the size of the lesion, prophylactic treatment is recommended for lesions > 4cm in diameter using embolisation or resection.

Renal cell carcinoma is the most common malignant renal neoplasm. It is more common in males and typically presents in the sixth and seventh decades of life. Symptomatic RCCs with haematuria, palpable abdominal mass, and flank pain are uncommon; most cases nowadays are diagnosed incidentally on cross-sectional imaging.

Simple renal cysts may also occasionally haemorrhage due to trauma, enlargement, or coagulopathy. There is a higher incidence in patients with acquired renal cystic disease under dialysis. There is also a higher incidence of symptomatic cyst haemorrhage in the setting of autosomal dominant polycystic kidney disease. This usually resolves spontaneously.

In selected patients with perirenal haemorrhage without demonstrable cause, repeat scanning after several weeks may be recommended to ultimately confirm or exclude the presence of an underlying renal neoplasm.

SUBUROTHELIAL HAEMORRHAGE

Suburothelial haemorrhage is an uncommon cause of haematuria (and pain), usually seen in patients with a bleeding diathesis or on anticoagulation. On unenhanced CT the haemorrhage is seen as a high-density mural thickening of the renal pelvis and/or proximal ureter. On CECT only, it may be difficult to differentiate the high-density mural thickening from enhancement.

POSTPROCEDURAL – POSTOPERATIVE COMPLICATIONS

CT is useful in evaluating symptomatic patients following renal or ureteral intervention. Familiarity with different procedures with their specific complications is essential. At times, consultation of the referring surgeon is helpful for tailored imaging procedures. Examples include vascular injury following biopsy or partial nephrectomy, with sequelae ranging from active bleeding, haematoma, renal infarct, AV-fistula, or pseudoaneurysm. Other potential complications of partial nephrectomy include urinary leak and infection.

A side effect of extracorporeal lithotripsy is subcapsular haematoma which occurs in up to 20% of patients; the clinical significance though is low (1%).

Ureteral injury may occur as a complication of pelvic surgery such as hysterectomy and rectal surgery. Unattended disruption

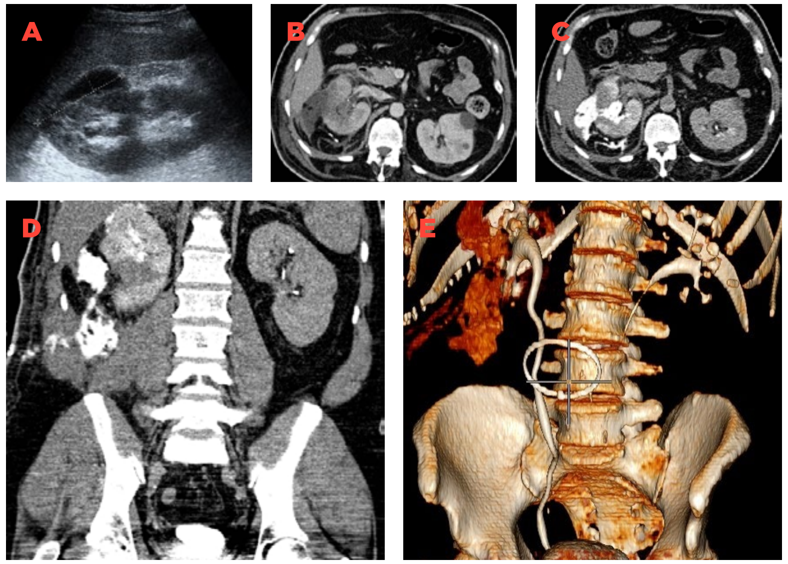


FIGURE 7

Patient with increasingly painful abdomen ten days after partial nephrectomy for papillary renal cell carcinoma. Initial ultrasound showing some perirenal fluid (A). CECT in the nephrographic phase showing decreased vascularity in the lateral aspect of the kidney (B). Delayed CT clearly shows urinary leakage from a midpole calyx with fistulisation to the skin (C) and (D). 3D-display of the urinary leakage (E). DJ-stent inserted.

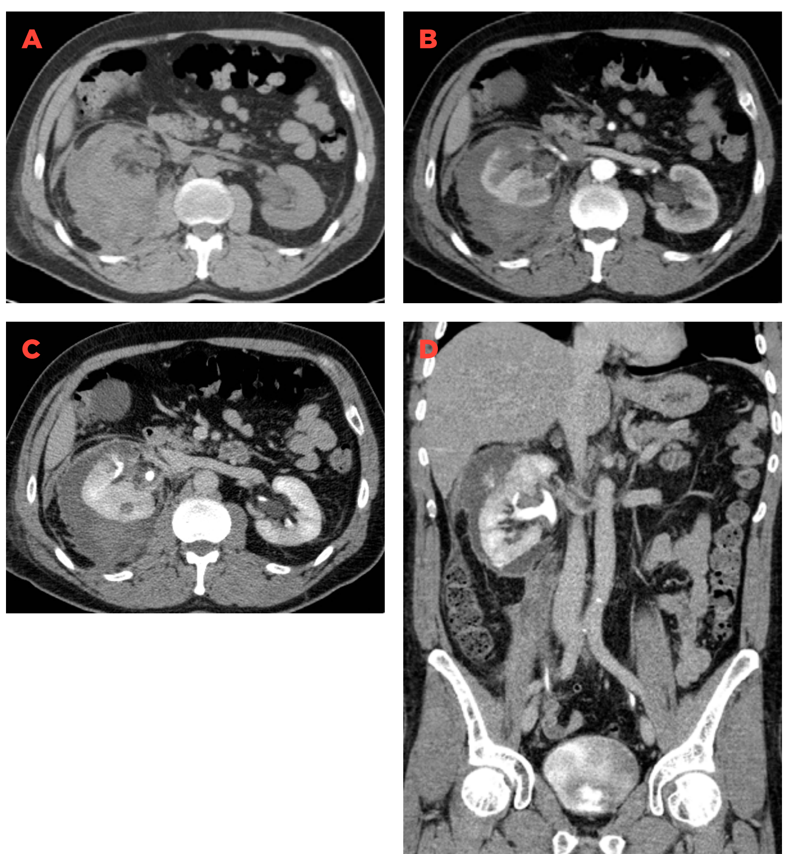
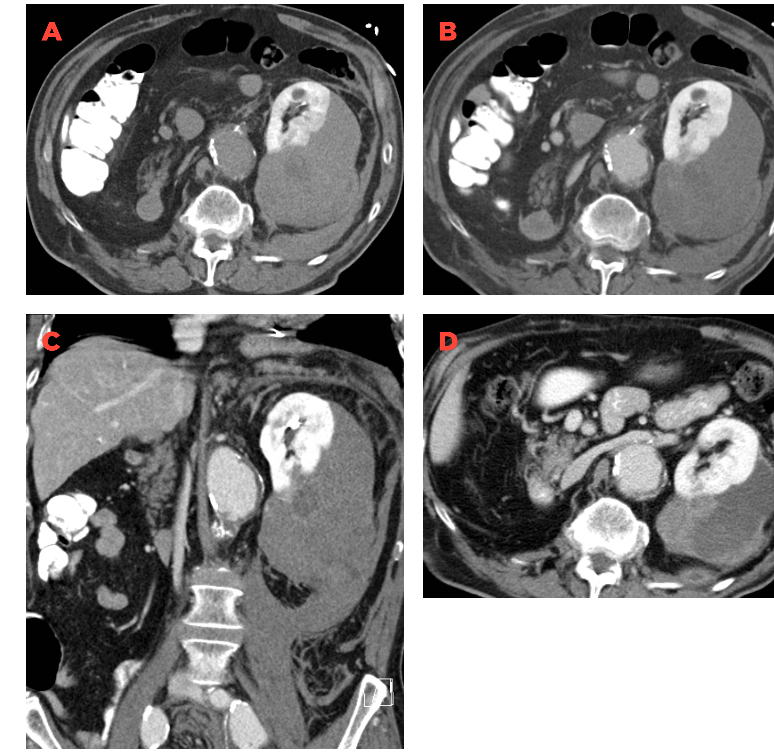


FIGURE 8

58-year-old male fallen from horse. Recurrent haematuria eight days after the event. Perirenal haematoma (A) and tear at the anterior aspect of the right kidney (B) with urinary extravasation on delayed scans (C) and (D).

FIGURE 9

77-year-old male with acute abdomen. ‘Spontaneous’ perinephric haemorrhage with hypovascular mass lesion at posterior aspect of the lower pole of the left kidney: axial (A) and (B) and coronal reformatted (C). CT 6 months later shows resorption of the haematoma and the tumour at the lower pole (D).



of a ureter may result in a urinary leak and development of urinoma, while clipping of a ureter will result in urinary tract obstruction and postoperative pain and decreased renal function. Careful attention and delayed excretory phase imaging is mandatory for visualisation of the site of leakage. Presence of an experienced radiologist during scanning of these patients is recommended.

SCROTUM

Ultrasound is the key modality for the assessment of scrotal content in the emergency setting; comparative imaging with the unaffected (asymptomatic) side is recommended. Ultrasound allows differentiation between testicular and extratesticular disease processes. The most common causes in the emergency setting are inflammation, torsion and trauma.

In acute epididymitis, the inflammation is usually located in the tail and body: focal or diffuse epididymal thickening with hypervascularity at colour-Doppler are seen. The inflammation can extend to the testis. Areas of liquefaction indicate abscess formation. A reactive hydrocele is often present. Isolated inflammation of the testis is extremely rare.

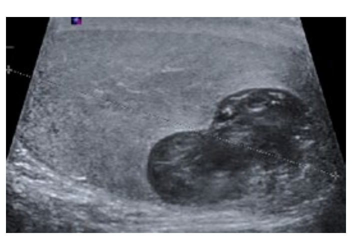
With torsion of the testis, the absence of intratesticular flow (compared to the other testis) is the most reliable criterion for diagnosis. Attention should be paid to reactive hyperaemia after spontaneous detorsion, thus mimicking orchitis.

Acute segmental testicular infarction is a rare condition in adults, most often idiopathic (no demonstrable aetiology), with a (wedge-shaped) avascular area in the testis, as well as the base to the testicular surface, and the tip towards the mediastinum. This condition can have a pseudotumoural appearance; familiarity with this rare condition can avoid misinterpretation and save unnecessary orchiectomy.

In cases of scrotal trauma it is essential to assess testicular integrity, e.g. integrity of the tunica albuginea to differentiate patients for conservative treatment from those requiring surgical intervention and repair. Particular attention is required in men with intratesticular haematoma and mild scrotal trauma only, to avoid missing an underlying testicular tumour. In these cases, MRI is helpful to differentiate haemorrhage from tumour.

FIGURE 10

33-year-old male with blunt trauma from sporting activity. Intratesticular haematoma at the lower pole of the testis with integrity of the tunica albuginea.



PENIS

Injuries of the penis are rare urological emergencies demanding immediate care. Causes are direct injuries (traffic accidents, fights), sexual intercourse or forceful self-manipulation. Fracture of the penis with rupture of the corpus cavernosum is the most frequent condition and can be associated with rupture of the corpus spongiosum and urethral rupture.

In classical cases, patients mention a cracking or popping noise with immediate pain and loss of erection. Haematoma, occasionally impressive, develops with or without deviation of the penile shaft. Haemorrhage of urethral discharge indicates injury of the spongiosum. Urinary retention may occur. Penile ultrasound and occasionally MRI is indicated for appropriate diagnosis and therapeutic management. Retrograde urethrography is mandatory if urethral injury is suspected.

PROFESSOR RAYMOND OYEN

obtained his MD degree at Catholic University Leuven, Belgium, in 1981. He accomplished his residency training in radiology at University Hospital Leuven and earned a PhD degree with his dissertation on the diagnosis and staging of prostatic carcinoma. Professor Oyen was appointed Professor of Radiology in 1994 and Head of the Department of Radiology in 2010. He has acted as President of the Scientific Council of the Royal Belgian Society of Radiology since 2014. He is the co-founder of the European Society of Uroradiology (ESUR) and became President-elect in 2016. Professor Oyen has authored a long list of scientific publications in the field of uroradiology. He is reviewer of six European radiological journals.

10

GYNAECO-LOGICAL AND OBSTETRICAL EMERGENCIES

GYNAECO-LOGICAL AND OBSTETRICAL EMERGENCIES: NON-RADIATING IMAGING SOLVES THE PROBLEM

BY **GABRIELE MASSELLI** AND **MARTINA DERME**

GYNAECOLOGICAL EMERGENCIES

Ruptured ectopic pregnancy

Ectopic pregnancy (EP) occurs when the fertilised ovum implants and matures external to the endometrial cavity. The incidence of EP is approximately 11 in every 1,000 pregnancies, and it remains the main cause of maternal death during the first trimester. Risk factors for EP include tubal damage following surgery or infection, smoking, in vitro fertilisation, and advanced maternal age. EP is most commonly located in the ampullary portion of the Fallopian tube (80%). The prevalence of tubal rupture is 29.5%. The spectrum of clinical findings in EP ranges from completely asymptomatic status to peritoneal irritation due to bleeding in peritoneal cavity or even hypovolemic shock. Early diagnosis and treatment of EP are crucial in order to reduce maternal mortality and preserve future fertility. The initial evaluation includes a quantitative measurement of serum human chorionic gonadotropin (hCG) and transvaginal ultrasound.

Transvaginal ultrasound has reported sensitivities of 87.0–99.0% and specificities of 94.0–99.9% for the diagnosis of EP. In 15–20% of patients, ultrasound provides a definitive diagnosis, showing an extra-uterine gestational sac (GS) containing a yolk sac and/or embryo that may or may not have cardiac activity. More frequently, it is only suggestive of an EP showing the presence of an adnexal mass and pelvic free fluid. Echogenic fluid has been reported in 28–56% of EP and it may signify tubal rupture. An important ultrasound limitation is the inability to differentiate haemorrhage from other fluids.

Magnetic resonance imaging (MRI) is an excellent problem-solving modality when ultrasound is equivocal or inconclusive before intervention or therapy. MRI provides additional information for complicated forms of EP, when diagnosis is unclear or ultrasound is equivocal, in particular for unusual implantation sites. The major roles of MRI are to identify fresh haemorrhage, to accurately localise the abnormal implantation site, and to identify associated congenital uterine anomalies or Mullerian abnormalities. However, the role of MRI may be restricted in haemodynamically unstable patients, particularly in cases with ruptured EP (Figure 1).

Computed tomography (CT) is not the imaging modality of choice for diagnosing EP, but it is occasionally performed when other diseases are suspected, in unrelated conditions, or in a trauma setting. CT demonstrates haemoperitoneum with or without contrast extravasation surrounding the uterus, but it has low soft tissue resolution for identifying the GS in EP. The rupture of EP, with serious bleeding and symptoms of shock, may require an emergent pelvic and abdominal CT inspection.

Expectant management is an option for clinically stable asymptomatic women with an ultrasound diagnosis of EP and a decreasing serum hCG value, initially less than 1,500 mIU/ml. Medical therapy, using methotrexate (MTX), should be offered to women with a serum hCG value less than 5,000 mIU/ml, and minimal symptoms. Surgery is usually needed when EP causes severe symptoms, bleeding, or when high hCG levels are present – typically laparoscopic surgery. For a ruptured EP, emergency laparotomy is required.

Adnexal torsion

Adnexal torsion is a gynaecological emergency caused by partial or complete twisting of the ovary, fallopian tube, or both along the vascular pedicle. It is estimated to occur in only 2.7% of gynaecologic emergencies. The cause of adnexal torsion is not well described. It is believed that an ovary of increased size is more likely to swing around its pedicle. If the torsion is not relieved, persistent vascular occlusion results in infarction and necrosis of adnexal structures. Early recognition is important to preserve the affected ovary and prevent serious complications, such as peritonitis and infertility, but the diagnosis of adnexal torsion poses a challenge because there are no specific clinical signs, manifestations, or biomarkers.

Although ultrasonography is the primary imaging modality for evaluation of adnexal

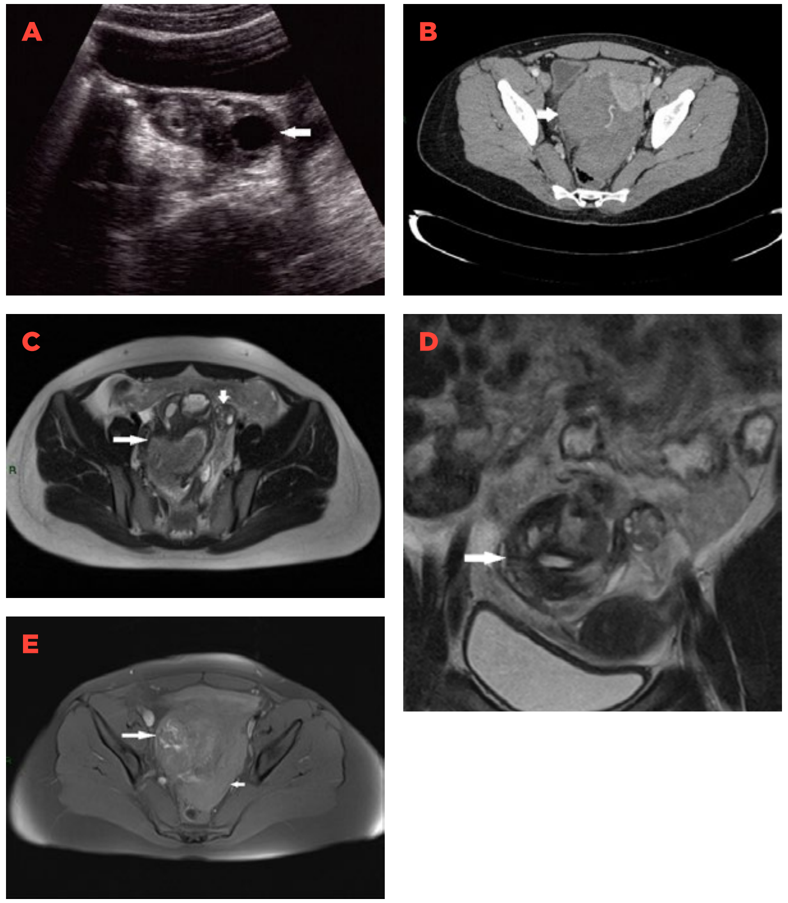


FIGURE 1

A 32-year-old woman presenting with acute pelvic pain and vaginal bleeding. Transvaginal ultrasound (A) showed the presence of a right complex sac-like ring (arrow). Axial CT scan (B) confirmed the presence of a right voluminous adnexal mass (arrow). Axial (C) and coronal (D) T2-weighted images of the pelvis showed a right heterogeneous adnexal mass (long arrow) with fallopian tube haematoma. Note the normal right ovary (short arrow) in C. Pre-contrast T1-weighted fat-saturated MRI image (E) showed the presence of fallopian tube haematoma (long arrow) and haemoperitoneum (short arrow). A right salpingectomy was performed.

torsion, the ultrasound findings are nonspecific and have not been fully established in a large series.

CT or MRI may serve as tools if the diagnosis remains unclear. Use of CT for evaluating a female patient presenting with acute pelvic pain in the emergency department has increased to exclude bowel or urologic diseases, such as appendicitis, diverticulitis, or ureter stones. Adding a coronal reformation to a transverse CT scan improves overall accuracy for diagnosing adnexal torsion and has proved valuable for detecting a twisted adnexal pedicle.

MRI is particularly helpful in young or pregnant patients with equivocal sonographic findings, as it provides excellent soft tissue contrast without radiation exposure. The characteristic MRI findings of adnexal torsion have been described as follows: fallopian tube thickening; whirlpool sign, which is a twisted ovarian pedicle or twisted fallopian tube; enlargement of the ovarian stroma; peripheral ovarian follicles; symmetrical or asymmetrical

wall thickening of the twisted ovarian cystic mass; uterine deviation towards the side of torsion; and free fluid. The presence and distribution of hypointensity on T2-weighed imaging may play a supplementary role in the detection of adnexal torsion (Figure 2).

Prompt intervention to preserve ovarian function should be laparoscopic wherever possible and detorsion the treatment of choice in prepubescent girls and women of reproductive age. In older and postmenopausal women, oophorectomy is the treatment of choice to completely remove the risk of re-torsion.

Ruptured haemorrhagic corpus luteum cyst

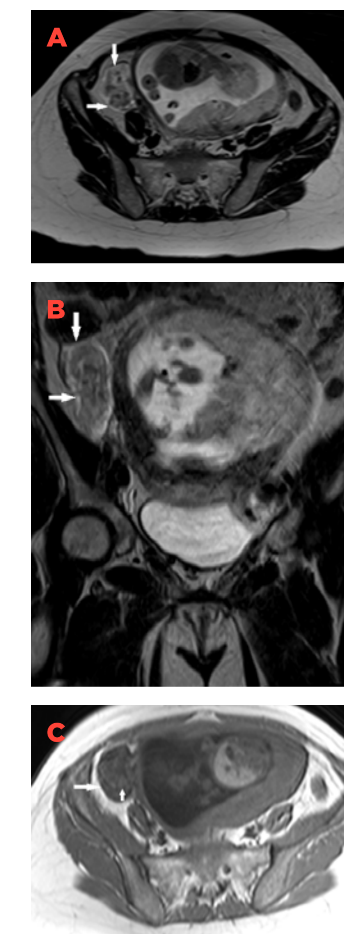
Ruptured corpus luteal cyst is a possible cause of spontaneous haemoperitoneum in women of reproductive age. Patients may present a wide range of clinical signs, from no signs to severe peritoneal irritation, which can be confused with, for example, acute appendicitis. The evaluation of serum hCG-levels is necessary to differentiate ruptured corpus luteal cyst from ruptured EP, which may have a similar presentation.

Various imaging modalities play an important role in diagnosing the ruptured corpus luteum cyst. Usually, ultrasound is the first imaging modality due to its high sensitivity and fast and easy access. On the other hand, it can be difficult to localise the site of the disease and bleeding.

Although MRI is the most adequate technique for pelvic evaluation, thanks to its high soft-tissue contrast capability, it is not usually used in the acute setting due to its considerably long

FIGURE 2

Ovarian torsion in a 42-year-old woman at 26 weeks' gestation with acute pelvic pain. Axial (A) and coronal (B) T2-weighted HASTE MRI images showed an enlarged, oedematous right ovary (arrows). Axial T1-weighted sequence (C) showed areas of increased signal intensity (short arrow) within the right ovary (long arrow) indicating haemorrhagic infarction. A right oophorectomy was performed.



acquisition time, limited availability, and high cost.

On CT examination, corpus luteum usually appears as a well-circumscribed unilocular adnexal lesion, rarely bilocular. The cyst walls appear slightly thickened (<3mm) and show a characteristic inhomogeneous contrast enhancement after administration of contrast medium due to increased vascularity. Contrast-enhanced CT may be helpful in excluding other intra-abdominal diseases, as for instance a ruptured hepatic adenoma that can cause haemoperitoneum in the young female patient.

Historically the treatment of corpus luteum haemorrhage was exclusively surgical. More recently, conservative management is possible and considered the first treatment of choice in patients with clear ultrasound diagnosis, haemodynamic stability and stable haemoglobin values over 4–6 hours of monitoring.

OBSTETRICAL EMERGENCIES

Placental abruption

Placental abruption (PA) is defined as the premature separation of the implanted placenta before the delivery of the foetus. It complicates about 1% of all pregnancies, and it is a major obstetric complication associated with an increased risk of foetal and maternal morbidity and mortality. Several risk factors have been associated with PA, including young or advanced maternal age, previous history of PA and/or caesarean section, multiparity, cigarette smoking, multiple gestations, hypertensive and thrombophilic disorders, abdominal trauma, and polyhydramnios. The main clinical features are vaginal bleeding, abdominal pain, uterine contractions or uterine tenderness, and signs of foetal distress.

The most important ultrasound criteria for PA (sensitivity 80%, specificity 92%) are the detection of pre/retroplacental fluid collections, evidence of marginal subchorionic or intra-amniotic haematomas, increased placental thickness (>5cm), and jelly-like movements of the chorionic plate. However, 25–50% of haematomas are mostly retroplacental and are undetectable using ultrasound, because the echotexture of recent haemorrhage is similar to that of the placenta or due to having small dimensions. Moreover, clots resulting from chronic abruption may drain through the cervix.

MRI is superior to ultrasound for the evaluation of placenta haemorrhage, because it improves soft-tissue contrast, and has a wider field-view. Diffusion-weighted and T1-weighted MR sequences, which show a sensitivity, respectively, of 100% and 94% and a diagnostic accuracy, respectively, of 100% and 97%, are more accurate than T2-weighted half-Fourier RARE, with its sensitivity of 94% and a diagnostic accuracy of 87%. In comparison, true FISP sequences have a sensitivity of 79% and a diagnostic accuracy of 90% for the detection of placental abruption. Moreover, MRI can be used to date haemorrhage on the basis of the paramagnetic effects of methaemoglobin and to classify intrauterine haematomas as hyperacute (first few hours, intracellular oxyhaemoglobin), acute (1–3

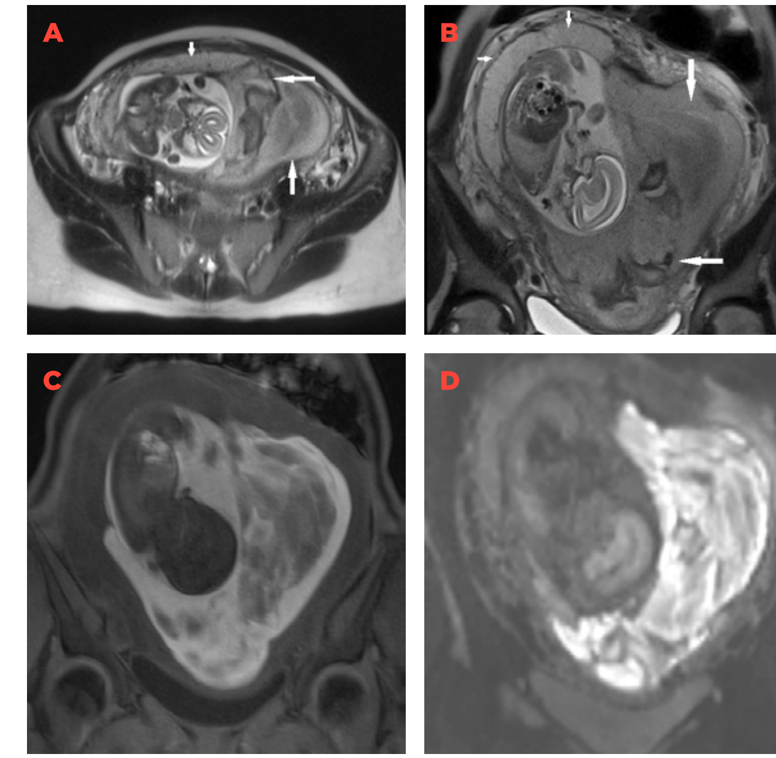


FIGURE 3

A 29-year-old woman at 30 weeks' gestation with acute pelvic pain and vaginal bleeding. Axial (A) and coronal (B) MRI T2-weighted images showed the intrauterine clot with mixed hypointense and hyperintense areas placed along the left side of the uterine cavity and extended inferiorly to cover the uterine ostium (long arrows). Coronal T1-weighted fat-saturated gradient echo (C) and diffusion-weighted (D) images showed heterogeneous signal of the haematoma, indicating coexistent acute and subacute haemorrhage. Note the normal placenta located on the right (short arrows). An emergency caesarean section was performed.

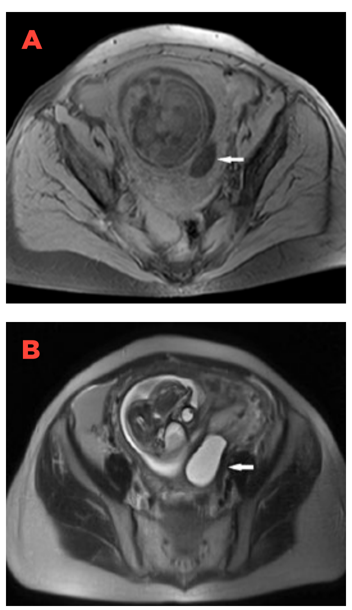
days, intracellular deoxyhaemoglobin), early subacute (3–7 days, intracellular methaemoglobin), late subacute (≥14 days, extracellular methaemoglobin) and chronic (>4 weeks, intracellular haemosiderin and ferritin) (Figure 3). Gadolinium-based contrast agents cross the placenta and are excreted by the foetal kidneys into the amniotic fluid. Despite the lack of any evidence of adverse effects after MR studies in the human foetus, gadolinium-based contrast agents are classified as category C drugs by the Federal Drug Administration (FDA) of the USA and should only be administered to a pregnant patient "if the potential benefit justifies the potential risk to the foetus and using the smallest dose of the most stable gadolinium agent".

Given that CT is the 'workhorse' modality for evaluation of pregnant trauma patients, radiologists must pay particular attention to radiation dose concerns. Several findings of PA may be seen on CT images. PA is best characterised on CT images as a contiguous retroplacental or full-thickness area of decreased enhancement that forms acute angles to the myometrium.

As abruption may rapidly worsen, requiring rapid surgical delivery to prevent adverse maternal and foetal outcomes, an accurate diagnosis of placental abruption and, possibly, the prediction of its worsening, are extremely important when considering a conservative treatment.

FIGURE 4

Uterine rupture in a 34-year-old woman at 26 weeks' gestation with vomiting, acute abdominal pain and tenderness in the upper quadrants. Abdominal ultrasonography revealed only intraperitoneal fluid representative of haemoperitoneum. Axial T1-weighted (A) and axial T2-weighted (B) MRI images showed a posterior uterine rupture (arrow) with extravasation of amniotic sac in the peritoneum. Emergency laparotomy showed a 3cm bleeding irregular uterine rupture.



Uterine rupture

Uterine rupture is a rare obstetrical complication in developed countries, and frequently results in life-threatening maternal and foetal compromise. The risk of uterine rupture in an unscarred uterus is extremely rare at 2 per 10,000 (0.02%) deliveries and the risk is mainly confined to multiparous women in labour. Uterine rupture occurs when a full-thickness disruption of the uterine wall, which also involves the uterine serosa, is present. Congenital uterine anomalies, multiparity, uterine myomectomy and/or caesarean deliveries, foetal macrosomia, labour induction, and uterine trauma all increase the risk of uterine rupture. The classic signs and symptoms of uterine rupture are foetal distress, loss of uterine contractility, abdominal pain, haemorrhage, and shock.

Diagnosis of uterine rupture by ultrasound relies on non-specific and secondary signs, including free fluid or haematoma formation. Ultrasound may help to select a safe trial of vaginal birth after Caesarean section (VBAC). Uterine scar rupture can be predicted by visualising a myometrial thickness of less than 2.0mm.

In comparison to ultrasound, MRI is less operator-dependent, and provides a more comprehensive examination with a larger field-of-view. MRI allows for better evaluation of soft tissues than CT and ultrasound. Finally, MRI allows clear visualisation of the uterine wall; therefore, it helps to diagnose both antepartum uterine rupture when ultrasound is indeterminate, showing the tear itself, and other uterine wall defects, including uterine dehiscence and uterine sacculation (Figure 4).

When a diagnosis of complete uterine rupture is established, the immediate stabilisation of the mother and the surgical delivery of the foetus are imperative.

Placental adhesive disorders

Placental adhesive disorders (PAD) include placenta accreta (placental villi attached to the myometrium), placenta increta (placental villi invading the myometrium), and placenta percreta (placental villi penetrating up to the uterine serosa). The incidence of PAD is 1 in 2,000 pregnancies, with a rapid increase in recent years, reflecting the rising number of caesarean sections and other uterine surgery. PAD may trigger life-threatening complications such as a catastrophic haemorrhage, haemorrhagic shock, uterine rupture, infection, and coagulation disorders when the implanted tissue is massive and deep, with a rich blood supply.

Ultrasound is the first imaging modality used to diagnose PAD. Sonographic features include loss of the normal hypoechoic retroplacental myometrium zone, thinning or disruption of the hyperechoic uterine serosa-bladder interface, focal exophytic masses, and lacunae in the placenta (this latter finding is the most predictive sonographic sign, with a sensitivity of 79%, and a positive predictive value of 92%). Colour-Doppler can add information and, when three dimensions are available, can often help to distinguish placenta accreta from placenta percreta, highlighting areas of increased vascularity with dilated blood vessels that cross the placenta and the uterine wall.

MRI is not used as the first imaging modality to diagnose PAD, but can provide additional information in equivocal patients, especially those with a posterior placenta and previous myomectomy. Lim et al. found that the volume of dark placental bands (first described by Lax) was the most predictive finding in true PAD. Derman et al. confirmed that the most reliable sign is a larger dark band on T2 Aste images. They added an additional finding: vessels of 6mm or larger, which presumably correspond to lacunae. Moreover, when placenta is percreta, MRI is able to depict infiltration of adjacent organs by showing tenting of the bladder, interruption of the myometrial line, and direct infiltration of pelvic organs (Figure 5).

In summary, if ultrasound findings suggest possible percreta or are inconclusive or negative in an at-risk woman, MRI can be very useful. Invasion of adjacent organs can be seen more conclusively on MRI than on ultrasound. Situations in which MRI may also contribute additional information include women with placenta praevia with a posterior or lateral implantation, a posterior scar from a myomectomy, a history of difficult placental removal in the past with a posterior or lateral placenta in the present pregnancy, or a history of endometrial ablation. The correct and prompt diagnosis of placenta percreta is important because this condition may cause uterine rupture, requiring an emergency caesarean section.

Placenta previa

Placenta previa is defined as the placenta overlying the endocervical os. The incidence is estimated to be 1 in 200 pregnancies at

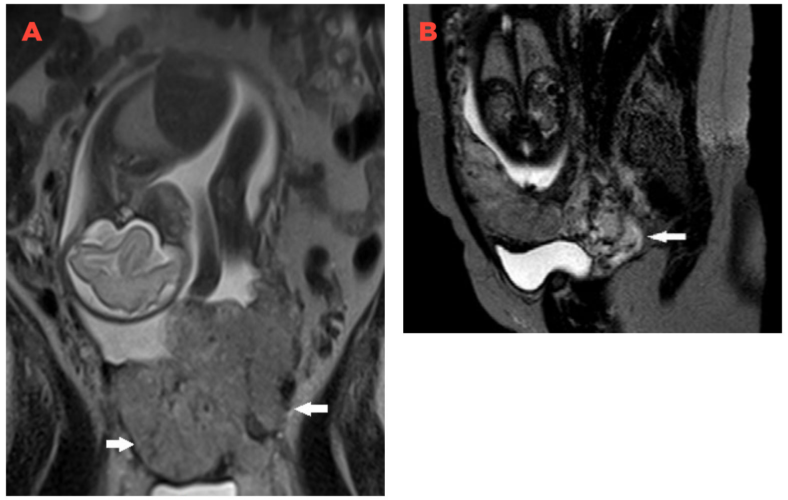


FIGURE 5

A 25-year-old woman at 28 weeks' gestation with acute pelvic pain. Coronal (A) and sagittal (B) T2-weighted MRI images showed multiple irregular areas of the placenta bulging into the myometrium with invasion of the right parametrium (arrows). These findings indicated placenta percreta. A hysterectomy was performed, which confirmed the presence of placenta percreta.

term. Risk factors include previous caesarean sections, previous spontaneous and elective pregnancy terminations, previous uterine surgery, increasing maternal parity, increasing maternal age, smoking, cocaine use, multiple gestations, and prior previa. Placenta previa is associated with numerous adverse maternal and fetal-neonatal complications. Many of these are direct consequences of maternal haemorrhage. In fact, there is an increased risk of postpartum haemorrhage in the setting of previa, even without accreta. This often is attributable to diffuse bleeding at the placental implantation site in the lower uterine segment. Now, most previas are diagnosed by antenatal ultrasonography. In cases of suspected placenta previa on transabdominal ultrasonography, the patient should undergo transvaginal ultrasonography to more accurately delineate the relationship between the placenta and the endocervical os. For example, transvaginal ultrasonography will 'reclassify' a diagnosis of low-lying placenta noted on transabdominal ultrasonography in the second trimester 26–60% of the time. When a placenta previa is suspected to be accreta on ultrasound, an MRI can complete the diagnosis. The only safe and appropriate mode of delivery for placenta previa is by caesarean section. Although caesarean delivery is universally accepted as the optimal approach if the placenta overlies the endocervical os, if the placenta is 2cm or greater from the os, a trial of labour is appropriate and the risk of bleeding is acceptable.

SUMMARY

Imaging findings are important when evaluating acute gynaecological and obstetrical emergencies because the symptoms and physical examination findings are often nonspecific and limited. Ultrasonography is the first-line imaging modality; however, when a definitive diagnosis cannot be established, CT and MR imaging may narrow the differential diagnosis.

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11

SPINAL AND PELVIC TRAUMA

THE NIGHT (AND DAY) WATCH: THE RADIOLOGIST'S ROLE IN SPINAL AND PELVIC TRAUMA

BY **JOSÉ MARTEL VILLAGRÁN** AND **MARIA JESÚS DIAZ CANDAMIO**

Spinal and pelvic fractures are a common occurrence in a busy emergency department.

Imaging is crucial for their early detection and classification in order to get the most suitable treatment. Radiologists, the doctors specialised in medical imaging interpretation, play an important role when someone arrives to the emergency room after suffering a spine or pelvic trauma.

THE SPINE AND THE PELVIS: MUCH MORE THAN OUR BODY'S SUPPORT

The spine and pelvis constitute the anatomical basis of the human body's support. A vertebra consists of the larger anterior segment, the vertebral body, and a dorsal part, the vertebral arch, both enclosing the spinal cord. To protect this enclosed delicate content, the 31 articulated vertebrae that constitute the spine are firmly attached by the spinal ligaments, allowing only limited movement.

Pelvic bones constitute an entire ring: the right and left ilium being connected anteriorly at the symphysis pubis and posteriorly to the sacrum at the sacroiliac joints. This bony ring is strongly united by means of strong ligaments to form a largely immobile, weight-bearing structure. This rigidity allows not only the required protection for the fragile content of the pelvis (viscera, vessels and nerves), but also provides the strong foundation that the body needs as it rests on top of the very mobile lower limbs.

So the clinical interest in the study of spinal and pelvic fractures is derived not only from the potential loss of this mechanical and supportive role, but also because of their protective shield for the spinal cord (in the case of the spine), and for the important vascular, neurologic, genitourinary and intestinal structures encased by the pelvic ring.

The consequences of spinal cord injury are often devastating with the possibility of paraplegia and tetraplegia. Pelvic fractures can also lead to incapacitating disabilities including painful walking, muscle weakness, and sexual or bladder dysfunction.

Vertebral and pelvic fractures can also imply a heavy economic burden to the patient and his or her family, rendering a person dependent on caregivers for many years to come depending on the age of the patient. The consequences for the state are also costly, not only due to health and rehabilitation expenditures, but also because of social support measures such as pensions. Furthermore, both spinal and pelvic injuries are associated with a significant mortality rate, with haemorrhage being the leading cause of death from pelvic fractures.

HIGH-ENERGY SPINE AND PELVIC TRAUMA INJURIES USUALLY AFFECT YOUNG MEN

Given the strength of these bony structures, only high intensity forces, so-called 'high-energy injuries' will be able to cause a disruption of this almost perfect system normally so resistant to trauma in healthy adults. Due to these high-energy impacts, spine and/or pelvic fractures can be associated with traumatic cranial, thoracic, abdominal or limb damage, in a so-called polytraumatised patient, by which the pelvic and spine fractures are usually the leading cause of an increase in mortality.

These high-energy injuries typically involve young male patients. Most (about 60%) of these injuries are the result of high-energy falls from a height greater than 4.5 meters or motor vehicle accidents. Diving is an important cause of cervical spine trauma. These injuries in young males typically occur either on the job or from sport activities.

LOW-ENERGY SPINE AND PELVIC TRAUMA INJURIES USUALLY AFFECT THE ELDERLY

At present, given the aging population, the prevalent vertebral and pelvic fractures that we see in the emergency setting in most

FIGURE 1

Odontoid process fracture (arrow) involving an ankylosing spondylitis patient. In patients with bone pathologies, such as ankylosing spondylitis, fractures can occur after minor trauma.

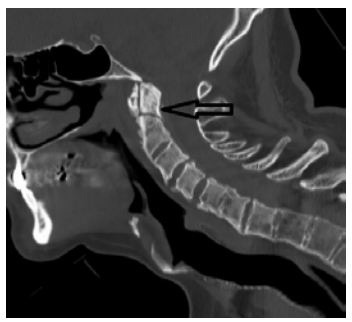
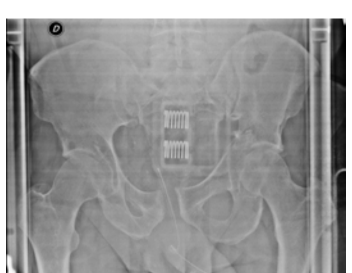


FIGURE 2

X-ray of a pelvic trauma. It is a common practice in trauma to place patients in cervical collars and on long backboards. The overlap of these devices complicates the x-ray assessment of the possibility of fractures. For cross-sectional imaging this overlap is not a problem, since they can 'see through' these devices.



hospitals appear in the elderly who have suffered a relatively mild trauma such as a fall while ambulating, or they are insufficiency fractures, due to low bone mineral density. Patients with debilitated bones due to processes such as ankylosing spondylitis or osteoporosis are also prone to fractures after otherwise minor trauma, caused by changed biomechanical properties (Figure 1).

Little pelvic 'avulsion' fractures in adolescents resulting from an athletic injury or pelvic stress fractures in joggers are stable pelvic fractures that heal with non-operative measures. These low-energy fractures are not always seen at the emergency room setting, and they do not usually require urgent medical management. They rarely need surgical treatment, and their medical and socioeconomic consequences are not substantial.

So the 'typical' case of trauma can be anything from a young male admitted after a road traffic accident to an older male admitted after a fall of less than 2 meters.

INITIAL MANAGEMENT OF THE TRAUMA PATIENT

Trauma patients often are first evaluated at the injury site by the emergency services. Symptoms or signs of significant vertebral or pelvic trauma such as limb paralysis or significant bleeding can be present that make the diagnosis easy. However, many times the clinical diagnosis is not obvious. Even if the suspicion of a vertebral fracture is low, immobilisation of the spine is nevertheless usually undertaken.

When there is a high probability of a pelvic fracture, a pelvic circumferential compression device can be applied for stabilisation of the suspected fracture and to control bleeding, as these fractures may bleed massively (haemorrhage being the main cause of death in these patients). These devices can limit the radiological assessment of trauma patients, particularly in the case of plain x-ray. Cross-sectional techniques allow a significant reduction of these problems (Figure 2).

After stabilisation, the patient is transferred to hospital where a detailed evaluation of his or her injuries is made and interventions performed in the order of their importance. If there is suspicion of spinal cord injury, the patient is directly referred to a centre specialised in the management of this complex pathology (Figure 3).

THE TRAUMA PATIENT AT THE HOSPITAL EMERGENCY DEPARTMENT (ED)

When the trauma patient arrives at the ED, a multidisciplinary approach involving emergency physicians, general surgeons, neurosurgeons, and orthopaedic surgeons is employed in the care of the patient. But there is also another crucial member of the round-the-clock trauma team not always mentioned: the radiologist.

Imaging plays a crucial role in the management of spine and pelvic trauma since physical examination is clearly not sufficient to reach an accurate diagnosis. Imaging should be done after primary stabilisation has occurred

FIGURE 3

Instable C6-C7 fracture. Discrete wedging of the C6 and C7 vertebral bodies with increase of the distance between the spinous processes (black line) which indicates ligament injury (A: plain x-ray film, B: CT image). This implies spine instability. This patient must be referred to a specialised centre.

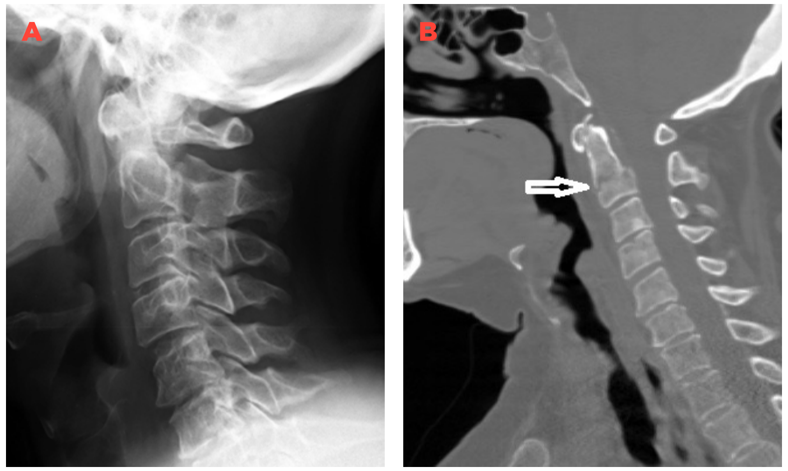


FIGURE 4

C2 odontoid process fracture. The first two cervical vertebrae (C1, the atlas, and C2, the axis) constitute the most mobile and complex joint in the spine, the atlantoaxial joint. It provides the underlying mechanics for head rotation, for example when you park your car. A: The x-ray was interpreted as normal. B: CT sagittal image showed the fracture.

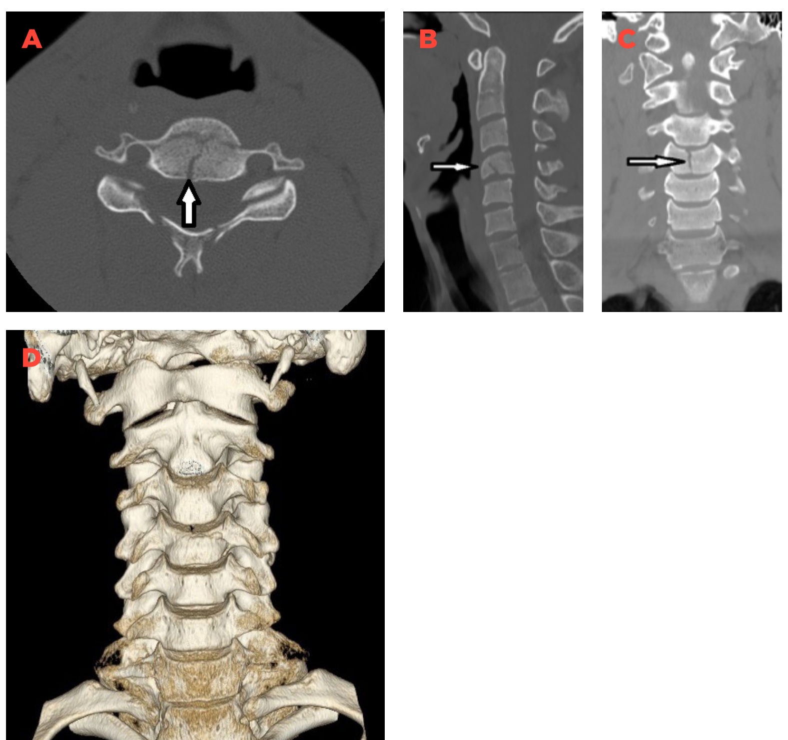


FIGURE 5

Vertebral body fracture. The fracture (arrow) is visible in the axial (A), sagittal (B) and coronal (C) CT images but it is undetected in the 3D reconstruction (D).

and life-threatening issues tackled in order of their importance. It is necessary to act quickly. The clinical course of a trauma patient will depend on the appropriate choice of the imaging techniques and the speed with which they are performed. The multidisciplinary team must ensure orthopaedic stabilisation of the fractures within 24 to 72 hours of the injury.

Plain x-ray films present limitations for the evaluation of fractures (Figure 4). Hospitals have sophisticated medical imaging equipment which together with x-ray can obtain three-dimensional images of the body by means of computed tomography (CT) and magnetic resonance imaging (MRI). These techniques are a realisation of so-called volumetric isotropic imaging, in which a 3D anatomic volume can be processed in any plane to better depict not only bone fractures and their consequences, but also the effects of trauma on the rest of the body, so that surgeons and interventional radiologists have an authentic road map to guide them. Although 3D reconstructions improve the communication of findings between doctors and patients, they do not always provide more information. On the contrary, multiplanar 2D reconstructions tend to demonstrate better the pathological findings (Figure 5).

MRI does not use ionising radiation and it is generally considered to be safer than CT scanning, it is more expensive and more time consuming than CT. Moreover, due to the intensity of the magnetic fields involved, it cannot be safely done with patients with certain types of devices in their bodies, including all but the most recent generations of pacemakers and other metal implants. For all these reasons, CT is the standard imaging technique to evaluate traumatic injuries involving bones at the emergency room (Figure 6).

Spinal and pelvic fractures are exceedingly rare in preadolescent children. Judicious use of radiographs and targeted CT must be made to avoid unnecessary radiation. If necessary, specific paediatric low-dose CT protocols should be utilised.

Patients with spinal or pelvic fractures can have a variety of other injuries, including other axial and appendicular skeletal injuries. A whole body ‘head to toe’ CT scan is necessary in polytraumatised patients, involving the administration of intravenous contrast. These whole body scans must be carefully considered in the case of children to avoid excessive radiation.

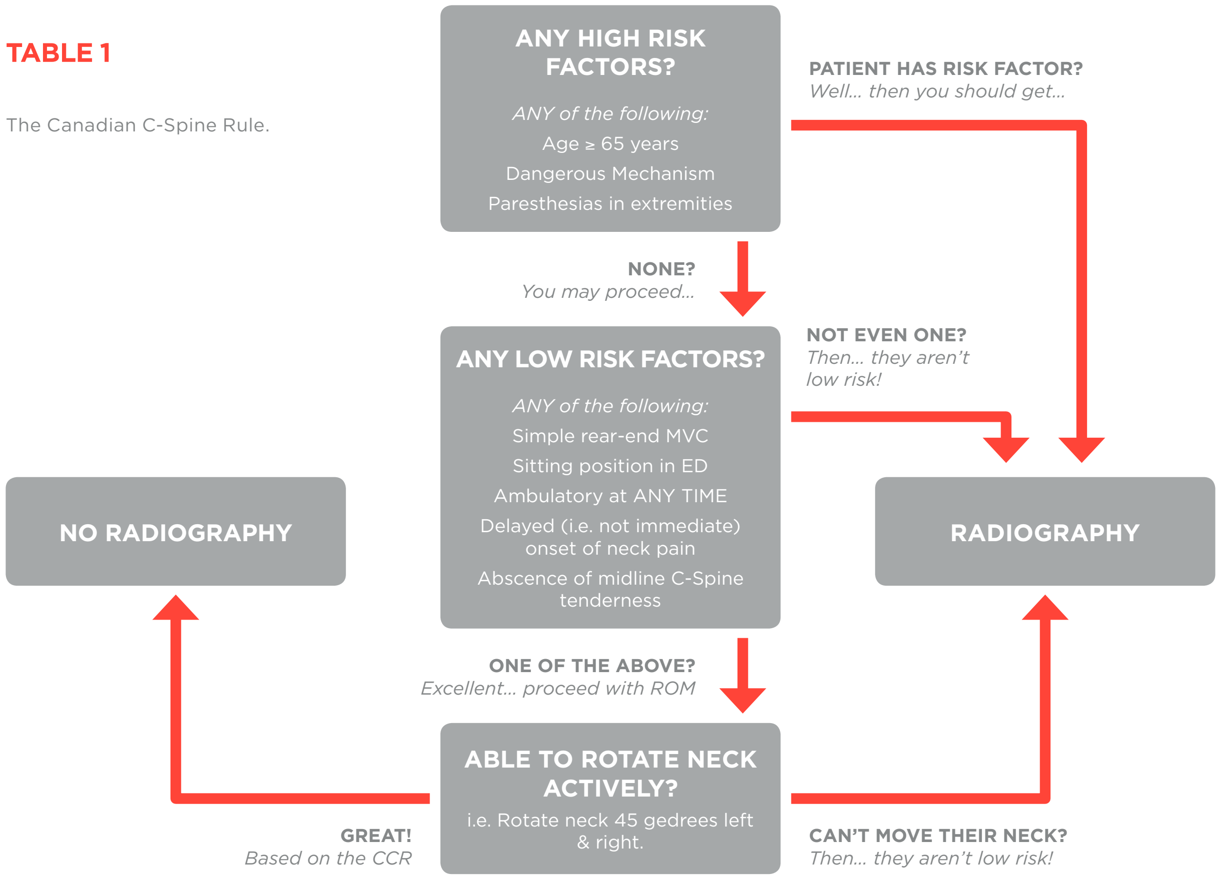
Rapid and accurate diagnosis of spinal and pelvic injuries is needed for early prevention of pelvic deformities. These fractures have been traditionally treated conservatively, but there

FIGURE 6

Whole spine sagittal slice. The CT allows studying the entire body in a few seconds and being able to visualise the whole spine.

TABLE 1

The Canadian C-Spine Rule.



is a trend toward performing more operations for those that are unstable, allowing earlier patient mobilisation and preventing significant pelvic deformities.

THE FOUR PHASES WITHIN THE RADIOLOGIST'S ROLE

The radiologist's role in vertebral and pelvic trauma can be divided into four successive phases.

1. First, **to decide, together with the clinicians, if imaging is necessary,** taking radiation dose into account to avoid unnecessary exposure.

2. If imaging is needed, the next step would be **to find the most suitable technique** specific to each trauma patient, depending on what is available in the particular trauma centre or emergency department, keeping in mind the clinical presentation and the mechanism of injury is a strong determiner of the presence of fracture.

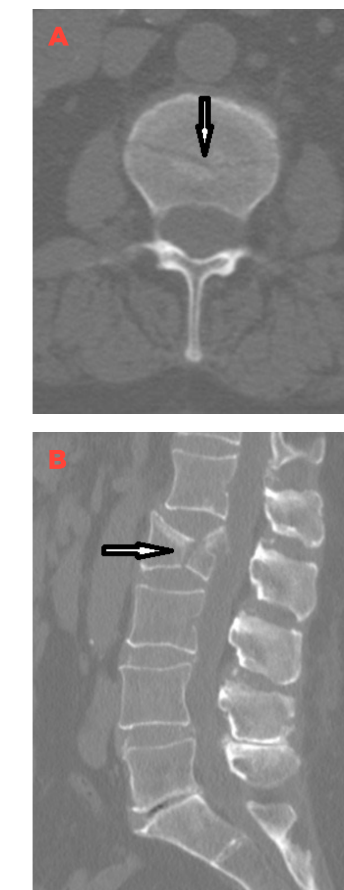
For instance, clinical criteria have been established to identify patients with a low probability of cervical spine injury, in order to spare unnecessary cervical spine imaging, the most widely used being the Canadian C-spine rule (CCSR) (Table 1). However, any trauma patient whose spine cannot be clinically cleared must receive a full cervico-thoraco-lumbosacral (CTLS) spine x-ray.

Although x-ray has a role as the initial imaging technique in some cases at the emergency department, if there is a strong clinical suspicion of a pelvic or spinal fracture, patients can be directly sent to CT. Approximately one-half of spinal fractures involve the thoracolumbar spine junction (T12–L2), (Figure 7) while 20% involve the cervical spine (Figure 4). Cervical fractures are especially significant, since neurologic injury occurs in 20% of spine fractures overall, but in as many as 40% of cervical fractures. An anteroposterior pelvic x-ray highlights many major pelvic disruptions and can help initiate treatment. But in many cases, due to the suspicion of significant and complex injury, radiologists choose to directly perform CT.

3. The third step would be **to document or to rule out the presence of fracture** and associated injuries. Many times this is not easy on plain film. Fracture lines may go undetected, especially if the fractures are not displaced. Stress and insufficiency fractures that occur typically in patients who have undergone radiation therapy for pelvic cancer are a very elusive diagnosis to make on plain films. Fortunately, they can be easily recognised on CT because of their typical locations and patterns. The most frequent is the sacral insufficiency fracture, usually vertically oriented

FIGURE 7

L2 fracture. Collapsing fracture with horizontal and vertical fracture lines and gentle posterior wall displacement. That means that spinal cord damage may be present, and an MRI study should be performed to confirm it.



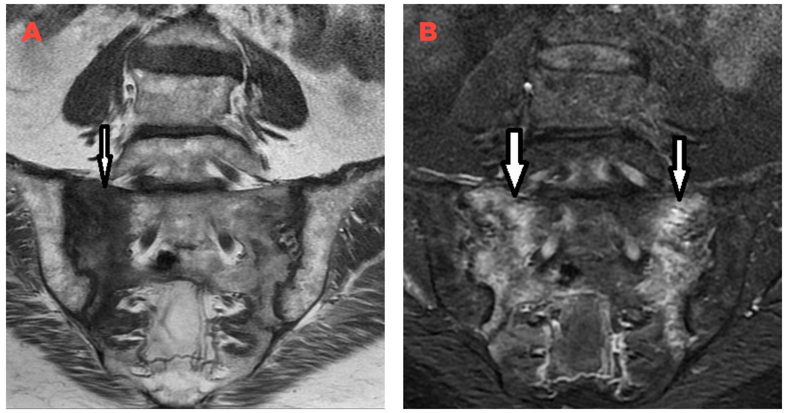


FIGURE 8

Sacral insufficiency fracture. Coronal MR T1-weighted (A) and T2-weighted images (B) shows bone marrow oedema as a sign of fracture (arrow). CT was normal.

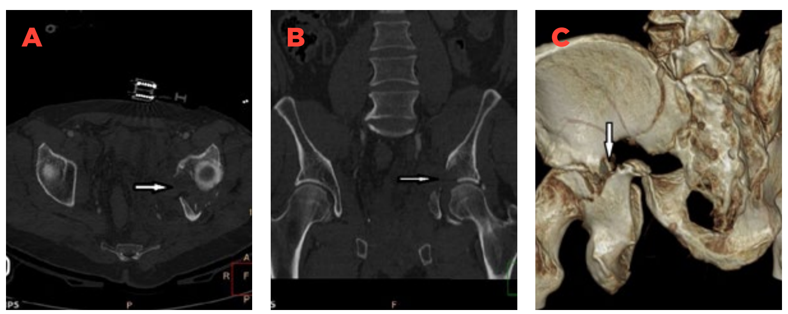


FIGURE 9

Acetabular fracture (arrows). CT Axial (A) and coronal (B) images. 3D reconstruction (C). The fracture of the acetabulum is visualised with an angulation of the angle of vision.

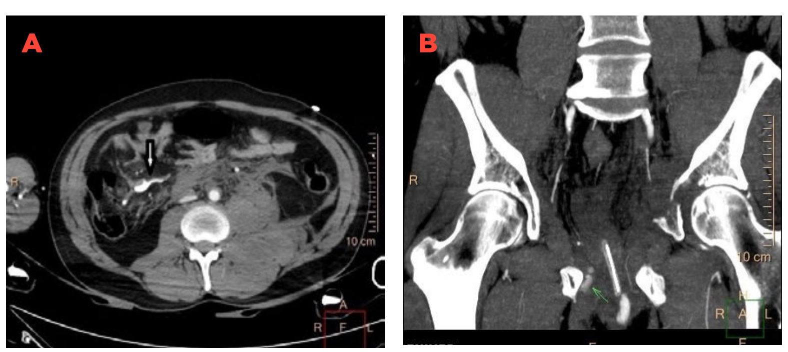


FIGURE 10

Two examples of bleeding in pelvic trauma. A: Mesenteric bleeding is observed in a patient with Chance fracture (arrow). B: Arterial bleeding is observed in a patient with unstable pelvic fracture (arrow).

through the sacrum, paralleling the sacroiliac joint. However, some occult fractures can be missed on CT. They are best detected using MRI (Figure 8).

More and more frequently, when a fracture is suspected, current emergency services protocols indicate the performance of a CT study of both the spine and the pelvis. Two and three-dimensional reconstructions of CT scans may provide a more useful evaluation of fracture morphology and of the overall displacement of the fracture (Figure 9). Many times these CT studies must be done using intravenous contrast due to the high likelihood of significant arterial bleeding requiring haemostatic embolisation. Iodinated contrast also allows a better depiction of associated soft-tissue and visceral traumatic injuries (Figure 10). Nevertheless, many fractures go unnoticed on CT. Recent studies indicate that MRI is more sensitive in the detection of fractures, and the new fast sequences facilitate even more effectively the study of patients with potentially serious injuries. Furthermore, MRI is the study of choice for determining the extent of damage to the spinal cord; overall, MRI is the most sensitive tool for detecting damage to neural tissue and bone. This is especially relevant for children as no radiation is involved. One example of an entity occurring in paediatric patients is 'spinal cord injury without radiographic abnormality'. Here however, if injury and neurologic deficits are strongly suspected, CT may in fact be needed or an MRI scan as well.

4. The fourth step would be **fracture depiction and classification** to aid in the decision on surgical versus non-surgical management. Once the fracture has been detected at imaging, it is crucial to determine its relevance, especially with regard to the stability of the fracture, to determine the need for surgery.

In both pelvic and vertebral fractures, several fracture classification systems have been established, taking into account not only the causal mechanism but also the risk of displacement of the fragments with the potential consequences. These classifications of the fractures imply a different treatment, either conservative or surgical.

A fracture is stable if the bone can withstand normal activity without deformation. Stable pelvic fractures heal well without much complication. Most traumatic spinal and pelvic fractures are treated conservatively with bed rest, immobilisation and bracing until the patient can tolerate mobilisation and weight bearing.

Unstable fractures are those that deform under normal activity. Unstable fractures and those with neurologic impairment, usually because of high energy trauma, may require surgical treatment, extensive rehabilitation, and often lead to long-term deformity, pain, and disability. They can be associated with injuries to visceral, vascular and nervous pelvic content.

A pelvic ring injury is associated with significant pelvic haemorrhage in up to 75% of patients. To guide the rapid and appropriate treatment of pelvic ring injuries, they are classified in patterns correlating with the direction and location of the applied force. The most used classification of pelvic ring injuries is the one from Young and Burgess using AP pelvic radiographs. Some pelvic injuries can

FIGURE 11

Denis-three column spinal stability concept. The spine can be longitudinally divided into three columns: anterior, middle, and posterior. Spinal stability is dependent on at least two intact columns. When two of the three columns are disrupted, abnormal segmental motion is allowed, i.e. instability is present.

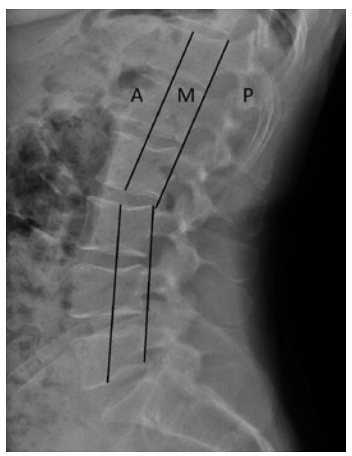


FIGURE 12

Stable fracture of L1. Discrete collapse of the upper L1 vertebral plate without involvement of the posterior wall or posterior elements. This means that there has been no spinal cord damage.

be treated without surgery, for instance if the pubic symphysis gap is less than 2.5cm. Open reduction and internal fixation (ORIF) is preferred for definitive management of unstable fractures.

The same applies to spinal fractures. The most used classification of spinal fractures is from Denis (Figure 11). Other classifications have been established such as the Thoracolumbar Injury Classification and Severity Scale (TLICS) which try to facilitate clinical decision making, taking into account imaging findings, such as injury morphology and integrity of the posterior ligamentous vertebral complex, as well as the patient's neurological status.

Minor fractures or those with column stability are treated without surgery using a spinal orthotic vest or brace to prevent rotational movement and bending (Figure 12). The goals of operative treatment are decompression of the spinal cord and stabilisation of the disrupted vertebral column (Figure 13).

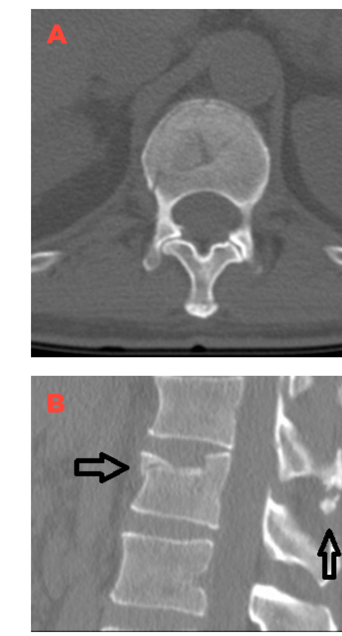
The outcome of spinal and pelvic fractures depends on the severity of the fracture pattern and associated injuries. If the fractures are stable, patients soon will be pain and morbidity free and early stabilisation of unstable fractures has also demonstrated improved outcomes.

FINAL MESSAGE

We hope that neither you nor your loved ones will ever have to visit the hospital emergency room due to spinal or pelvic trauma. If you do, you can be at ease: the radiologists will detect if there is a fracture, and will include you in the decision making process with the rest of the medical team. Although radiologists continue to work 'in the dark', we are there night and day to care not only for your spine and pelvis but for your entire anatomical integrity. Although the technological advances are crucial, the human factor – the radiologist – is fundamental to detect not only what and where the problem is but also to establish its relevance. Your radiologist, not always in the dark, is watching after you

FIGURE 13

Chance's fracture. This fracture is also called 'safety belt fracture' and is an unstable fracture. In this case, the L1 vertebral body is wedged, and there is also a fracture of the spinous process. Two columns are affected, being an example of an instable fracture.



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12

DIAGNOSIS OF UPPER LIMB TRAUMA

RADIOGRAPHS ARE HERE TO STAY IN THE DIAGNOSIS OF UPPER LIMB TRAUMA

BY **PHILIPPE PEETRONS**

RADIOGRAPHY

Radiographs still represent the basis of emergency imaging of upper limb injuries. They are easily and quickly obtained and evidence almost all bone injuries correctly except a few. Orthogonal biplane projections show precisely the respective position of bone fragments. Anterior-posterior and lateral projections are standard in assessing bone displacement that eventually require orthopaedic or surgical reduction, using either external or internal fixation. Isolated or simultaneous soft tissue lesions are better investigated with ultrasound.

X-ray equipment and ultrasound are available in most hospitals in the emergency department, allowing for a quick and secure diagnosis without patient transport and loss of time. Major bones that become involved in upper limb injuries are the humerus, which is part of the shoulder, the radius, which is part of the elbow, and the wrist. Aside from x-ray and ultrasound, computed tomography (CT) is also used, but in the emergency situation, there is no need for MRI.

Fractures of the neck of the humerus

Fractures of the neck of the humerus are common after a direct fall onto the shoulder. They are easily recognised on x-rays, but the establishment of the grade of severity of the fracture may require further investigation by CT for selection of the optimal treatment option (Figure 1). Gleno-humeral dislocations are anterior-inferior in 80% of the cases or otherwise posterior-superior. Orthogonal x-ray projections are usually sufficient for diagnosis and treatment orientation (Figure 2). Associated fractures, a Bankart lesion of the glenoid rim or the glenoid labrum or a Hill-Sachs impaction fracture of the greater tuberosity of the humeral head are seen after fracture reduction on radiographs (Figure 3). CT might be indicated for detailed investigation of the bone injury and arthro-magnetic resonance (MR) or arthro-CT for investigating the cartilage, but these examinations can be postponed and obtained after reduction of the dislocation. Acromio-clavicular dislocation is also seen on plain x-rays and evidences an elevation of the clavicle due to the pulling effect of the clavicle upwards by the trapezius muscle (Figure 4).

Dislocation of the elbow

Dislocation of the elbow mainly occurs following a fall onto the extended wrist in forced pronation movement and is a major emergency situation, because of a potential involvement of injury of the ulnar nerve which is closely located to the bone surface. Formation of bone fractures is frequent because the elbow is a stable and resistant joint, difficult to dislocate. Usually at least two bones are fractured, the ulnar coronoid process and the radius. Radiographs clearly show the different

FIGURE 1

Fracture of the neck of the humerus: (A) radiograph obtained in an anterior-posterior projection evidences the fracture (arrow); (B) CT gives a more detailed representation of the impaction of the humeral diaphysis (*) in the humeral head: total shoulder replacement was adopted as treatment option because of high risk of late necrosis of the humeral head.

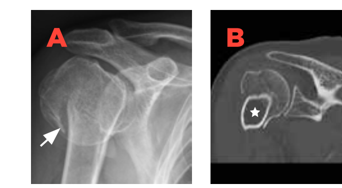


FIGURE 2

Anterior-inferior dislocation of the gleno-humeral joint: (A) radiograph in an anterior-posterior projection shows the inferiorly displaced humerus (arrow); (B) lateral projection shows the anteriorly displaced humerus (arrow).

FIGURE 3

Same patient as in Figure 2 after orthopaedic reduction of the dislocation. Notice re-established normal anatomical relationship between the glenoid and the labrum. Notice also the abnormal contour of the greater tuberosity of the humeral head due to an impaction Hill-Sachs fracture.

FIGURE 5

Dislocation of the elbow joint. Diagnosis is obvious on radiograph in a lateral projection. However injuries of the ulna and radius are difficult to evaluate precisely due to bone superimposition.

FIGURE 7

Ultrasound of the ulnar nerve evidences a 'mass' on the course of the nerve at the level of the elbow after reduction of a 'terrible triad' (see Figure 6). This mass is due to nerve (arrow) interruption: neuroma.

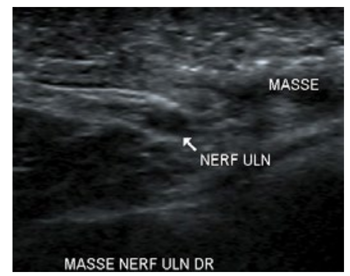
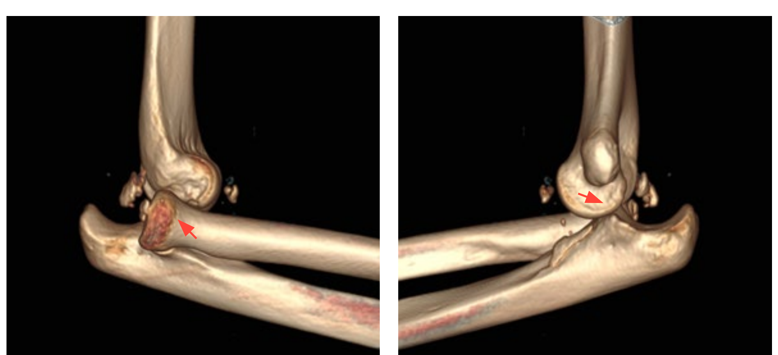


FIGURE 4

Acromio-clavicular joint dislocation. Elevation of the clavicle laterally (arrow) is caused by action of trapezius muscle on the clavicle.

FIGURE 6

Dislocation of the elbow: CT 3D-reconstruction. (A) The lateral volume-rendered view better evidences impaction of the head of the radius on the capitellum of the humerus (arrow). (B) The medial volume-rendered view better shows the displaced fracture of the coronoid process of the ulna (arrow). These three injuries, associating elbow dislocation, radial and ulnar fractures, are called the 'terrible triad' and are best assessed by CT.



fractures in this situation, as well as posterior dislocation of the forearm (Figure 5). Results of orthopaedic reduction of the fracture are also regularly assessed radiographically. In these cases, CT is able to deliver more information on bone lesions (Figure 6) and ultrasound investigates the vascular and nerve damage best (Figure 7). Elbow fractures are sometimes difficult to assess. When the humerus is involved, the diagnosis is relatively easy because displaced fragments of the fracture are easily recognised due to the thinness of the humeral bone (Figure 8). Elbow radius fractures may be less obvious because of their subtle radiographic appearance, requiring additional projections. When a radius head fracture is suspected, multiple projections of the elbow, two orthogonal views and obliques are requested. The presence of fluid in the joint following trauma is a reliable indicator of an underlying fracture. To diagnose joint effusions, surrounding soft tissue must be carefully examined on lateral projection; these show as a proximal displacement of the anterior fat pad by the fluid. Such peri-articular fat displacement is also well seen by ultrasound (Figure 9).

Forearm and wrist fractures

Forearm and wrist fractures are regularly seen without difficulty on x-rays. The degree of displacement of the fracture, sometimes needing surgical treatment, can be measured on the lateral and more rarely on anterior-posterior projection (Figure 10). The proximal radial epiphysis will be displaced posteriorly when the

FIGURE 8

Fracture of the distal humerus: (A) radiograph in a lateral projection shows a distal fracture of the humerus. Displaced fragments are obvious (arrows). (B) CT slices reformatted in a coronal plane shows a fracture of the distal humerus involving the lateral epicondyle (arrow).

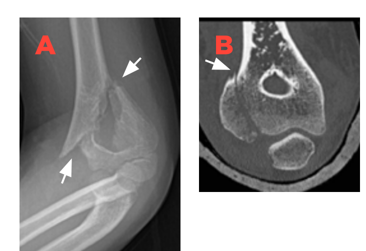
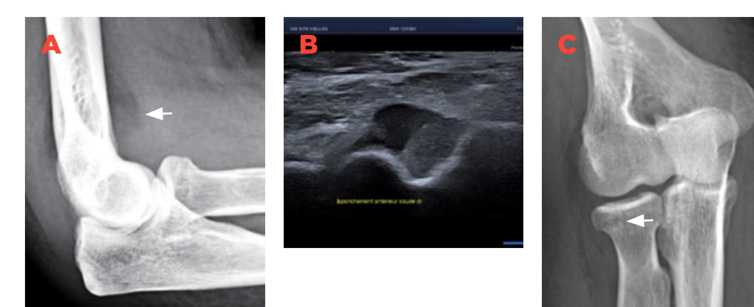


FIGURE 9

Subtle fracture of the radial head: (A) radiograph in a lateral projection shows proximal displacement of the anterior fat pad (grey zone in front of the distal humerus, arrow) caused by anterior joint effusion. (B) Ultrasound confirms the anteriorly located effusion (anechoic – black) which displaces the anterior fat pad (hyperechoic – white). (C) Radiograph in an anterior-posterior projection shows at second look a thin non-displaced vertical fracture line in the head of the radius (arrow).



impact has occurred with the wrist in extension, which is the most common mechanism, and anteriorly when the wrist was in flexion (Figure 11). Lesions of the forearm in children are often compression injuries affecting only one side of the cortical bone and therefore more difficult to see (Figure 12). Lesions of the carpal bones can also be difficult to assess on plain x-rays because of the difficulty of clearly identifying the margins of the bones. Multiple projections can be useful to see these fractures. Scaphoid fractures (Figure 13) are problematic lesions to diagnose correctly because of poor vascularisation of the proximal part of the scaphoid bone. If such a fracture is missed, the risk of proximal scaphoid necrosis is high. This major complication leads regularly to severe osteoarthritis of the wrist, the so-called 'scaphoid non-union advanced collapse (SNAC)' (Figure 14). Most of the other carpal bone fractures, the triquetrum, the pisiform, the capitate and the hamate need further evaluation by CT (Figure 15). Lesions of wrist ligaments are also important to recognise on initial orthogonal radiographic projections. Despite x-rays not being able to evidence soft tissue components precisely, rupture of intercarpal ligaments, mainly the scapholunate and the lunotriquetrum, leads to intercarpal bone instability which also may result in osteoarthritis of the wrist. One of these lesions is called 'scapholunate advanced collapse (SLAC)' (Figure 16). Retrolunate or anterior dislocation of the lunate are important diagnoses to identify

FIGURE 10

Open displaced fracture of the distal forearm. (A) Radiograph in an anterior-posterior projection evidences displacement (arrow). (B) Lateral projection confirms major displacement of the segments of fractured radius (arrow). (C) The open fracture was treated by orthopaedic reduction and external hardware.

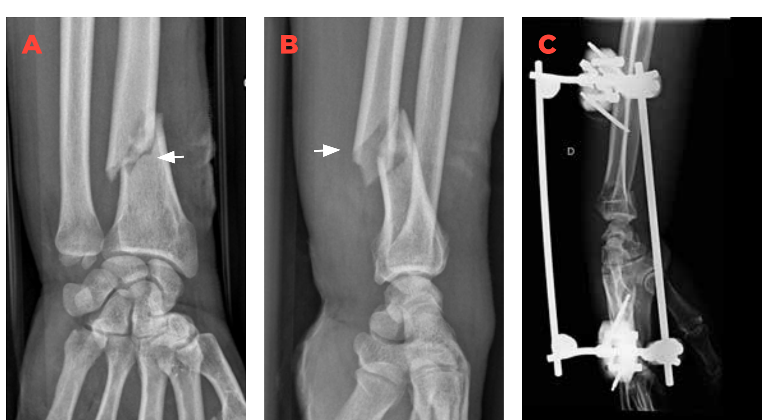


FIGURE 11

Anterior displacement of the distal epiphysis of the radius in a wrist fracture on anterior-posterior (A) and lateral (B) projection (arrows).

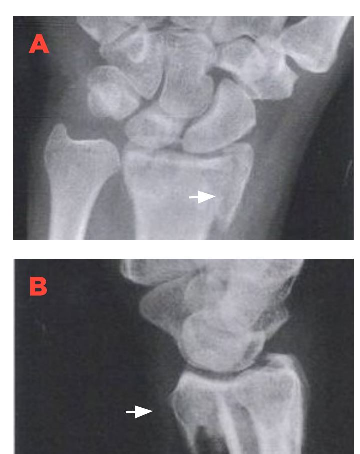


FIGURE 12

Fracture of the distal radius in a child in anterior-posterior (A) and lateral (B) projection (arrows). The unilateral incomplete fracture is best seen in lateral projection.

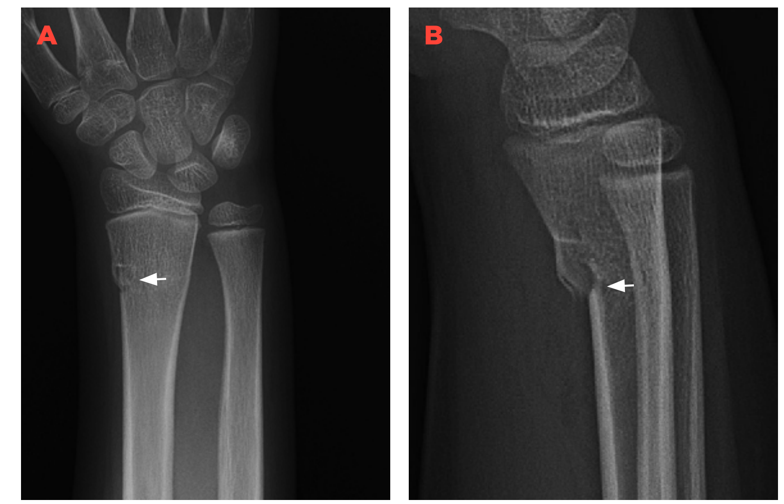


FIGURE 13

Scaphoid fracture: coronal CT reformatted view in a coronal plane of a scaphoid fracture (arrow).

FIGURE 14

Late complications of undiagnosed or undertreated scaphoid fractures. (A) Osteonecrosis of the proximal scaphoid bone which appears denser than the other carpal bones on CT view reformatted in a coronal plane (*). (B) 'SNAC' lesion (see text) with severe osteoarthritic degeneration of the wrist after a non-united fracture of the scaphoid (arrow).

FIGURE 15

CT slice reconstructed in a sagittal plane shows a vertical displaced fracture of the base of the hook of the hamate with anterior displacement (arrow).

FIGURE 16

Radiograph in an anterior-posterior projection shows a large gap (*) between the scaphoid and the lunate carpal bone with osteoarthritic changes in the wrist illustrating a 'SLAC' lesion (see text) which results from injury of the scapho-lunate ligaments.

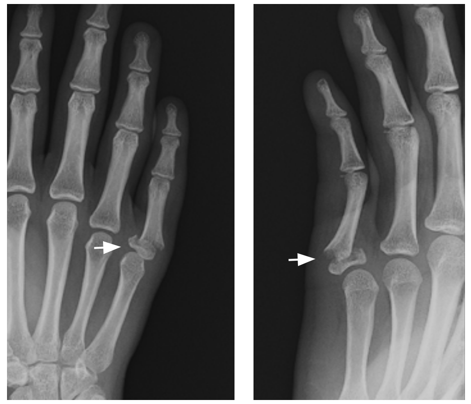


FIGURE 17

Displaced fracture of the base of the proximal phalanx of the little finger on radiograph obtained in an anterior-posterior (A) and lateral (B) projection (arrows).

FIGURE 18

Radiograph of a non-displaced oblique fracture of a proximal phalanx (arrow).

because of frequent progression to wrist osteoarthritis. The lateral view best confirms these dislocations. Metacarpal and finger fractures are easy to diagnose radiographically (Figures 17 and 18); all relevant information for treatment options and planning is obtained.

COMPUTED TOMOGRAPHY

The CT modality offers thin contiguous axial slices and the ability of three-dimensional reconstruction and volume reformatting. CT is indicated when diagnosis is doubtful on radiographs, or when clinical suspicion is high despite apparently normal radiographic appearance or when radiographic information obtained is incomplete. The presence of a cast does not degrade image quality on CT. The main indication for CT is the diagnosis of a scaphoid fracture and late complications as well as non-union, pseudo-arthrosis and proximal scaphoid necrosis. Other carpal bone fractures are best seen on volume acquisition and multiplanar reconstructions. In the shoulder, CT scan is able to see to a better degree impaction of the humeral diaphysis in the humeral head. The degree of impaction and the rotation of the humeral head are causes of humeral head necrosis. In the most severe injuries, total replacement of the shoulder might

FIGURE 19

CT view reformatted in a sagittal plane shows a posterior displacement of the scapula fracture. The spine of the scapula (inferior part) is displaced posteriorly from the acromion and coracoid processes (arrow).

FIGURE 20

Coronal (A) and sagittal (B) views of the rotator cuff in ultrasound. Notice the anechoic (black) zone at the end of the supraspinatus (A) and in the middle of the rotator cuff (B) corresponding to an acute full thickness rupture or the supraspinatus tendon.

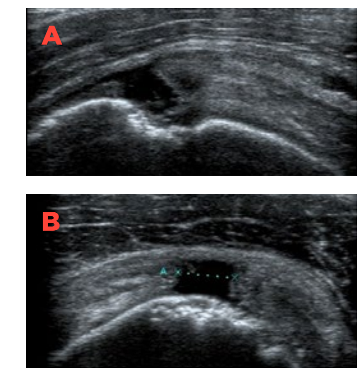


FIGURE 21

Ultrasound of a rupture of the ulnar collateral ligament in the right elbow. This ligament can be torn in forced valgus stress of the right elbow: the movement of throwing in baseball pitchers for example. In this image the proximal, humeral insertion is thickened and there is an effusion (anechoic) in the deep part of the ligament.

become indicated instead of more conservative treatment. Scapular injuries are also best seen and their mechanism understood with CT. The scapula is a thin bone and fracture may progress to other parts of the scapula. These rare but significant lesions require CT for complete diagnosis (Figure 19). Elbow dislocations and coronoid and radius fractures are best depicted in detail on CT.

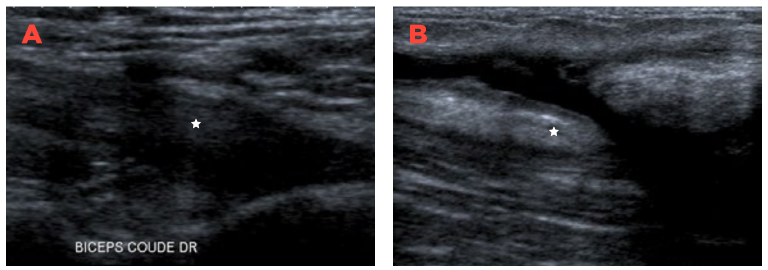
ULTRASOUND

The basic role of ultrasound does not include assessing bone fractures. The main role of ultrasound is to disclose soft tissue injuries, which may be closed or open. In closed injuries, ligaments and tendons are mainly involved. In the shoulder, acute full-thickness tears of the rotator cuff represent the most common situation (Figure 20). Minute cortical and undisplaced fractures can, however, be missed on x-rays, but confirmed with ultrasound. The advantage is that ultrasound examination is guided by elective pain revealed by placement of the probe at the suspected fracture site which is then scanned in detail by the operator.

In the elbow, lesions of the ulnar collateral ligament (Figure 21) and avulsion of the olecranon

FIGURE 22

Ultrasound longitudinal images of the anterior elbow. Rupture of the distal part of the tendon biceps brachii (A) and full thickness tear of the same tendon in a more proximal location (B). In both images, the torn tendon (*) is floating in anechoic (black) fluid, representing haemorrhage and debris of the tendon.



by the triceps muscle are uncommon but, when present, easily recognised by ultrasound. Full-thickness tear of the distal biceps tendon is a common clinical emergency situation that has to be identified to avoid muscular functional impotence if not surgically treated (Figure 22).

Significant muscular injuries are far less frequent in the upper limb than in the lower limb.

In open wounds, ultrasound is also often used to assess the involvement of tendinous or nerve lesions. Tendon tears (Figure 23) and nerve interruptions are best seen because of high spatial resolution which is able to detect millimetric abnormalities, such as foreign bodies (Figure 24).

FIGURE 23

Ultrasound longitudinal image of a flexor digitorum tendon in the palm of the hand after a sharp glass wound. Notice the anechoic zone within the tendon representing the cutting lesion of both superficial and deep flexors.

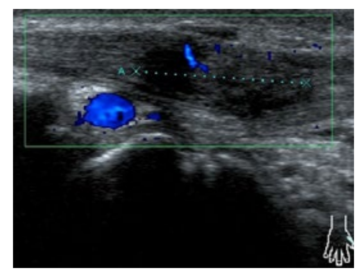
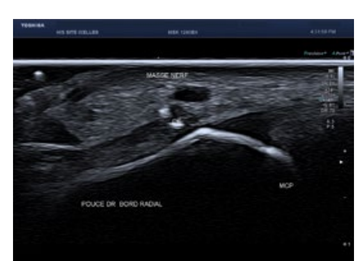


FIGURE 24

Ultrasound longitudinal image of a finger near the proximal interphalangeal joint. The little mass effect on top of the image represents the nerve injury (1.7mm in diameter), cut by several little pieces of glass. The two little hyperechoic (white) dots represent the remaining glass splinters in the finger (0.7mm of length).



DR. PHILIPPE PEETRONS

has been head of the Medical Imaging Department at IRIS Sud Hospitals, one of the largest public hospitals in Brussels, Belgium, since 2000.

Dr. Peetrons has held different positions: Chairman of the Belgian Society of Radiology and Chairman of the Section Ultrasonography of the Belgian Society of Radiology. He is currently professor in medical imaging at the Free University of Brussels. He is a member of the European Society of Musculoskeletal Radiology and board trustee of the Ultrasound Subcommittee of the society, member of the International Skeletal Society, and member of reviewing committees in ultrasound and radiology journals.

Dr. Peetrons is the past-president of the 12th, 16th and 26th Annual Meetings of the Musculoskeletal Ultrasound Society. He has been a permanent member of the faculty of this society since 1997. He is a board trustee of the French Society of Musculoskeletal Radiology. He has authored more than fifty papers listed on PubMed, and co-authored ten books on ultrasound. He is the author of Atlas d'Echographie du systeme locomoteur, *one of the reference books on musculoskeletal ultrasound in French. His name is now associated with a grading system of muscular injuries using ultrasound and MRI, which is widely used in sports medicine literature. Dr. Peetrons gives lectures on musculoskeletal ultrasound abroad and received the Arthur Bloomfield Award for Excellence in Continuing Medical Education in 2006, awarded by the American Academy of Continuing Medical Education (AACME).*

13

DIAGNOSING ACUTE INJURIES OF THE LOWER LIMBS

THE CONTRIBUTIONS OF ALL CURRENT CROSS-SECTION IMAGING MODALITIES TO DIAGNOSING ACUTE INJURIES OF THE LOWER LIMBS

BY **GUNNAR ÅSTRÖM**

Rapidly performed imaging techniques are mandatory for depicting life-threatening injuries in the brain, chest and abdomen in the emergency situation, for example after high-velocity, high-fall, gunfire or blasting attacks.

Less known to the public is that major injuries of the lower limbs also have the potential to threaten life. This chapter covers such conditions and how different radiologic methods can be used in the emergency department or in close collaboration with it. Furthermore, the impact of imaging on the management of typical fractures and soft tissue injuries will be presented.

Typical sport injuries, however, will not be covered. The last paragraphs describe subtle findings that should not be missed on primary imaging after a patient recovers from an emergency.

PATIENT EVALUATION AND MANAGEMENT IN THE EMERGENCY ROOM

Lower-limb patients handled by an emergency department can be categorised into two groups: patients suffering from emergency multi-trauma, and patients seeking medical care for another type of less violent injury, for example after a minor fall or most sport injuries. Multi-trauma patients need to be evaluated and treated immediately in the emergency department. The other patients are evaluated, managed and then sent to the correct treating department, for example the orthopaedic department, to radiology for the requested imaging (either radiographs, computed tomography (CT), magnetic resonance imaging (MRI), ultrasound (US), or even sent home to wait for a planned imaging.

For patients with potentially life-threatening conditions, oxygenation and circulation of the head and body are the most important factors for survival. Access to the femoral artery and vein are important to compensate the traumatised body with fluids including electrolytes and medication intravenously and to measure coagulation, lactate and other vital parameters such as gases, oxygen and arterial blood pressure. The necessary venous and arterial accesses are mostly guided by palpation. However, in some cases, the use of ultrasound-guidance with or without Doppler techniques might facilitate these procedures, especially in children. In cases with difficulties regarding venous access, the use of intraosseous injections in a non-fractured extremity might be favourable. The three most common sites for intraosseous access are the proximal tibia medial to the patellar ligament, the distal medial tibia and the lateral proximal humerus, the latter is preferred because it permits higher flow volume. The intraosseous needle can for the most part be placed, with good anatomical knowledge, without image guidance. In a few cases, the needle has to be checked before the infusion by radiographs or CT. Ultrasound with Doppler modality might be used for the measurement of circulation in the inferior extremity and for the visualisation of deep venous thrombosis or for the depiction of degrees of nerve injury early and throughout management in the emergency department or in the operating theatre. It might also be helpful to detect gas from infections, especially if the gas is in liquor. Other early treatments regarding the lower extremities can, for example, be closed reduction and immobilisation of badly dislocated fractures and major joint dislocations of the knee and ankle (Figures 1 and 2) with a danger of skin, arterial or nerve injuries. These closed reductions can most often be performed without imaging. However, imaging can be performed if enough time is available and the emergency room has equipment for radiographs or fluoroscopy.

Afterward the critically injured patient is transported for an acute trauma-CT examination, which nowadays is performed with multi-detector computed tomography (MDCT) equipment. It is favourable if this

FIGURE 1

Young male with motorbike-accident in the forest. Open left-sided femoral fracture, which was immediately close reducted and placed in a femoral traction device (Hare splint). Thereafter, a MDCT was performed and the VRT-images (volume rendering technique) showed posterolateral dislocation of the distal fragment and multiple small bone fragments.

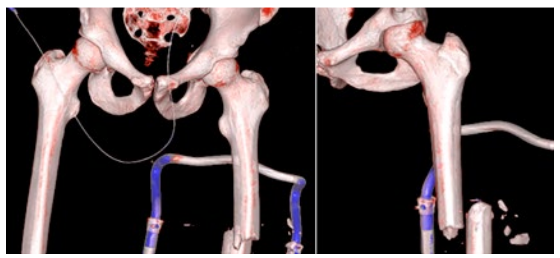
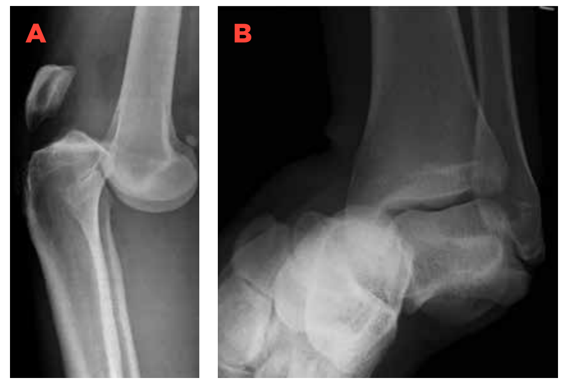


FIGURE 2

(A) Lateral radiograph shows an anterior dislocation of the tibia to the femur. (B) Anteroposterior radiograph demonstrates a medial dislocation of the foot in the subtalar joints.



equipment is located in the emergency department or in the surgery ward. In most departments protocol includes imaging from head to hip. This means that a request for imaging the whole or parts of the lower extremities should be submitted before the examination. Now, some equipment allows imaging from head to foot even in the arterial phase after intravenous injection of iodinated contrast agent. The latter is very beneficial if arterial injuries are suspected both in the torso and in the lower leg.

TRAUMA-CT WITH MULTI-DETECTOR COMPUTER TOMOGRAPHY (MDCT)

For a multi-trauma emergency patient, rapid transportation to a well-equipped trauma unit is mandatory for detection of injuries and survival. MDCT with sub-millimetre isotropic slices with reconstructions in three planes is the state-of-the-art for these emergency patients. In many institutions, a 'trauma-CT' only covers head to hips. Therefore, when indicated, radiographs have either not been performed or have been negative as an examination covering the entire or at least a part of the lower extremities has to be requested separately. The CT scout or topogram-planning view for MDCT can give important information rapidly (Figure 3). A whole trauma-CT examination (topogram, planning procedures and all diagnostic scans) including the lower extremities can be done in less than 10 minutes. If arterial injuries are suspected in a lower extremity without any suspected arterial injuries in the torso, it might be beneficial to perform the lower extremity imaging as

FIGURE 3

(A) Topogram or planning view can sometimes rapidly give important information as in this shooting case with bilateral comminuted femoral fractures (arrows) and multiple bullets and bullet fragments. (B) CT-angiography with thick MIP images (maximum intensity projection) reveals no pathological changes of the opacified superficial femoral arteries. (C) Axial scan showing the arteries (arrowheads), the strike artefacts from one bullet, and multiple bone fragments. There is also air in the left lower thigh (black areas) in the soft tissue from the penetration violence.

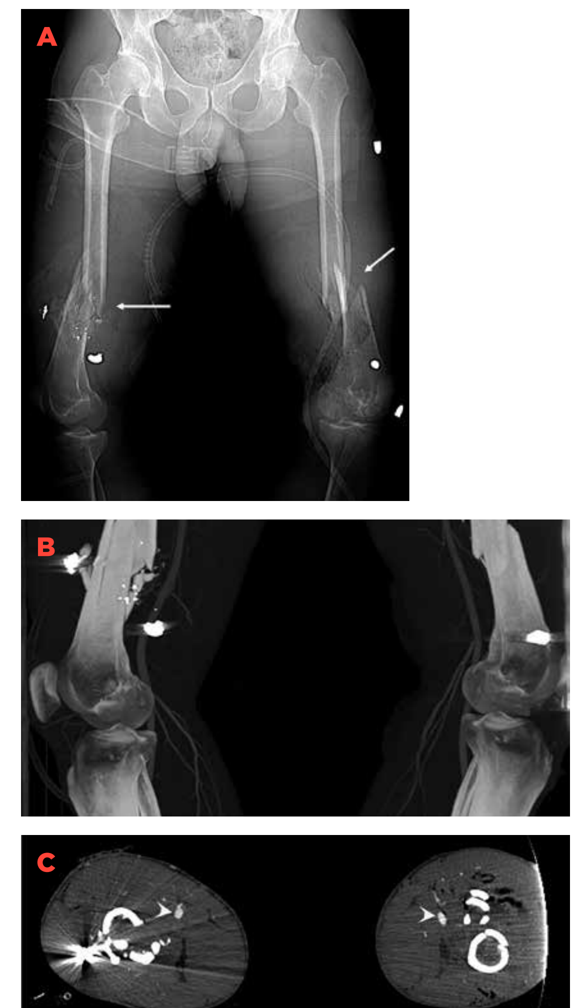


FIGURE 4

Male shot in the right thigh. (A) Coronal (frontal) MDTC-angiography reconstruction demonstrates that the right thigh is much more voluminous than the left one. The bullet (open arrow) causes streak artefacts and superior to the bullet, just medial to the femur, a pseudoaneurysm is seen (white arrowhead) together with an active extravasation (white arrow) from the deep femoral artery. The pseudoaneurysm (arrowhead) and the extravasation (arrows) can also be seen on the DSA images before endovascular treatment (B+C). (D) Post-embolisation DSA image (D) shows the coils filling the pseudoaneurysm (black arrow) and the artery branch (black arrowheads). The bleeding has successfully been stopped. Black asterisk indicates the bullet (B–D).

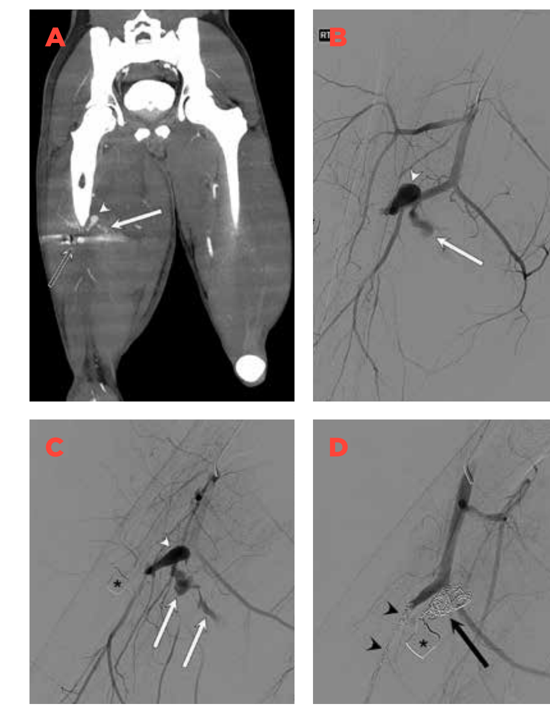
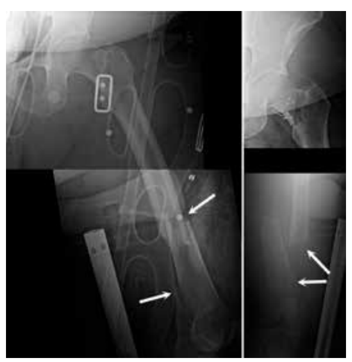


FIGURE 5

Dashboard injury. Plain radiographs in the emergency setting occasionally suffer from non-optimal quality but they are mostly sufficient. In this high-velocity accident the femoral diaphysis is fractured at two levels (arrows). At the proximal level the distal fragment is dislocated and rotated. The upper right image demonstrates a sagittal fracture in the femoral neck (open arrows), which is a result of the force the trauma caused along the femur.



the first step after the injection of contrast agent to detect arterial bleeding. In the case of injury only to the lower extremity, multiphasic imaging might increase the possibility of detecting venous haemorrhage (just as one example).

It is important to directly define the location of arterial bleeding, huge muscle or fracture bleeding, muscle macerations and unstable major fractures as well as joint dislocations and subluxations. Subsequently all other obvious injuries, i.e. other fractures and soft tissue swellings indicating a ligamentous injury or an infection, must be found for the orthopaedic surgeon to plan when and in which order the findings should be handled.

When an acute normal-ranged trauma MDCT has been prepared without extra CT imaging of the lower leg, it is beneficial to continue when needed with plain films of the symptomatic parts of the lower limbs. However, quite often the orthopaedic surgeon requests MDCT, despite the previously obtained plain films, for a pre-surgical understanding of, for example, a comminuted fracture of the proximal tibia, the ankle or the calcaneus. In cases of low-energy trauma, CT could be focused on the symptomatic part of the extremity. When the trauma-CT is ready, the patient can be transported elsewhere or back to the emergency department. The CT, CT-angiography or plain films of the lower extremity allow surgical or interventional radiology management of fractures and soft tissue injuries. Digital subtraction angiography (DSA) and subsequent endovascular treatment or surgery of an injured artery might also be needed (Figure 4).

RADIOGRAPHS

Radiography is still the most used modality on acute lower extremity bone fractures, joint dislocations and their follow-up. Standard anterior and lateral views are usually diagnostically adequate for assessment of lower extremity bone and joint trauma. In the knee, ankle, and foot, however, overlapping bones make image interpretation challenging. Therefore, additional views are needed. In general, diagnosis of fractures can be performed quickly using radiographs and it provides relevant information as to whether adjacent joints are involved and how the fracture fragments are positioned. In multi-trauma patients and in severe comminuted fractures the quality of the radiographs may suffer from inappropriate positioning of the extremity or joint due to pain and from soft-tissue swelling (Figure 5) despite their still being efficient. Furthermore, some fractures might be occult, for example some neck or intertrochanteric fractures of the hip. Thus, additional imaging with stress views or other modalities, such as MRI (Figure 6), could be essential. More recently, there are also CT scanners that allow examinations from the knee to the foot in a standing weight-bearing position. Such an examination might increase subluxations in, for example, a Lisfranc injury in the tarsometatarsal joints of the foot (Figure 7).

MAGNETIC RESONANCE IMAGING

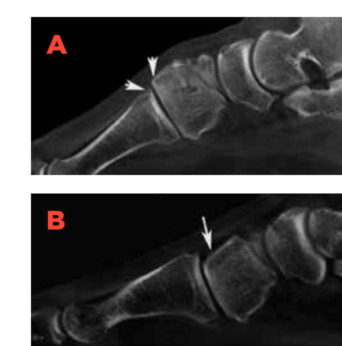
The use of MRI in orthopaedic trauma has been limited by cost and availability. In a review article published in 2009, 3% of emergency departments in the US had an MRI unit. Today, this percentage is probably higher, and almost all

FIGURE 6

Occult hip fracture: Low-energy trauma and pain in the left hip. Anteroposterior view radiograph (left) shows no fracture, however, an MRI examination with water sensitive sequence with fat saturation (right) reveals bone marrow oedema and a cervical neck fracture (arrowheads).

FIGURE 7

Weight-bearing CT shows an unstable Lisfranc's joint at the first tarsometatarsal joint. (A) Standing position in rest shows a normal joint alignment (arrowheads), however in weight-bearing standing position (B) an obvious abnormal depression of the medial cuneiform is seen (arrow).



hospitals probably have at least one. According to the article, institutions used MRI on average 23 times in the years 2000–2005 (1% of all images taken) for emergency examinations of the lower extremities. The utilisation of MRI in the emergency setting since then, however, has been on the rise. Nevertheless, the problem with availability gives the clinician a headache when MRI might be helpful for the management decision – to transfer the patient to another facility or wait for a scanner to become available.

Claustrophobia, magnetic metal in the body, e.g. some types of outmoded orthopaedic hardware, residues from blasting attacks, and heart pacemakers or other sensitive devices as well as the relatively long scanning time and the narrow gantry have also been limiting factors. Unconscious patients that cannot inform of implants or devices have to be considered at risk. For these reasons this method is not often used for the lower extremities in acute emergency situations.

However, aside from life-threatening injuries to the patient, MRI is the best method to evaluate soft tissue and joint derangements such as tendon and ligamentous tears as well as muscle injuries. MRI can, without adding contrast agent, also demonstrate the development of venous thrombosis, however, this could also easily be seen with the cheaper and much more available ultrasound. High-field MR scanners with a magnetic field strength of 1.5 to 3.0 tesla, and features such as multi-channel coil design with parallel imaging, offer excellent image quality in reasonable time: nowadays, for example, five minute protocols for the knee. An open configuration of the gantry offers better access to patients with multiple trauma, however, these scanners are not available in all institutions and they have poorer spatial resolution and longer scanning times.

In a trauma patient it is favourable to start with a large field-of-view (FOV), and then focus on the region of interest. The radiologist on duty can tailor the examination and stop the imaging as soon as enough information for the patient's management is acquired. Common spin echo or fast-spin echo sequences are mostly used in musculoskeletal trauma imaging. Water sensitive sequences with different fat suppression techniques are important in trauma-MRI since the injuries produce oedema and bleeding. When large FOVs are used a STIR sequence (fat suppression) is preferable to a T2-weighted sequence with fat saturation, since it is less sensitive to magnetic field inhomogeneity and provides a more even fat suppression. Fracture lines, on the other hand, are better seen on T1 or T2-weighted sequences.

ULTRASOUND

Ultrasound (US) today constitutes a fast real-time method without ionising radiation and it has superior spatial resolution compared to MRI and MDCT, however, ultrasound is dependent on the skill of the operator, the acoustic window, the depth under the skin and frequency of the transducer. In the acute emergency room situation, ultrasound can be helpful in finding and following a vascular injury or deep vein thrombosis by means of Doppler-techniques or it can be helpful in demonstrating that the thrombotic vein is not compressible, or it can be used to find

nerve injury. It can also be used as a guide when puncturing the femoral artery and vein, especially in children. In non-acute settings, ultrasound is also used to visualise and sometimes to guide drainage of fluid collection. In an acutely swollen leg with blistering and redness, the presence of ultrasonographically demonstrated subcutaneous thickening as well as the presence of gas shadowing and fascial fluid is an easy initial bedside test to increase the suspicion of necrotising fasciitis, thereby initiating an MDCT examination for disease extent and therapy. Ultrasound is also an excellent method for demonstrating superficial ligamentous and tendon injuries, especially the patellar and Achilles tendons.

TYPES OF POSTTRAUMATIC INJURIES DEMONSTRATED BY IMAGING

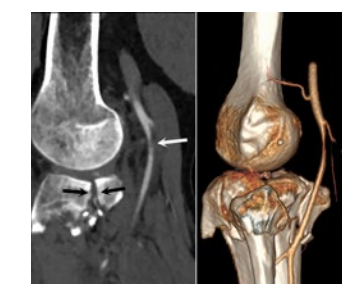
Haemodynamic instability and arterial injury

Haemodynamic instability is often caused by blood loss. A bleed is typically of venous origin or from fracture surfaces. However, penetrating injuries form bullets or knives can include an artery and dissect or transect it causing arterial bleeding (Figure 4). Physical and sonographic examinations after extremity trauma have been found to be fairly reliably in detecting occult arterial lesions.

A posterior dislocation of tibia compared to the femur or a posterior dislocation of a tibial plateau fracture can cause compression or dissection of the popliteal artery (Figure 8). The compression is often treated by means

FIGURE 8

Proximal tibia fractures sometimes cause injuries to the popliteal artery. The arrow in the sagittal reconstruction image (left) points to a segmental smooth narrowing of the opacified lumen. The VRT image (right) shows that the narrowing is true and not due to an overly thin slice on the reconstruction image. It is often difficult to distinguish between an arterial vasospasm and dissection as the cause of narrowing. An arterial vasospasm is mostly transient and a clinical follow-up can help in the diagnosis.



of an early reduction of the dislocation. Some years ago, these types of injuries indicated digital selective angiography (DSA) often followed by endovascular treatment.

Nowadays, with better MDCT scanners and protocols, the arteries are seen after injection of iodinated contrast agent and a diagnosing DSA is not needed. With bullet wounds, the use of a Vitamin E capsule at the bullet's entry point, and, when applicable, the exit wound, will help the interpretation.

Blunt trauma with muscle oedema and/or bleeding in the calf and foot compartment might rapidly lead to compartment syndrome. This can be detected clinically by manual palpation or by measurement of the compartmental muscle pressure by inserting a needle.

Nerve injury

Both MR and ultrasound serve quite well in experienced institutions with the clinical Sunderland criteria for nerve injuries, and both methods can depict a nerve transection or nerve neuroma. Neuroma formation is an expected finding as the nerve attempts to regenerate, which appears as hypoechoic enlargement on ultrasound (Figure 9) and enlarged high signal intensity fascicles on water-sensitive fat-supressed MR sequences (Figure 10). The common peroneal or fibular nerve is particularly vulnerable to trauma given its superficial location immediately adjacent to the proximal fibula, where fibula fracture may also produce nerve trauma.

With a relatively normal soft tissue window to the nerve, a nerve injury is seen well on ultrasound, even digital nerves. After a laceration, complete transection is characterised by nerve discontinuity and retraction, where the nerve endings will appear hypoechoic and enlarged. Partial-thickness lacerations do not show discontinuity or retraction, but can show hypoechoic neuroma formation. Similarly, crush injuries can cause the involved peripheral nerve to appear hypoechoic and enlarged. Transducer pressure over the neuroma can elicit symptoms, including phantom pain, which can indicate if a neuroma is indeed symptomatic. MRI is used in some major institutions on larger nerves and MR diffusion tensor tractography might play a future role. However, the role of MRI or US in the emergency setting with extensive soft tissue injuries before or during surgery is yet to be defined.

Necrotising fasciitis

Necrotising fasciitis, which can arise after trauma, is a severe rapidly progressing condition: within hours there can be often fatal soft-tissue infection and necrosis which mostly spread along the fascia planes with muscle and subcutaneous involvement. The agents are most commonly streptococcus or anaerobic bacteria. Treatment is intravenous antibiotics, selected according to the result of

FIGURE 9

Common peroneal nerve transection (partial): 12-year-old boy with laceration above the knee from glass. Ultrasound images along the long axis (A) and short axis (B) up to the common peroneal nerve proximal to the knee show hypoechoic enlargement (arrows) of the proximal common peroneal nerve representing neuroma formation. Note continuity with the normal-appearing more proximal common peroneal nerve (arrowheads), and normal adjacent tibial nerve (curved arrows). The common peroneal nerve was in continuity distal to the neuroma.

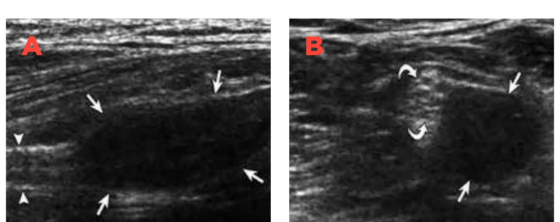


FIGURE 10

Sagittal (A) and axial (B) MR images (T2 SPAIR) of the ankle show a transected posterior tibial nerve. Arrows point to the thickened enlarged nerve (end-bulb neuroma) just above the level of the ankle joint. Note the increased signal intensity in the enlarged nerve fascicles of the neuroma. Arrowhead points to the absent nerve distal to the transection, where there is a small scar in continuity.

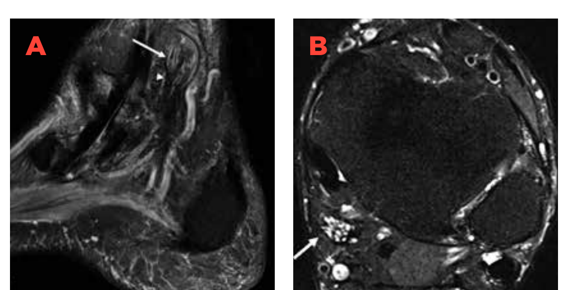


FIGURE 11

Patient with acute necrotising fasciitis in the left thigh after trauma. (A) Topogram (planning image): The thigh is enlarged and gas formations in the soft tissues (black areas) indicate the extent of the infection. The axial CT scans (B–D) were obtained after two days. In (B) an excessive gas-forming infection is seen at the fascia planes and deep in the muscles. In (C) and (D), note a dramatic reduction of the gas involvement seen after fasciotomies (asterisk), antibiotics and hyperbaric treatment.

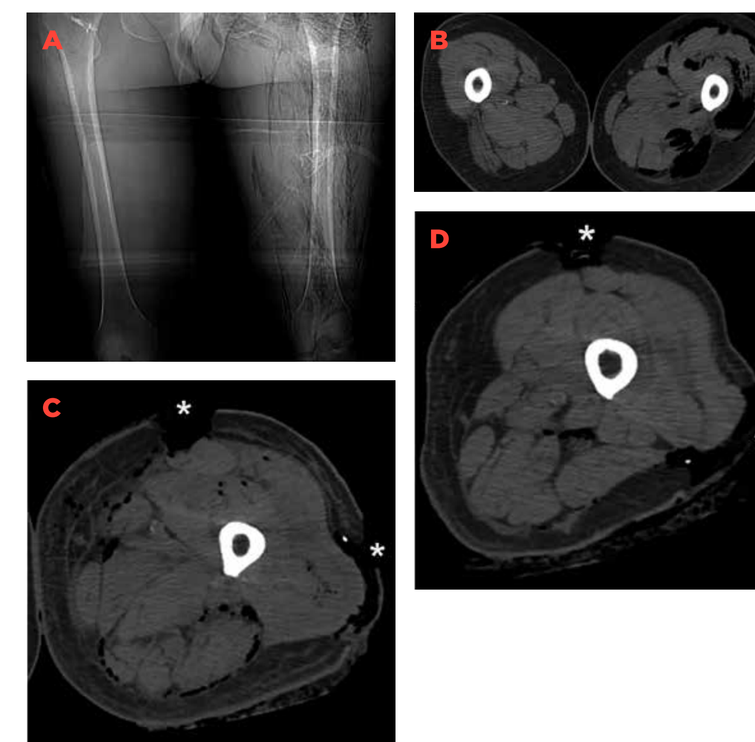
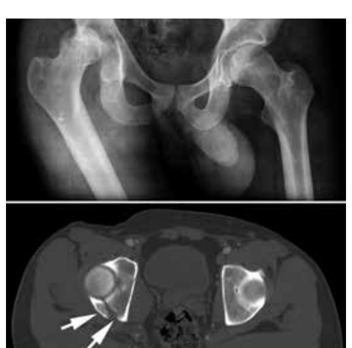


FIGURE 12

Gunshot fracturing the right distal femur. VRT image from an MDCT-angiography shows that the proximal tip (arrow) of the distal fragment is not in conflict with the superficial femoral artery.

FIGURE 13

Dashboard injury due to a high-velocity motor vehicle accident. Anteroposterior radiograph of the hips and pelvis depict a posterior luxation of the hip. The radiograph cannot visualise any acetabular fractures. The hip was open reducted at the emergency department. A subsequent MDCT scan demonstrates a sagittal fracture and bone fragment of the posterior acetabulum (arrows).



bacteriological tests on samples, and extensive surgery of necrotic tissue including fasciotomy 1–2 times a day often with controlling MDCT to depict any soft-tissue gas formation, which is very specific to the disease (Figure 11). Another complementary treatment, which is available at some hospitals, is hyperbaric oxygen therapy (HBOT). At Karolinska Hospital in Stockholm, 280 kPa x 2 is available. As far as imaging goes, ultrasound might see gas in the superficial tissue, which can give a rapid diagnosis, however it is difficult to define the extent of the disease. CT is preferred over MRI for gas detection but underestimates spread, while MRI is preferred for oedema although overestimates spread.

Major injuries of the hip and femur

Comminuted femoral fractures (Figures 1, 3, 5, 12) constitute a risk for circulation collapse if major bleeding is untreated. Early reposition of severely dislocated fractures and immobilisation of the fracture as early as possible is beneficial. A typical fracture in a motor vehicle crash is the dashboard injury. The bent knees are compressed to the dashboard with an axial load through the femora, which often causes a posterior luxation of the hip (Figure 13). It can be seen with (Figure 13) or without an acetabular fracture on the most inferior part of a normal-ranged MDCT. Also a sagittal femoral neck fracture can occur (Figure 5). This injury pattern can also include femoral fractures (Figure 5) and/or patellar fractures. Femoral fractures must be treated with nails or plates. MRI is recommended by the American College of Radiology (ACR) as the most appropriate test when hip fracture is suspected despite no indication from plain

FIGURE 14

The energy of the force needed for a fracture is less in a patient with a hip prosthesis. The fracture is mostly located at the lower level of the stem.

FIGURE 15

Female on bisphosphonate treatment with a minor fall. The radiograph to the left shows a subtle stress reaction (arrow) laterally in proximal diaphysis, which was not primarily reported. Lateral stress reactions/fractures are a known side effect of bisphosphonate treatment. One week later a typical atypical subtrochanteric femoral fracture occurred without any new trauma.

FIGURE 16

Proximal fracture of the tibia. Radiograph (A) shows two split fractures and a medial metaphyseal compression fracture. The orthopaedic surgeons suspected plateau compression and requested an MDCT. The frontal MDCT reconstruction (B) and the axial reconstruction (C) show the non-displaced split fractures and a small anterior compression. Orthopaedic surgeon treated with a plaster.

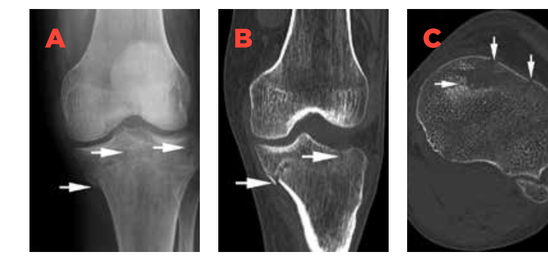


FIGURE 17

Anteroposterior radiograph (left) and coronal MR image demonstrate a Segond fracture with an avulsed lateral cortical fragment (arrows) just beneath the tibial plateau. The MR image also depicts lateral ligamentous injury, medial collateral ligament injury (arrowheads) and anterior cruciate ligament tear (curved arrow).

FIGURE 18

Lateral radiograph (A) shows an impaction in the lateral condyle (deep notch or sulcus sign) (arrow) and a suprapatellar effusion (curved arrows). The combination of the deep notch sign and effusion is highly indicative of an anterior cruciate tear. The mechanism is an impaction between anterior superior tibia and the condyle. Sagittal MR images some time later show the deep notch sign (arrow) (B) and the anterior cruciate tear (arrows) (C).

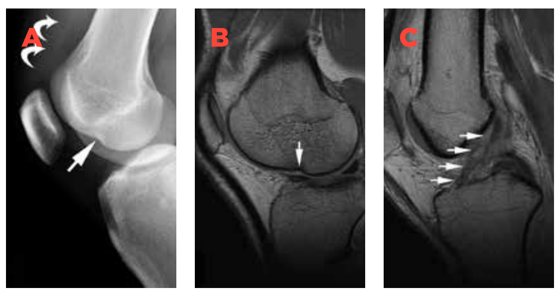


FIGURE 19

Sagittal (A) and axial (B) MDCT reconstructions of a knee with a Hoffa's fracture (arrows). This fracture occurs for example in a dashboard-like injury – the proximal tibia has been posteriorly forced in a flexed knee.

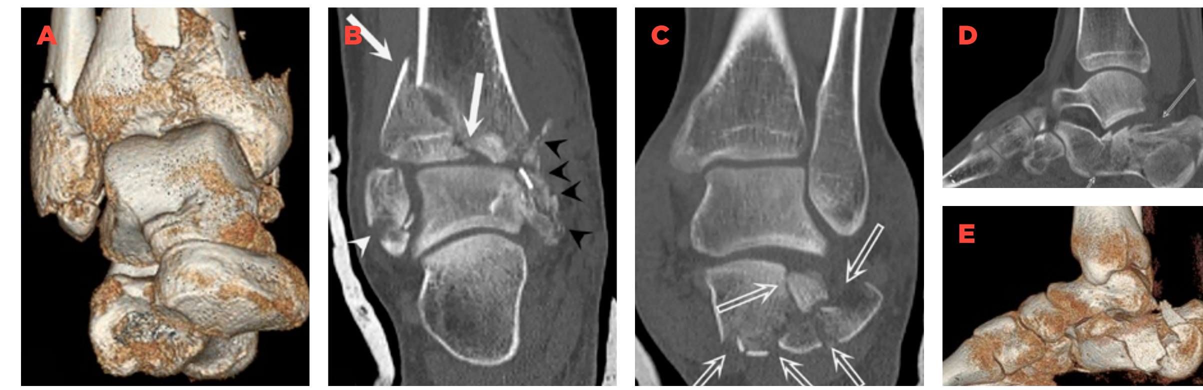
x-rays (Figure 6). Less impact force is needed to cause a fracture in patients with osteoporosis, hip prosthesis and in patients with atypical stress reactions due to, for example, bisphosphonate treatment (Figures 14, 15).

Injuries of the knee

Knee dislocations and fractures can also cause arterial injuries (Figures 2A and 8). Comminuted fractures of both sides of the joint with minor joint engagement can often be repaired based on radiographs with excellent long-term prognosis. Orthopaedic surgeons often require an MDCT with reconstructions when a joint-bearing proximal tibia fracture, a typical tibial plateau fracture, is found (Figure 16). These, often comminuted, fractures represent a complex injury and should be evaluated according to the Schatzker classification system. This classification helps separate the fractures into groups with similar mechanisms and patterns, which then have similar treatment options. Ultrasound or MDCT-angiography (Figure 8) can visualise arterial injuries. MDCT can sometimes demonstrate soft-tissue findings indicative of cruciate ligamentous injuries but remains unreliable for predicting unstable meniscal injuries that would require operative treatment. Nowadays, some institutions add an MR examination before surgery to check whether associated ligamentous and meniscal injuries have occurred. However, the clinical significance of preoperatively depicting these injuries still has to be defined in larger studies.

FIGURE 20

Young man landing on feet from a 3 meter fall. He suffered a right-sided comminuted Pilon-fracture (fracture of the distal tibial plateau) (white arrows) and multiple fractures of the medial (black arrowheads) and lateral malleolus (white arrowhead points to the most distal one) (A, B), and a left-sided comminuted calcaneus fracture (C–E). Coronal (C) and sagittal (D) reconstructed images show the compressed fragmented calcaneus with multiple fractures and a very incongruent joint surface. VRT images (A, E) are helpful, together with the reconstructed MDCT images, for the orthopaedic surgeons.



In the knee there are some subtle radiographic or MDCT findings of bone, which indicate important ligamentous injuries and/or fractures. A Segond fracture (Figure 17) at the posterior lateral rim of the proximal tibia and an impression-impaction (deep notch or sulcus sign) (Figure 18) on the lateral condyle are both associated with anterior cruciate ligament tears. Segond fractures are due to rotational force also associated with medial collateral ligament and meniscal injuries. The arcuate sign represents an avulsion fracture, involving three attaching ligaments of the upper fibular head, indicating a major injury in the posterolateral corner of the knee associated with cruciate ligament tears, posterior meniscal tear and posterolateral instability.

The fracture and other associated injuries in the posterolateral complex causing the instability must be stabilised together with repair of the cruciate ligament for an optimal outcome. A final injury is the Hoffa fracture (Figure 19), which is a coronal plane fracture of the femoral condyles, mostly in the lateral condyle, which is caused under direct impact along the femur with the knee flexed. Oblique radiographs are important and CT is often necessary. A Hoffa fracture must be stabilised.

Injuries of the ankle and foot

Radiographs for these injuries are performed with anterior-posterior, lateral and mortise views. Ankle fractures are classified

FIGURE 21

A female 21-year-old pedestrian after a car accident. Frontal radiograph of the foot shows injury through the Lisfranc joint (the tarsometatarsal joints). Note the comminuted fractures through the basis of metatarsal bones II–V, and huge distance between the proximal metatarsals I-II depicting a total tear of the Lisfranc ligament (between the medial cuneiform bone and the medial proximal part of the second metatarsal bone). The patient also suffered dislocation of the first metatarsophalangeal joint, which was subsequently close reducted. Subsequently the patient was transferred to surgical management of the Lisfranc injuries.

FIGURE 22

A patient with subtle fractures in the basis of metatarsals II–IV and a suspicion of a widening of the space between metatarsals I–II. CT depicts a fragment in the wide space due to an avulsion of Lisfranc ligament attachments.

according to the AO classification. Comminuted injuries might primarily be examined with radiographs and complementarily imaged with MDCT. Comminuted calcaneus and Pilon fractures (joint-bearing tibial fractures), are often associated with thoracolumbar fractures in high fall patients (Figure 20). Calcaneus fractures are evaluated according to the Sanders classification. However, despite its popularity, doctors cannot seem to agree on how exactly to use it. A patient with a suspected injury but primarily negative radiographs and positive physical examination with persistent symptoms of more than a week should be further examined with MRI, MDCT or ultrasound. When suspecting a Lisfranc injury of the metatarsal joints, the radiographic evaluation might be improved with provocation tests or weight-bearing images, if tolerated, with radiograph or CT (Figure 7). For a suspected acute tendinous rupture, the next best test is MRI followed by MDCT and ultrasound.

Injuries that sometimes go unchecked

When an emergency patient undergoes a battery of life-saving treatments and radiology, the situation is quite stressful for the medical team. The major important findings are reported and it might be easy to miss subtle findings associated with major joint

injuries that, if left untreated, could lead to an unsatisfactory outcome for the patient. With rising numbers of lower extremity MDCTs, the chance of making these sometimes very small findings will increase. Some of these tip-of-the-iceberg lesions can be seen in the figures.

One of these types of findings comes from the use of novel treatments, such as bisphosphonates for osteoporosis and myeloma or bone metastases. This medication can lead to an atypical subtrochanteric stress fracture finding that is important to report for orthopaedic management before a total fracture occurs (Figure 15).

Regarding the knee, see paragraph about subtle findings in 'Injuries of the knee' (Figures 17–19).

In the foot, fractures and ligamentous injuries in the Lisfranc joints, or tarsometatarsal joints, can be obvious (Figure 21), however, very subtle changes might not be so obvious, such as a somewhat larger space between the heads of the first and second metatarsal bones, sometimes associated with a tiny cortical avulsion from ligament insertion (Figure 22). A radiographic examination, when tolerated, under manual provocation or weight-bearing radiographs or CT, can be helpful to depict subluxation, which can indicate surgical management (Figure 7)

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14

VASCULAR EMERGENCIES

VASCULAR EMERGENCIES: CROSS-SECTION IMAGING HAS LARGELY REPLACED DIAGNOSTIC ANGIOGRAPHY

BY **FABRIZIO FANELLI, ALESSANDRO CANNAVALE, MARIANGELA SANTONI** AND **MARIANNA GAZZETTI**

INTRODUCTION

Vascular emergencies are mainly classified as traumatic or non-traumatic. Their imaging relies mainly on computed tomography (CT) imaging, which currently represents the most common imaging modality in emergencies. It is a robust, readily available modality in all hospitals. CT scanners are always located in close proximity to the trauma or emergency departments. A spiral CT scanner is recommended for vascular emergencies, and it should be at least 16 slices (MDCT), considering that imaging of the whole aorta, which is approximately 48cm in length, may take 10–20 seconds with a 16-slice CT, 6 seconds with a 64-slice, or well below 3 seconds for 256–320-slice or dual scanner. Imaging protocols for vascular imaging are generally based on three phases: non-contrast, arterial, and the venous and delayed phase. This refers to the acquisition of images when the contrast passes through the arteries and through the veins or when it has gone out of the vascular system and accumulated in interstitial tissue to be washed out by the kidneys, showing the urinary excretory structures. Delayed phases, half a minute or several minutes after the injection of intravenous iodinated contrast medium, are often used to clearly depict organ malperfusion, for example in vascular dissections or abdominal trauma. They can also be used to identify additional venous or organ bleeding, either in trauma or following a needle biopsy or any other percutaneous procedure, such as catheter drainage of fluid from an abscess, or urine or bile. The most important advantages of modern CT systems are fast imaging acquisition and quick image reconstruction in planes other than axial transverse using multiplanar (MPR) or centre-line processing with curved planar reconstruction (CPR).

TRAUMATIC VASCULAR EMERGENCIES

MPR images can guide selection toward the most appropriate treatment, being either closed endovascular or open surgical; they can also identify the sites and causes of vessel damage and active bleeding. Appropriate scrutiny of CT images will often reveal structural abnormalities in a vessel, such as transection, dissection, pseudo-aneurysm, and arterial cut-off, all of which are related to significant vascular injury. Most often, vascular-injured patients may partially respond to fluid resuscitation or in some cases not respond. The most recent guidelines suggest that a whole body MDCT, from head to mid-thigh or knees, should be the default first-line imaging in severely injured patients who respond at least partially to resuscitation. MDCT must be available within no less than 30 minutes of the request, ideally it will be earlier and should be performed before angiography or surgery. Other investigations should not delay CT scan. In clearly haemodynamically unstable patients, CT should follow immediate surgery or intravascular balloon occlusion for bleeding control. Here, an occluding balloon is placed percutaneously and inflated at the bleeding site to block the blood flow. Most common scenarios of vascular trauma are traumatic aortic injuries and traumatic abdominal or pelvic vascular injuries. Blunt or open trauma to the body may lead to chest, abdominal or pelvic haemorrhage or damage to larger vessels, resulting in pseudo-aneurysm.

Traumatic aortic injuries

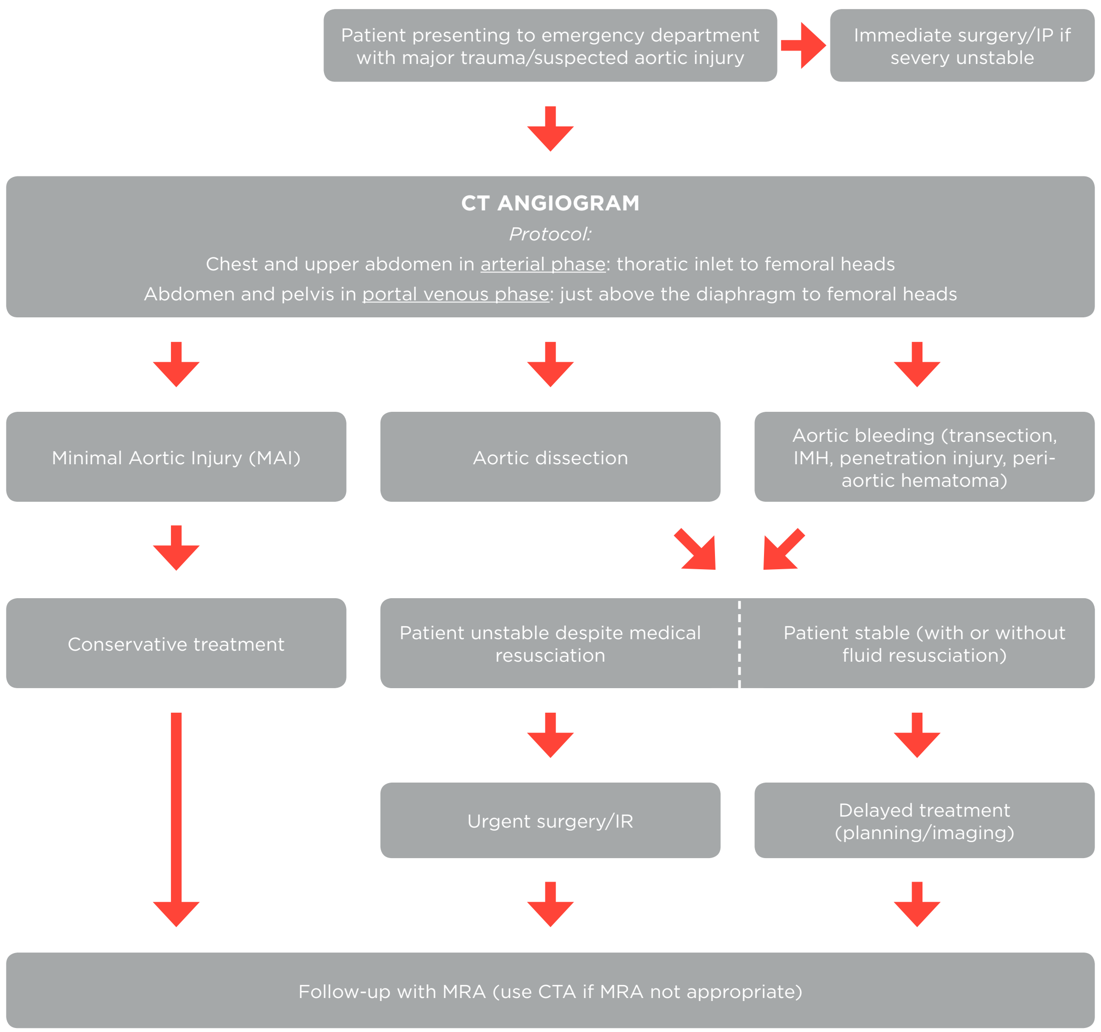
Traumatic aortic injury (TAI) is a life-threatening consequence of major blunt or penetrating thoracic trauma, with high early mortality if the relevant trauma is untreated. Sudden deceleration is the chief mechanism of blunt thoracic trauma. Approximately 70% of TAI patients are vehicle crash victims from frontal or lateral impact, while motorcycle, aircraft and pedestrian accidents, fall from height, and crush injury to the chest account for the remainder. From a clinical standpoint, TAI must be excluded after a relevant trauma, especially when associated with hypotension, fractures, including those of the spine, scapula, long bones or pelvis, pulmonary contusion, and haemothorax or blood effusion in the pleural space.

Imaging

CT angiography is the method of choice for the diagnosis of aortic injury after major trauma, as it has been shown highly sensitive

FIGURE 1

Flowchart showing the imaging and clinical approach to a trauma patient with suspected aortic injury.
Abbreviations: IR– Interventional Radiology; IMH – Intramural haematoma.



at approximately 98% and with a specificity of nearly 100%. CT images can show luminal irregularities or intimal flaps, i.e. disrupted wall layer, floating in the vessel lumen, outer wall contour irregularities, or pseudo-aneurysms and periaortic haematoma, signs of contrast extravasation or frank transections of the aorta. Recommended CT angiogram protocol and decision making is generally welcomed (Figure 1). The most common site of damage is the aortic isthmus, which is the transition zone between the relatively free-moving proximal part of the thoracic aorta and the fixed portion at the aortic isthmus immediately distal to the left subclavian artery.

CT signs

The most common CT signs of TAI are divided into indirect or suggestive and direct or definitive. Indirect signs of TAI include mediastinal or periaortic haematoma, retrocrural haematoma, located behind the tendons of the diaphragm, or a small calibre of the aorta distal to the injury site. The location of a mediastinal haematoma is critical because if there is a distinct fat plane between the aorta and haematoma, alternate sources of bleeding, such as venous, intercostal arterial, or bony, should be searched for. Periaortic haematoma without any definitive sign of aortic injury may be related to an occult intimal injury. Several studies have shown that conventional angiography may not provide any additional benefits in patients with occult intimal injury, but intravascular ultrasound (IVUS) or transoesophageal echocardiography (TEE) can provide additional information. The direct signs of TAI include active contrast extravasation, contained rupture or traumatic pseudo-aneurysm, intramural thrombus or haematoma (IMH), aortic dissection, and abnormality of the aortic contour, including sudden calibre change, also known as pseudocoarctation. When there is a high-risk mechanism of injury, such as car accident with deceleration, evaluation of other associated injuries is also critical. The common associations of TAI are severe head injury, lung and cardiac injury, diaphragmatic rupture, intra-abdominal bleeding, and pelvic and long bone fractures.

Classification

Different classifications have been proposed, however the most commonly used is from Azizzadeh et al. that classifies TAI into four categories: grade I or intimal tear, grade II or intramural haematoma, grade III or pseudo-aneurysm and grade IV or rupture (Figure 1). Minimal aortic injury (MAI) is a particular aortic injury that literally matches the definition of grade I, intimal tear. However there are several different definitions in the literature that elude to 'small' intimal flap, intraluminal thrombus or intramural haematoma without any external contour abnormality and with minimal or no periaortic haematoma, as being MAI. Patients with grade I and MAI can usually be treated with medical therapy alone. Invasive treatment is currently advocated for the treatment of grades II–IV. Some authors recommend endovascular treatment in grade II lesions only in the presence of severe periaortic haematoma at the level of the aortic arch. Sometimes a staged approach for aortic repair in lower traumatic aortic injury grades (grades II and III) can be considered, treating more severe co-existent injuries to the head and brain or visceral organs, prior to the aortic injury. Nevertheless, a short-term follow-up to exclude progressing pseudo-aneurysm or haematoma formation is recommended. Follow-up imaging for grade I or MAIs and imaging after endovascular intervention is currently being debated. There is no current consensus from the Society of Vascular Surgery and other international societies on the imaging follow-up, although they recommend expectant management with serial follow-up. Different follow-up protocols have been proposed; hence, long-term follow-up is suggested: CT-Angiography (CTA) examination after 1, 3, 6, and 12 months after the injury followed by annual cardiovascular magnetic resonance angiography scans. In addition, most studies suggest that observation typically ends when the aorta returns to its normal appearance. After treatment by percutaneous stent-graft implantation, regular CT follow-up needs to be performed, especially before patient discharge. Post-discharge graft surveillance is needed, as the aorta dilates at the site of implantation and the dilation is greater in patients that receive a stent for traumatic injury repair than for aneurysm repair. Mostly, CTA is obtained during follow-up, but since traumatic injuries are more common in the relatively younger population, MRI is becoming an attractive option for examination to avoid cumulative radiation exposure, the more so as most of the approved stent-grafts are MRI compatible. Many centres do follow-up examinations by CTA that are performed after 1 and 6 months, then annually for the first 5 years, and less frequently thereafter, mostly every 2–3 years, on a case-by-case basis.

Vascular injury in abdominal or pelvic trauma

In case of abdominal or pelvic trauma, three phase CTA plays an important role in the detection of direct and indirect signs of bleeding or arterial injury. Selective, rather than routine, acquisition of the delayed phase series (8–10 minute delay) is recommended for detecting injuries of the urinary tract, as well as further characterising solid visceral organ injuries that involve the vasculature. Oral contrast, delineating the digestive tract, is not routinely given for CT in this indication. A direct sign of active bleeding into the abdomen or pelvis is an extravasation blush during the arterial phase that enlarges in the venous or delayed phase. Indirect signs of bleeding are arterial spasm, pseudo-aneurysm, arteriovenous fistula, or vessel truncation. The various injuries seen on the CT images may be grouped according to the injury site and the organs involved.

Haemoperitoneum and active haemorrhage

CT has high sensitivity and specificity for the detection of blood pouring in the peritoneal cavity. Haemoperitoneum starts near the site of injury and spreads along the expected anatomic pathways. When the patient is in a supine position, blood originating from the liver collects in Morrison's pouch under the liver and passes down the right paracolic gutter to the pelvis. From the spleen, blood passes via the phrenocolic ligament to the left paracolic gutter and then accumulates in the pelvis. Blood from a splenic injury may also extend to the right upper quadrant. Although peritoneal lavage is a classical and sensitive detector of intraperitoneal haemorrhage, it is unable to detect the source or origin of the bleeding. The 'sentinel clot' sign indicates adjacent, focal higher attenuation clotted blood as a marker for the organ that is the cause of haemorrhage. A large amount of blood may collect in the pelvis without much haemoperitoneum seen in the upper abdomen. Ongoing haemorrhage may appear as a region of extravasation of contrast material and is indicated by high attenuation, with values ranging from 85 to 350 HU. The areas of contrast extravasation noted on CT scans often correspond to the site of bleeding seen on angiography.

Visceral arteries trauma

Most pseudo-aneurysms or bleeding in an abdominal organ result from blunt trauma or penetrating injuries, many of which are iatrogenic, i.e. associated with biopsy or nephrostomy tube placement. The arteries most commonly involved are the superior mesenteric artery, coeliac trunk or renal arteries and their branches. CT is highly reliable for diagnosing parenchymal injuries, showing main arterial occlusion, and active bleeding. CT is not as accurate for diagnosing branch arterial injuries, including pseudo-aneurysm or arteriovenous fistula. In kidneys that develop pseudo-aneurysms, the initial CT scan often shows parenchymal laceration without pseudo-aneurysm, because acute thrombus may temporarily seal the vessel laceration. Over several days or weeks, clot lysis occurs with subsequent formation of a pseudo-aneurysm. A typical pseudo-aneurysm is seen as a focal, rounded region of less than one centimetre in diameter, equal in attenuation values to the vessel lumen or surrounding arterial structures on an arterial phase image. Multiphasic acquisitions are helpful for differentiating active extravasation from pseudo-aneurysms that do not actually bleed. On delayed phases, foci of extravasated blood are typically larger, and the relative hyperattenuation persists throughout the various phases of image acquisition, whereas pseudo-aneurysms remain identical in size and shape and the attenuation values are similar to the aorta in all early and delayed phases. This differentiation has important therapeutic implications: active bleeding requires urgent endovascular or surgical management whereas pseudo-aneurysms may be treated semi-urgently (Figure 2).

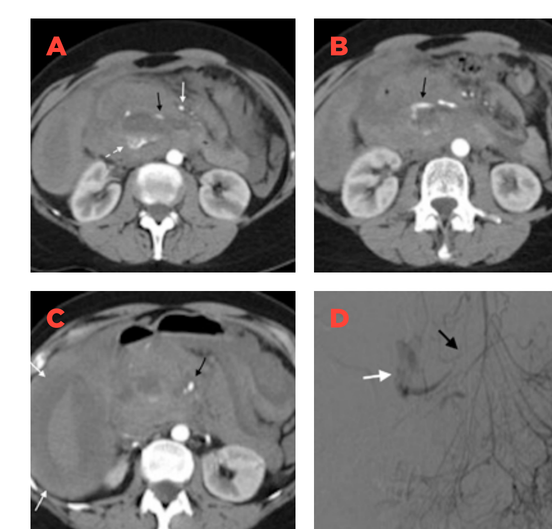


FIGURE 2

64-year-old female under anticoagulant therapy had a blunt abdominal trauma. (A) CT angiogram in the arterial phase shows quite small SMA (superior mesenteric artery) due to spasm (white arrow). There is a small branch of the SMA that may be damaged (black arrow). Active bleeding with haematoma is noted in the right mesentery (dashed arrow). (B) The damaged vessel looks abnormal (black arrow). (C) There is also a large haematoma in the liver (segment 6), but there is no active ongoing contrast extravasation (white arrows), the SMA is patent (black arrow). (D) The invasive angiogram confirms the damaged vessel (black arrow) and the contrast extravasation (white arrow).

Vascular pelvic trauma

Patients who suffer major blunt pelvic trauma and sustain displaced fractures have a high risk of major pelvic vascular injuries, with significant mortality and morbidity. Approximately 40% of patients with a pelvic fracture may have an associated pelvic vascular injury and haemorrhage is the leading cause of mortality in 60% of cases. The rupture of the large iliac arteries is an uncommon but life-threatening consequence of pelvic trauma. The incidence of iliac artery injury has been reported as being 0.4% of all arterial trauma. Rupture may be an acute event with signs of internal haemorrhage, which translates into groin and back pain and haemodynamic changes or may arise secondarily and from a false or pseudo-aneurysm. Rapid detection and assessment of pelvic vascular injury afforded by the shorter acquisition times and increased spatial resolution of MDCT are useful for properly triaging critically injured trauma patients, also allowing an overall evaluation of multiple parenchymal and orthopaedic lesions. However, in patients with unstable haemodynamic conditions and in whom iliac artery injury is highly suspected, a rapidly performed ultrasound (US) examination may be preferred. Pelvic multiphasic CT allows for accurate differentiation between arterial and venous injury. On a portal venous phase image, an arterial haemorrhage should have a higher attenuation than that from a venous source, but significant overlap makes this distinction difficult. Contrast extravasation seen on a portal venous phase image but not on the earlier arterial phase image is more likely venous in nature.

Venous injury

Venous injuries are usually present in the setting of penetrating trauma; however, they are an uncommon imaging finding, likely because of the comorbid trauma-related injuries that either result in death or cause haemodynamic instability, when large calibre veins are involved, requiring immediate surgical intervention before imaging. Modern MDCT scanners are able to provide superior image detail of venous trauma. However, venous opacification, even during the portal venous phase, is often less than that of the arterial structures during the arterial phase, because of haemodilution of the contrast material and its elimination by the kidneys. This lessened venous opacification may create inherent and unavoidable limits in the evaluation of the venous structures. Therefore, it is imperative for the radiologist to understand that although current imaging protocols are not designed specifically to evaluate the venous system; venous injuries may nevertheless be identified, with the potential for important alteration of management. Venous injuries can be identified at CT by finding either direct or indirect signs of the injury. Direct signs include thrombosis and/or occlusion, avulsion and/or complete tear, rupture, and active extravasation. Indirect signs are perivascular haematoma, fat infiltration or stranding and vessel wall irregularity. These are indeterminate findings, because a venous injury may or may not be present and can often be seen in association with other adjacent injuries.

Injuries of the Inferior Vena Cava (IVC) are associated with high morbidity and mortality rates. Investigators have reported that more than one-third of patients with an IVC injury die before reaching the hospital, and in hospital, mortality is greater than 60%. Given the high mortality and the common occurrence of other severe comorbid injuries, IVC injuries are not commonly diagnosed at imaging. Imaging options include conventional venography and CT venography. Few to no data exist to compare conventional venography to CT venography for the evaluation of the IVC in the trauma setting, therefore each case should be considered individually based on the patient's clinical presentation. A common imaging pitfall is the mixing of unenhanced blood with contrast material, which can simulate a thrombosis or vessel injury. The same applies to other large abdominal veins.

NON TRAUMATIC VASCULAR EMERGENCIES

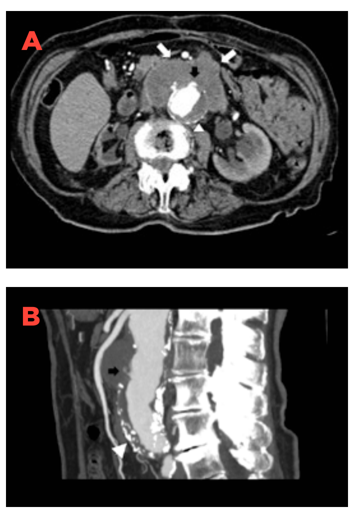
Causes of non-traumatic bleeding may be spontaneous necrotic pancreatitis or bleeding from tumours. Spontaneous bleeding may occur also from minor trauma and may affect any organ system. This may be most commonly found in patients undergoing anticoagulant therapy. Common sources of spontaneous haemorrhage are visceral, for instance hepatic, splenic, renal and adrenal, as well as gynaecological, coagulopathy-related and vascular. Less common vascular causes include rupture of a splanchnic artery aneurysm, an outpouching of the external arterial wall, mainly the splenic (about 60%) and hepatic arteries (about 20 %) and erosion of a vessel by an adjacent neoplastic or inflammatory disorder, such as acute pancreatitis. Abdominal haemorrhage due to anticoagulant or bleeding diathesis, as may occur in hepatic failure, haemophilia, idiopathic thrombocytopenic purpura, or systemic lupus erythematosus, commonly involves multiple sites and especially the body wall muscles, such as the rectus muscle of the anterior abdominal wall or the paraspinal ilio-psoas muscle. Given the technical difficulty of identifying by ultrasound the bleeding site and selectively binding the target vessel, multiphase CT examination has been widely accepted as an optimal imaging tool. A bleeding site may be defined as a non-homogenous high-density area or as haematoma, with attenuation values of 50 to 80 HU in non-contrast scans. Active ongoing contrast medium extravasation is defined as much higher attenuation areas on the arterial phase, which initially appeared as a jet or fountain with a tapered edge and afterward was confirmed on venous and late phases, where the contrast-enhanced blood was mixed with the fresh and clotted blood already present within the haematoma.

Rupture of abdominal aortic and iliac artery aneurysm

Aneurysmal dilatation of the aorta (AAA) is defined when the diameter is 50% more than normal. In autopsy studies, the 1-year incidence of abdominal aortic aneurysm rupture according to initial diameter was about 9% for diameters of 5.5–5.9cm, 10% for diameters of 6.0–6.9cm, and 32% for diameters of 7.0cm or more. CTA plays an important role in the diagnosis of AAA as well as in postoperative management. CTA diagnosis of AAA rupture may be made with direct and indirect signs: an indirect sign is the presence of an abdominal aortic aneurysm with adjacent periaortic haematoma extending into the perirenal and pararenal spaces of the retroperitoneum.

FIGURE 3

A 69-year-old male presenting with abdominal and back pain, with a previous history of aortic surgical repair. (A) CT angiogram in axial view confirmed the presence of typical calcifications along the outer aortic wall (arrowhead), as observed, postaortic repair with infrarenal surgical graft. Axial CT angiogram in the arterial phase shows infrarenal periaortic haematoma (white arrows) and small contrast extravasation (black arrow). (B) Sagittal reconstruction confirms the small anterior blush (black arrow) and peripheral calcifications (arrowhead).



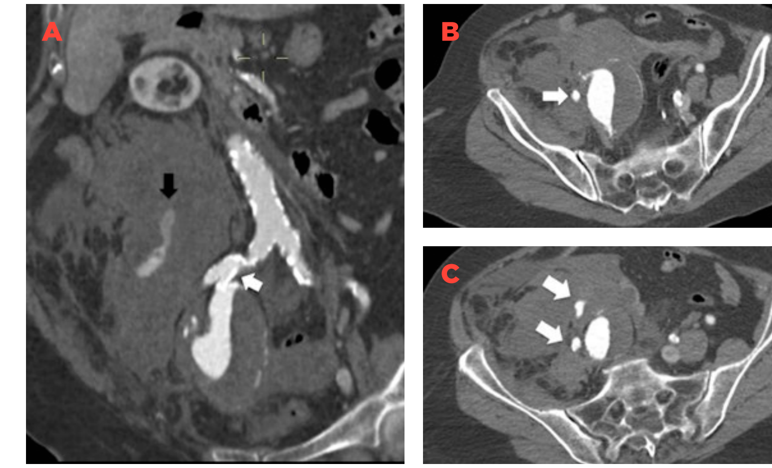
This finding can also be easily confirmed on a non-contrast CT scan. CTA may detect otherwise active bleeding direct signs, seen as an extraluminal contrast blush (Figure 3). It can also detect extension of an aneurysm into the common, external, and internal iliac arteries; the presence and extent of mural thrombosis; the anatomy of arteries that supply blood to the kidneys, including the accessory renal arteries; and stenosis or occlusion of the vessels. This additional information is important for the choice of treatment. It has been shown that patient eligibility for endovascular repair depends on the anatomy of the proximal aneurysm neck. Great effort has been put into the development of specialised software for planning endoluminal treatment of AAA. Most of the measurements required for determination of the optimal dimensions and type of aortic stent-graft now are obtained with MDCT and 3D reconstruction. Similar findings may be found in the rupture of an iliac artery aneurysm, which has a high risk of rupture when 3.5–4cm in diameter. Haemoperitoneum may be the sign of a recent wall tear or if a direct sign of bleeding can be seen such as a contrast jet in the arterial phase. Haemoperitoneum will be mainly located in the pelvis in dependent areas (Figure 4).

Aortic dissection

Acute or type B aortic dissection is a life-threatening condition that results from a splitting of layers of the aortic wall and must be diagnosed and treated promptly. Aortography, the traditional imaging method for confirming diagnosis, has increasingly been supplanted by TEE and magnetic resonance (MR) imaging, which have high sensitivities and specificities of 95%–100%, for the depiction of

FIGURE 4

A 65-year-old female presenting with right iliac fossa pain and hypotension. (A) CT angiogram shows in the coronal view the presence of a 38mm aneurysm of the right internal iliac artery (white arrow), with active contrast extravasation (black arrow) and right iliac fossa and flank haematoma. (B, C) Axial images confirm the spots of contrast extravasation (white arrows).



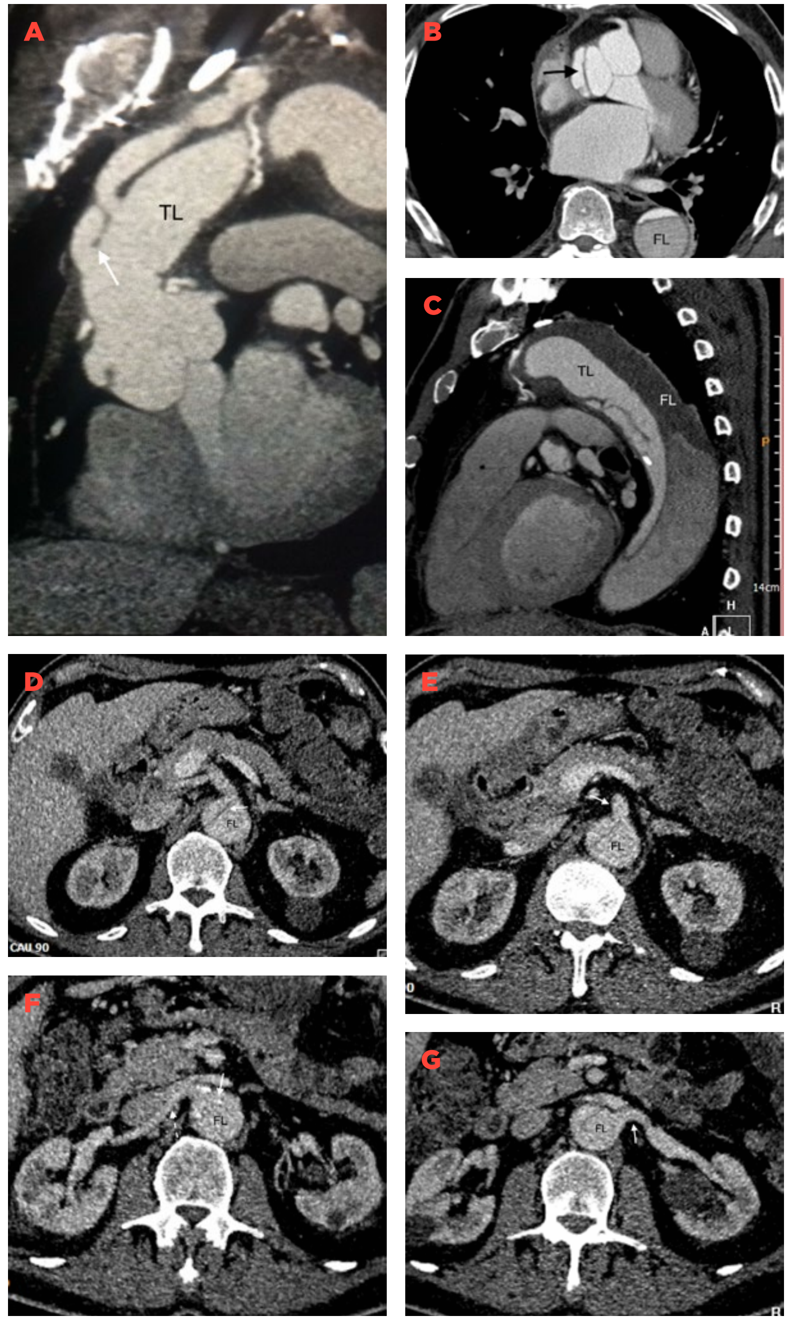
acute aortic dissection. However CTA represents the most reliable technique in the acute setting as compared to MR and echocardiography. Also for preoperative planning, CTA has a sensitivity and specificity comparable to those of MR imaging and TEE. Findings of a contrast-enhanced double lumen and an intimal flap in the aorta which separates the two dissected channels are diagnostic. Classically the aortic dissection is classified according to the Stanford classification into type A, or primary tear in the ascending aorta, and type B, or primary tear in the descending aorta. A revised classification of aortic dissection has been proposed in relation to the potentially different surgical approaches:

Type A dissection, which begins in the ascending aorta and may or may not extend distally into the descending aorta (Figure 5).
Type B dissection, which begins distal to the left subclavian artery.
Type B* which is a type B dissection with aortic arch involvement and proximal extension into the transverse arch between the innominate and left subclavian arteries and which may or may not extend distally into the descending aorta.

Complicated aortic dissection may lead to instable arterial pressure, pain and organ or limb ischaemia. CTA can detect infradiaphragmatic ischaemic complications related to the main abdominal arterial branches, mainly evident in the arterial phase. There are two types of branch vessel occlusion: static and dynamic. In static occlusion, the intimal flap extends into the wall of the branch vessel. In dynamic occlusion, the intimal flap prolapses across the branch-vessel origin and covers the lumen like a curtain. In the presence of ischaemia, resulting from compression of the true lumen by the false lumen, one therapeutic option is represented by endovascular fenestration, which means creating a hole in the endoluminal flap, thus equalising the pressure in both channels and decreasing the risk of external rupture of the aortic wall. Reliable identification of true lumen and false lumen are important for treatment planning.

FIGURE 5

A 60-year-old man, with hypertension and hypercholesterolemia, presented with chest pain radiating to the back. (A) Sagittal CT angiogram images show type A aortic dissection due to the presence of a flap in the ascending aorta (black arrow). (B) The dissection flap in the ascending aorta is better shown in axial view. The FL (false lumen) in the thoracic descending aorta has lower attenuation values than the TL (true lumen) and is larger. (C) Sagittal view shows the extension of the dissection in the descending thoracic aorta: TL has better enhancement than the FL. (D) Axial view shows the celiac artery coming off the TL, which is separate from the FL by the dissection septum or flap (arrow). (E) The superior mesenteric artery (arrow) is perfused by both the TL and FL. (F) Axial view shows the right renal artery (dashed arrow), is detached from the TL, which can be recognised due to the presence of intimal calcifications (white arrow). (G) The left renal artery is perfused by the FL.



Less common and less reliable identifiers of true and false lumina are patterns of eccentric calcification, which means calcification in the dissection membrane facing only one lumen, intraluminal thrombus, and the cobweb sign, which is a thin linear intraluminal filling defect. Shaded surface display (SSD) is an image post-processing method that allows the clear depiction of both lumina and differentiation between the true lumen and the false lumen.

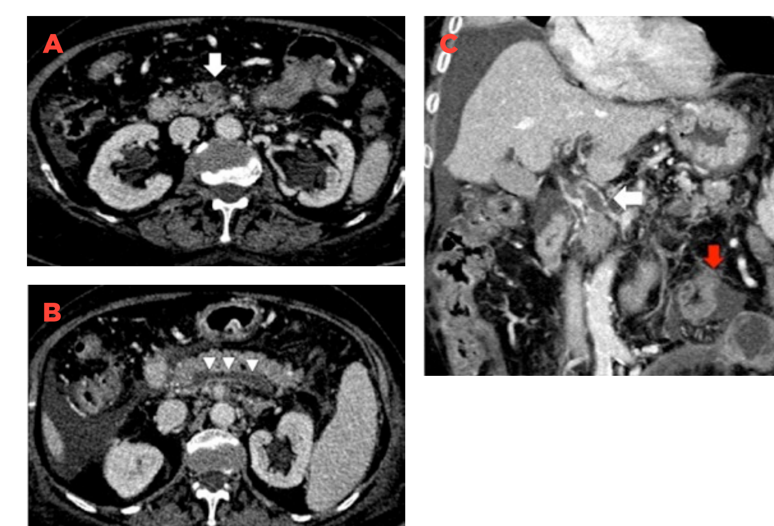
Acute mesenteric ischaemia

Three categories of acute mesenteric ischemia are recognised: arterial occlusion, non-occlusive ischaemia, and venous thrombosis. Unspecific findings at radiography may include the sentinel loop sign or paralytic ileus, dilated segments of the small intestine, as well as pneumatosis coli, which is gas in the wall of the digestive tract, and portal venous gas, which accumulates in the intrahepatic branches of the portal vein. Intravascular gas is usually a sign of necrosis of the wall of the digestive tract as a dramatic consequence of severe vascular obstruction. Secondary to submucosal haemorrhage or oedema, bowel wall thickening with a ‘thumbprint’ appearance may be seen together: these observations have equal significance. Specific contrast-enhanced CT findings in patients with mesenteric ischaemia typically include focal or segmental thickening in the bowel wall caused by submucosal haemorrhage or oedema, pneumatosis coli, or portal venous gas, meaning that infarction of the digestive wall will occur.

Emboli in the mesenteric arteries may appear as centred filling defects. In mesenteric venous thrombosis, typical findings are thrombus and lack of enhancement in the mesenteric veins after intravenous administration of contrast material (Figure 6). There may be portal vein thrombosis also associated in advanced stages. Systemic arterial embolism is often

FIGURE 6

65-year-old male with atrial fibrillation, but not compliant to the anticoagulant therapy. CT abdomen in the portal vein shows acute occlusion of the superior mesenteric vein (A, axial – arrow), splenic-mesenteric confluence (B, axial view – arrowheads) and of the portal vein (C, coronal view – black arrow). Note the concomitant thickened small bowel loops and small amount of free intraperitoneal fluid (C – red arrow).



caused by bacterial endocarditis, paradoxical embolism through a defect in the interventricular septum, or atrial fibrillation.

Splenic infarction is also common, and embolism due to cardiac thrombus caused by wall motion abnormalities is well known. Splenic infarcts are typically wedge shaped, non-enhancing, peripheral, and close to the capsule and are easily differentiated from ordinary parenchyma.

Non-occlusive mesenteric ischaemia is a decrease in arterial perfusion, without occlusion of the mesenteric arteries. This condition may be commonly caused by decreased cardiac output with resultant splanchnic hypoperfusion and generally affects patients older than 50 who have a history of myocardial infarction, congestive heart failure or aortic insufficiency. Multi-detector CT scanners provide increased spatial resolution with thin axial sections and decreased scanning time and thus enable the depiction of even the smallest branches of the mesenteric vasculature without motion artefacts. This capability allows the diagnosis or the exclusion of small thrombi. Curved multiplanar reconstructions (MPR) enable the depiction of vessels along their entire course, from the origin of the superior mesenteric artery to the bowel wall.

Acute limb ischaemia

Acute limb ischaemia (ALI) may be defined as the acute limitation of blood flow to a limb, with symptoms including rest pain and foot ulcers, which presents within 14 days. Both MRA and CTA can be used to depict ALI and have similar sensitivity and specificity, although MRA has higher sensitivity for calcified arteries below the knee vessels. CTA currently represents the most-used technique in the urgent setting, as it is readily available and cheaper than MRA. Moreover, it allows obtaining a panoramic view and better visualises metallic stents and bypasses. Direct invasive angiography may be indicated when there is intermediate to high suspicion of obstruction and endovascular treatment can be directly performed. Invasive angiography could be indicated on the basis of a Duplex-ultrasound scan that is mainly used as a first-level imaging technique. This approach may be indicated in patients with low renal function, to reduce the amount of iodinated contrast. Angiography is only indicated if the limb is salvageable, otherwise bailout surgical techniques are indicated. ALI can be due to thrombosis or an embolic event, most often emboli originate from a cardiac source, but approximately 85% of acute peripheral arterial occlusion occurs because of local thrombosis, most commonly within a surgical bypass graft. On CT angiogram this will present as absence of flow in the bypass graft and most often no flow or trickle flow in the distal runoff vessels. In the native vessel, thrombosis typically occurs at the site of pre-existing atherosclerotic stenosis in calcified disease and appears as an abrupt segmental non-opacification of the involved artery. In particular, in embolic occlusion, the embolus is often a centred or eccentric rounded filling defect with 'ring' perfusion in axial view and most often, it is located at vessel bifurcation, i.e. at the popliteal artery bifurcation into the anterior tibial artery and tibio-peroneal trunk. It is important to differentiate between thrombosis and embolus due to their different surgical or endovascular approaches; on some occasions, differentiation is not that easy.

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STOPPING BLEEDING WITHOUT SURGERY

STOPPING BLEEDING WITHOUT SURGERY: RADIOLOGICAL MANAGEMENT OF VASCULAR INJURIES

BY **BRIAN J. SCHIRO, CONSTANTINO S. PEÑA** AND **BARRY T. KATZEN**

INTRODUCTION

Since the beginning of written history, traumatic injuries have been chronicled and are a natural part of the evolving human experience, and many treatments were documented throughout antiquity. Skeletal remains dating back to 2400 BC have been discovered with splints transfixing broken bones. The Edwin Smith Papyrus from 1600 BC details accounts of wound treatments of the head, neck, shoulder, and chest. Meat was one of the first things to be used as a haemostatic agent, and closed reduction of nasal fractures is described. Egyptian hieroglyphs from 1300 BC illustrate the methods of shoulder reductions following dislocation injuries, and in AD 1020, the Canon of Medicine by Avicenna described methods of wound healing with stabilisation, immobilisation, and ways to prevent infection – all of which are principles in use today.

Although accidental injury is the most commonly experienced type of civilian trauma, the majority of modern emergency medical knowledge and progress in trauma care has been generated from encounters with wartime injuries. First recounted in early stories dating back to the Trojan War and later throughout the Middle Ages, penetrating injuries from stab wounds and arrows led to massive haemorrhage and overwhelming infection. At that time, most of the wounded died on the battlefield due to lack of urgent medical attention. This greatly improved when medical evacuation from the frontline to a triage unit was instituted in the Napoleonic Wars. After the discovery of gunpowder and development of firearms in the 16th century, penetrating trauma and soft tissue injuries resulted in more substantial wounds. Local tissue destruction created by high velocity projectiles was a fertile ground for infection. When infection was first recognised as a pathologic process, open wounds were treated initially with cautery by pouring boiling oil into the wound. This practice was later replaced by ligature of bleeding vessels and debridement of the wounds.

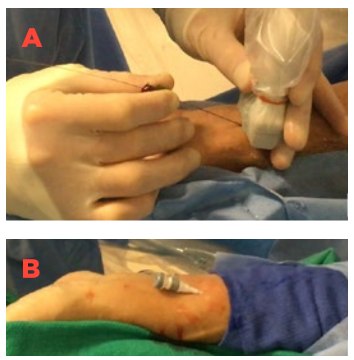
During the United States Civil War in the 1860s, limb amputations were the most commonly performed surgical procedures for soldiers who sustained gunshot wounds, but mortality rates of 33–54% remained despite treatment. In 1895, Wilhelm Conrad Röntgen discovered x-rays and within five months, Italian physicians were using radiographs on the battlefield to locate bullets for more precise surgical treatments, significantly reducing the rates of bleeding and infection. In World War I, weapons of war became more sophisticated and deadly. With the development of more devastating ballistic weapons, concussive injuries from high explosives and artillery shells were a major contributor to the number of dead. This resulted in severe multi-organ and vascular injuries. As with all early wars, wounds led to death often times from infection. Later, with the discovery of penicillin in 1928 and its use in military operations in 1942, death from infection markedly diminished and vascular injuries became more prevalent in terms of mortality. Vascular surgery was an experimental field in World War II, but techniques for limb salvage through vascular repair became routine in subsequent wars. With the dropping of the atomic bomb, death occurred on a massive scale, albeit a relatively small number compared to the overall fatalities in the war. Those who did not succumb from the initial blast injuries died days to years later as a result of burns and the horrifying effects of radiation poisoning. Modern knowledge of the effects of medical grade radiation is based on data from the bombs dropped on Hiroshima and Nagasaki.

To the fortune of humanity, these weapons of mass destruction have not been unleashed since that time. Modern war injuries are commonly the result of high-velocity gunshot wounds and blast injuries from bombs (e.g. suicide bombers) and other improvised explosive devices (IEDs). Nonetheless, injuries created by modern weapons lead to life altering, if not life ending, changes, including limb amputations. Modern advances in medicine and trauma care have transformed treatment for traumatic injuries.

As surgery revolutionised the treatment of trauma 60 to 70 years ago, interventional radiology (IR) has revolutionised treatment and played a key role in improving the outcome of trauma patients. IR evolved from diagnostic radiology in the 1960s as an extension of the use of radiology imaging modalities to perform interventions that were less invasive and safer than the traditional surgical alternatives.

FIGURE 1

Seldinger technique. Percutaneous access into a vessel (in this case, the left radial artery in the wrist) is done by placing a needle through the skin and into the artery (A). A wire is then threaded through the needle, and the needle is exchanged for a catheter or vascular sheath (B).



This became a fertile ground to rapidly develop innovative methods of minimally invasive endovascular treatments from balloon dilations of narrowed arteries; to endovascular stents for treatment of atherosclerotic disease and aneurysms; to embolisation of bleeding arteries; and to tailored treatments to slow and cure certain cancers. In the following sections, we detail methods of treating traumatic injuries by interventional techniques.

BIRTH OF INTERVENTIONAL RADIOLOGY

The evolutionary history of trauma care must be paralleled with the birth of a new field of medicine. Interventional radiology (IR), an integral and primary therapeutic approach to trauma care and other advanced disease processes, arose in the middle of the 20th century. IR allows the direct visualisation of blood flowing through a vessel through the intravascular injection of iodinated contrast material. This revolutionised the diagnosis of vascular injuries. Originally, small diameter hollow tubes, catheters were advanced into a blood vessel from a surgical vascular incision in order to inject contrast material into the vessel and allow imaging of the vessel lumen to diagnose vascular injuries and disease. This surgical technique was supplanted by Sven Ivar Seldinger in 1953 when he developed a percutaneous method of accessing (catheterising) a vessel with a needle through the skin (Figure 1). This avoids the need for a surgical incision.

This work was preceded by vascular catheterisation. Famously, a young physician, Werner

FIGURE 2

The interventional suite. Operators performing an endovascular aneurysm repair (EVAR). Whereas abdominal aortic aneurysms (AAA) were previously treated with large open surgeries requiring long hospital stays and long recovery periods, interventional radiologists now can treat AAA with minimally invasive techniques requiring only small groin punctures. The innovative tools of IR have revolutionised the care provided to patients.

Forssmann, passed a small urinary catheter into a vein in his own arm in 1929, against the direct orders of his chief, the renowned pioneer in surgery, Professor Ferdinand Sauerbruch, at Charité Hospital, Berlin, Germany. Using x-rays, he advanced the catheter into his right heart to prove that this could be done safely. While at the time, people believed that this was madness and would lead to sudden cardiac death; this is standard practice in medicine today. It is not surprising that Forssmann went on to receive the Nobel Prize in Physiology or Medicine many years later for his work. Others read of his technique of cardiac catheterisation and developed it further for the diagnosis of vascular disease. In 1964 Charles T. Dotter, the father of IR, expanded the use of percutaneous catheterisation techniques, to not only include imaging and diagnoses, but also therapy as he detailed when crossing an occluded superficial femoral artery in a patient's leg and restoring blood flow. This was the first attempt at providing a therapeutic procedure with use of imaging. 'Interventional Radiology' was coined soon thereafter by professor Alexander Margulis, of the University of San Francisco, USA. The field rapidly exploded in the next few decades with the development of specific catheters and wires, angioplasty balloons, stents, endografts, and embolic agents (Figure 2).

As perhaps the most innovative field in medicine, IR techniques and devices continue to revolutionise the world of healthcare. IR has now become its own primary specialty in the United States with dedicated residency training programmes and specialty certification by the American Board of Radiology.

TRAUMA IMAGING

Angiographers – the predecessors to interventional radiologists – used their increasing

FIGURE 3

Stents and stent grafts. (A) A thoracic endograft used for treating aneurysms and vascular injuries in the aorta. This device has a bare metal stent at its proximal end and is covered with a Dacron mesh over the remainder of its length. (B) This stent graft is used to treat aneurysms and vascular injuries in the iliac arteries of the pelvis. (C) A bare metal stent typically used to treat atherosclerotic occlusive disease (stenoses or occlusions) in the superficial femoral artery in the lower limbs.

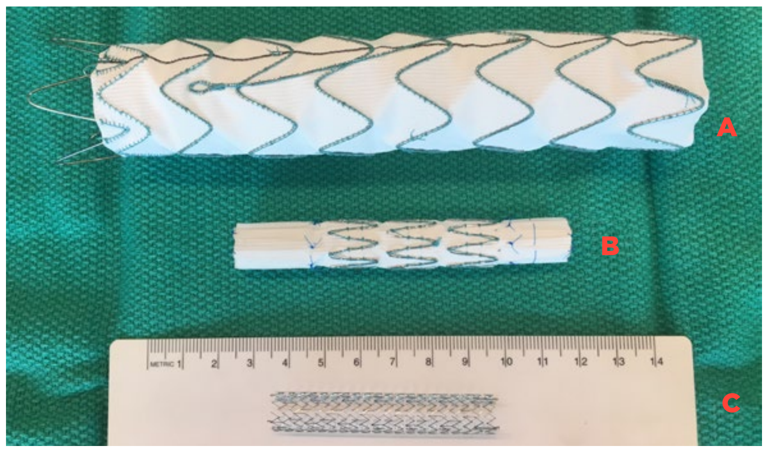


FIGURE 4

Model of a thoracic endograft placed in the descending thoracic aorta to treat a degenerative aneurysm.

skills of navigating thorough the circulatory system using image guidance to develop imaging techniques and diagnostic criteria that would accurately identify the source and location of bleeding, allowing precise guidance for primary surgical therapy. Trauma patients were rushed to the angiography suite to diagnose acute aortic injuries, solid organ injuries, and vessel trauma including pelvic haemorrhage. The benefit of accurate localisation of the cause of bleeding had the immediate effect of reducing the mortality and morbidity of surgery in trauma patients with haemorrhage. In the 1960s and 1970s, the realisation that catheters could be used as a 'surgical' instrument was born, as was the field of interventional radiology. Not only could the bleeding be identified, but also the bleeding artery could be blocked, or occluded, from the inside, leading to a major shift in the treatment paradigm. Open surgery was no longer required to stop bleeding from trauma in places with appropriate technology and with physicians with the unique skills and support to care for these types of patients.

With the advent of computed tomography (CT) in 1972, cross-sectional imaging began to augment catheter angiography. By the

1990s–2000s, the development of slip ring technology and multidetector CT imaging allowed for the necessary imaging speed, coverage, and resolution to perform less invasive CT angiography (CTA). At the same time, magnetic resonance (MR) sequences and the use of gadolinium-chelated agents allowed for the development of magnetic resonance angiography (MRA). With the increased speed and resolution of CT imaging, CTA, and also in some cases MRA, supplanted catheter angiography as the primary modality to diagnose vascular and solid organ trauma. In most instances, traumatic injuries can be diagnosed with CTA and MRA noninvasively and quickly; this allows the interventional radiologist to primarily provide emergency consultative services as a therapeutic physician.

TOOLS FOR TREATING VASCULAR TRAUMA

Today the interventional radiologist has a number of tools which can stop bleeding by occlusion of the bleeding artery, the equivalent of surgical ligation (tying off), or 'repairing' the artery from the inside, by placing tubes that cover the site of injury.

Endografts

Endografts or stent-grafts (Figures 3 and 4) are metal scaffolds covered in impervious fabric (typically Dacron or ePTFE: expanded polytetrafluoroethylene). These are mounted on self-expanding or balloon-expandable stents and are often used in large or medium-sized arteries (and sometimes in veins) to cover or mend a disrupted vessel eliminating extravasation or blood leaking outside of the lumen of the injured vessel. They are inserted into the artery or vein through a catheter over a wire in a vessel accessed remotely from the location of the injury. Once deployed, blood flows through the channel created by the endograft rather than the damaged native lumen of the blood vessel.

Coils and plugs

A mainstay of treating vascular injuries in small end-vessels is coil embolisation. In this technique, a catheter is placed near the site of injury. A small metal coil (Figures 5 and 6) is then advanced through the catheter where it expands in the vessel and blocks the flow of blood distally. Coils are usually packed tightly in the vessel in order to best block the flow of blood. Some coils have fibres or filaments that promote coagulation to stop blood flow.

FIGURE 5

Vascular coil. This small platinum coil is advanced through a microcatheter and packed into a small artery to occlude flow permanently.

FIGURE 6

Vascular coils. 63-year-old female with severe splenic trauma after a motor vehicle accident. She underwent splenectomy but developed bleeding two days later. A pseudoaneurysm was identified on CTA (images not shown), and confirmed on angiography (A) (arrow). The artery is irregular due to vasoconstriction or spasm from severe blood loss. Coil embolisation was performed through a microcatheter in the splenic artery (B and C).

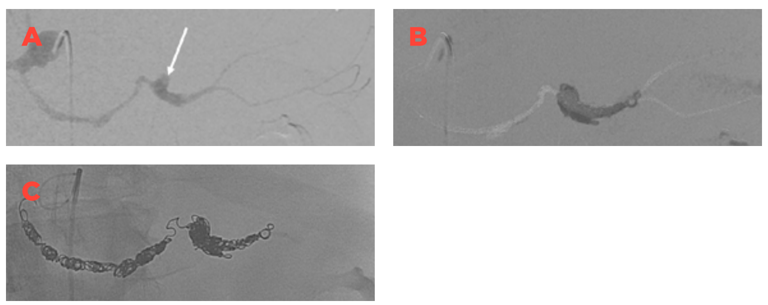
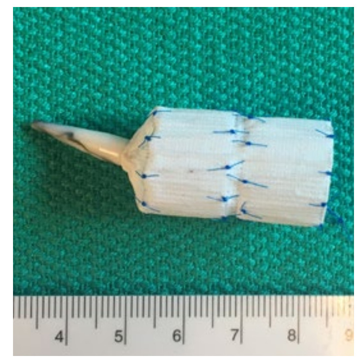


FIGURE 7

Vascular plug. Plugs come in multiple sizes and shapes. This plug is used to occlude large vascular conduits to stop blood flow.



Vascular plugs (Figure 7) can also be used in medium and large arteries to occlude blood flow. These are used often in treating fistulous communications between arteries and veins and for occluding flow in aneurysms. Vascular plugs are usually larger than coils and can be deployed in a controlled manner.

Particles

Similar to coils, particles can be injected into small blood vessels where they flow in the same direction as the blood to stop bleeding. Numerous agents are available and selection of the agent depends on the goal of therapy. Calibrated particles can range from 45–1200 microns in size and result in ischaemia to the target tissue. These may include polyvinyl alcohol, glass beads, and acrylic beads. These agents are rarely used in trauma due to the unnecessary ischaemia imposed on the distal tissue. These particles are often used to treat vascular tumours or other cancerous lesions by starving the tissue of oxygen and nutrients carried in the blood.

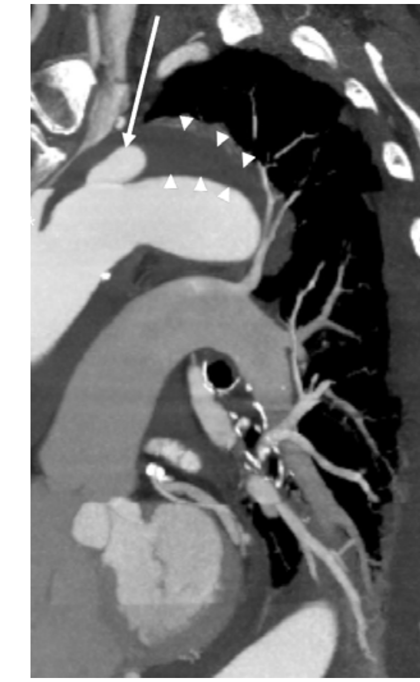
Gelatin sponges (Figure 8), on the other hand, are used routinely to stop bleeding in small vessels. In this technique, the gelatin sponge is cut into small pieces by the interventionalist and reconstituted in a mixture of saline and iodinated contrast. The mixture is then injected into the damaged vessel until haemostasis has been achieved. Over the next several hours to weeks, the gelatin sponge is resorbed and the vessel usually recanalises after it has healed.

FIGURE 8

Gelatin sponge. Gelatin sponge is cut into small pieces (inset) and mixed in a syringe with saline and iodinated contrast for visualisation. It is then injected into small vessels for temporary occlusion. The gelatin is absorbed in the following hours to weeks following the procedure.

FIGURE 9

Traumatic aortic injury with pseudoaneurysm. 52-year-old male involved in a motor vehicle accident. Sagittal oblique reformat from CTA shows a focal pseudoaneurysm (arrow) arising from the descending thoracic aorta proximally, just beyond the origin of the left subclavian artery (*). Haematoma (arrowheads) surrounds the aorta near the site of injury.



Liquid embolics

More recently, liquid embolic agents have been developed to stop bleeding from blood vessels. NBCA (N-butyl cyanoacrylate), a type of liquid glue, has been developed that can be directly injected into a blood vessel through a catheter at the site of injury to immediately stop blood flow. A similar product is ethylene-vinyl alcohol copolymer that polymerises while it propagates distally with blood flow as it is being injected from the tip of the catheter. The use of these products requires experienced operators and is often cost-prohibitive.

Another embolic agent used percutaneously is thrombin. Thrombin is a direct component of the coagulation cascade. When injected into flowing blood, the blood clots immediately. This is particularly useful in treating pseudoaneurysms, focal outpouchings of weakened vascular walls (usually containing one or two layers of the wall) where blood is swirling in a circular fashion.

With these novel IR tools in mind, the sections that follow describe the therapeutic procedures offered by IR by category of injury.

MANAGEMENT OF VASCULAR TRAUMA

Traumatic aortic injury

Traumatic aortic injury (TAI) is a general term for a spectrum of aortic injuries

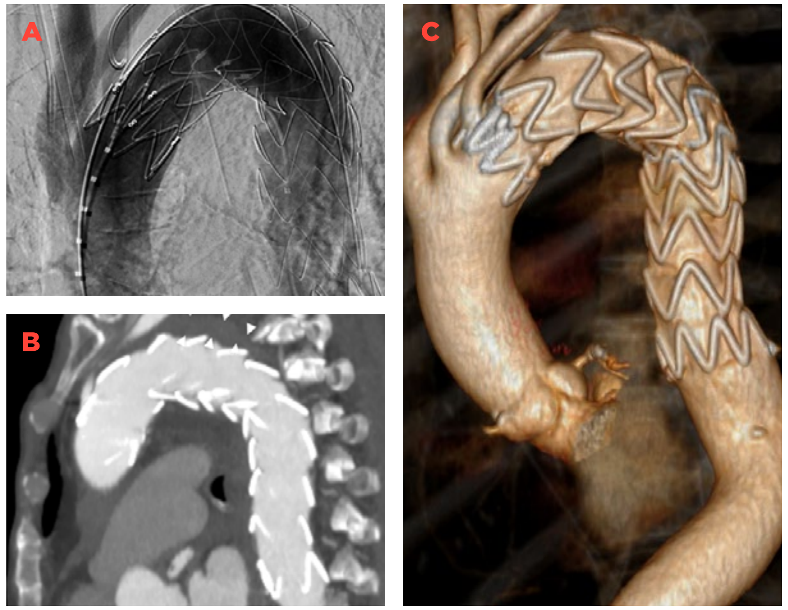


FIGURE 10

Traumatic aortic injury repair. Following placement of an endograft in the aorta in the same patient from the previous figure, angiogram (A) and sagittal oblique (B) and volume rendered (C) images from CTA show resolution of the pseudoaneurysm. Note residual haematoma (arrowheads) which will absorb over time.

encompassing intramural haematoma, aortic dissection, aortic transaction, and aortic pseudoaneurysms. TAI is an immediate life-threatening emergency. TAI occurs in up to 25% of high-speed motor vehicle accidents and other high-velocity injuries and result in death at the scene of the accident in 70–90% of cases. Of those who arrive at the Emergency Department (ED), 29% of patients die within the first hour, and the in-hospital mortality for the remaining patients is 44%.

The type and location of the injury within the aorta determine the treatment method. Intimal tears (rips within the lumen of the artery) can initially be treated conservatively with tight control over blood pressure and heart rate. More severe injuries, including extravasation or pseudoaneurysm (Figure 9), are treated with surgery or endovascular intervention.

The most common traumatic injury to the aorta occurs distal to the left subclavian artery – as a result of concussive injury or blunt trauma – at a location where the aorta is fixed in place by ligamentous attachments. Interventional endovascular therapy has become the treatment of choice with these patients, greatly reducing the mortality and morbidity rates associated with the trauma and therapy. The treatment involves transcatheter placement of an endograft (Figure 10). Limitations in endograft technology have limited the placement of a graft in the ascending aorta and aortic arch, and open surgery is usually indicated; however, recently investigators have been exploring the possibility of endografts in the ascending aorta.

FIGURE 11

Peripheral vascular injury. 78-year-old male with an injury undergoing endovascular aneurysm repair (EVAR). (A) Angiogram of the left external iliac artery shows bleeding outside of the artery (arrows) into the pelvis. (B) Following stent-graft insertion (dashed arrows), the bleeding has stopped and blood flows through the channel created by the stent-graft.

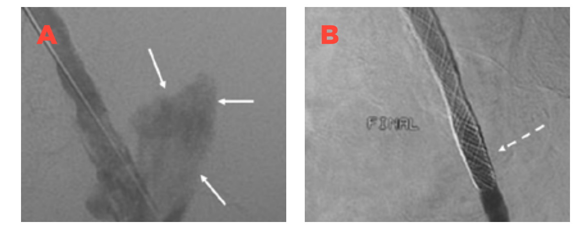
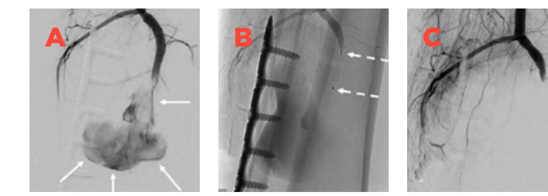


FIGURE 12

Peripheral vascular injury. 24-year-old male was hit by a car with a penetrating wound to his leg. (A) Angiogram shows active bleeding from the peroneal artery (arrows). (B) A vascular plug (dashed arrows) was placed into the artery to stop the bleeding. Plates and screws are along the fibula bone from a previous injury. (C) Angiogram after embolisation shows cessation of extravasation.



Peripheral vascular injuries

Although TAI is the most devastating injury encountered in vascular trauma, peripheral vascular injury can also lead to high rates of mortality and morbidity. Both penetrating and blunt injuries to peripheral vessels can lead to bleeding and exsanguination, resulting in death. The majority of these injuries can be treated using an endovascular approach obviating the need for surgery. Penetrating injuries to a peripheral artery can be treated by placing a covered stent (stent graft) at the site of the injury if the vessel is large enough (Figure 11). In smaller end-arteries, vessels can be occluded with coils, plugs (Figure 12), or particulate embolisation to treat pseudoaneurysms and extravasation. IR-driven therapeutic procedures have replaced the need for surgery in almost all cases of vascular trauma to the peripheral arteries.

SOLID ORGAN INJURY

Splenic trauma

The spleen is a highly vascular solid organ and is quite susceptible to trauma (Figure 13). High-speed, deceleration, penetrating, and concussive injuries can result in splenic trauma. Injuries are categorised using imaging according to the location and degree of damage to the vessels and parenchyma (Table 1). In general, most injuries are self-limiting and can be managed nonoperatively. Type IV and V injuries often require splenectomy. If there is evidence of active extravasation or pseudoaneurysm formation in the parenchyma, IRs perform catheter angiography and embolisation. If a focal region of extravasation or pseudoaneurysm is identified, gelatin sponge or permanent agents can be administered directly into the area of haemorrhage. Coil

TABLE 1

American Association for the Surgery of Trauma Grading for Splenic Trauma

GRADE	INJURY TYPE	DESCRIPTION OF INJURY
I	Haematoma	Subcapsular, <10% surface area
	Laceration	Capsular tear, <1cm parenchymal depth
II	Haematoma	Subcapsular, 10–50% surface area intraparenchymal, <5cm in diameter
	Laceration	Capsular tear, 1–3cm parenchymal depth that does not involve a trabecular vessel
III	Haematoma	Subcapsular, >50% surface area or expanding; ruptured subcapsular or parenchymal hematoma; intraparenchymal haematoma ≥5cm or expanding
	Laceration	>3cm parenchymal depth or involving trabecular vessels
IV	Laceration	Laceration involving segmental or hilar vessels producing major devascularisation (>25% of spleen)
V	Laceration	Completely shattered spleen
	Vascular	Hilar vascular injury with devascularisation of spleen

TABLE 2

American Association for the Surgery of Trauma Grading for Liver Trauma

GRADE	INJURY TYPE	DESCRIPTION OF INJURY
I	Haematoma	Subcapsular, <10% surface area
	Laceration	Capsular tear, <1cm parenchymal depth
II	Haematoma	Subcapsular, 10–50% surface area intraparenchymal, <10cm in diameter
	Laceration	Capsular tear, 1–3cm parenchymal , <10cm in length
III	Haematoma	Subcapsular, >50% surface area of ruptured subcapsular or parenchymal haematoma; intraparenchymal haematoma >10cm or expanding
	Laceration	>3cm parenchymal depth
IV	Laceration	Parenchymal disruption involving 25–75% hepatic lobe or 1–3 Couinaud's segments
V	Laceration	Parenchymal disruption involving >75% of hepatic lobe or >3 Couinaud's segments within a single lobe
	Vascular	Juxtahepatic venous injuries; i.e., retrohepatic vena cava / central major hepatic veins
VI	Vascular	Hepatic avulsion

TABLE 3

American Association for the Surgery of Trauma Grading for Kidney Trauma

GRADE	INJURY TYPE	DESCRIPTION OF INJURY
I	Contusion	Microscopic or gross haematuria, urologic studies normal
	Laceration	Subcapsular, nonexpanding without parenchymal laceration
II	Haematoma	Nonexpanding perirenal haematoma confined to renal retroperitoneum
	Laceration	<1.0cm parenchymal depth of renal cortex without urinary extravasation
III	Laceration	<1.0cm parenchymal depth of renal cortex without collecting system rupture or urinary extravasation
IV	Laceration	Parenchymal laceration extending through renal cortex, medulla, and collecting system.
	Vascular	Main renal artery or vein injury with contained haematoma
V	Laceration	Completely shattered kidney
	Vascular	Avulsion of renal hilum which devascularises kidney

FIGURE 13

Fractured spleen. (A) CT scan with contrast shows a Grade III injury with a focal laceration in the periphery of the spleen (arrows) with surrounding haematoma (arrowheads). (B) CT scan of a normal spleen for comparison.indicate lacerations extending through the left lobe of the liver.

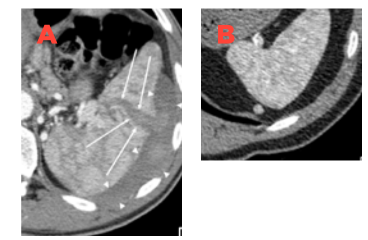


FIGURE 14

Fractured liver. 38-year-old male involved in a motorcycle accident. CT scan with contrast showing a Grade IV hepatic laceration. Low-density linear regions (arrows) indicate lacerations extending through the left lobe of the liver.

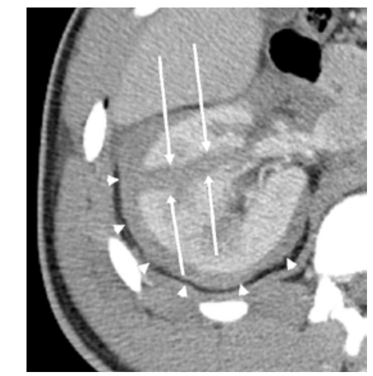


FIGURE 15

Fractured kidney. 19-year-old female involved in a high-speed motor vehicle accident. CT scan with contrast showing a Grade IV laceration. A low-density linear region (arrows) indicates a laceration with surrounding haematoma (arrowheads).

embolisation can be performed in the distal arterial branches. This leads to local infarction of the splenic parenchyma, which is generally well tolerated. If there is more diffuse injury, proximal embolisation of the splenic artery can be performed with coils or plugs to decrease arterial pressure to the spleen. Parenchymal infarction rarely occurs with this method since collateral blood flow offers sufficient blood supply to the spleen.

Whenever splenic artery embolisation or splenectomy is considered, prophylactic immunisations should be given to the patient. One important function of the spleen is to prevent bacterial infection from encapsulated organisms. These include certain streptococcal and meningococcal species among others; thus, vaccinations against pneumonia and meningitis should be administered.

Liver and kidney trauma

Similar grading systems exist for liver and kidney injuries (Tables 2 and 3). As with the spleen, the degree of injury noted on imaging dictates initial treatment. Most injuries can be treated non-operatively, particularly in the liver. However, if pseudoaneurysm or contrast extravasation is noted, intervention is indicated. Rarely with severe injury may nephrectomy be necessary. Figures 14 and 15 show representative cases of liver and kidney injuries.

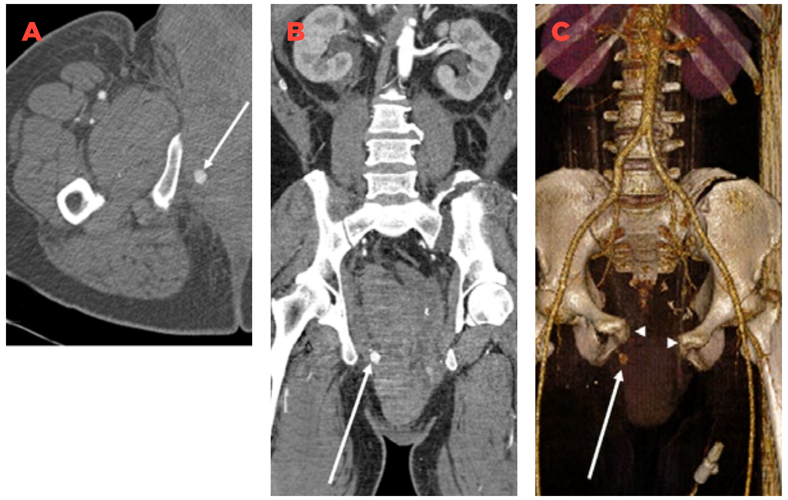


FIGURE 16

Pelvic fracture with pseudoaneurysm. 48-year-old male involved in an All-Terrain Vehicle (ATV) accident. Axial (A), sagittal (B), and volume rendered (C) CTA images show a small pseudoaneurysm (arrows) arising from a distal branch vessel in the pelvis. There is a large haematoma in the pelvis. Note the associated pelvic fracture with widening and offset of the pubic symphysis (arrowheads in C).

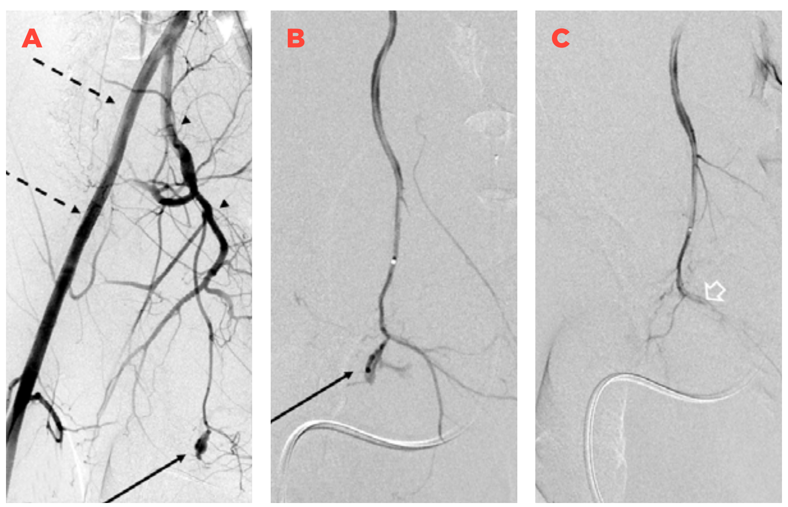


FIGURE 17

Embolisation of traumatic pelvic pseudoaneurysm. Angiographic images obtained from a similar case to that shown in the previous figure. (A) Non-selective angiogram showing a small pseudoaneurysm (solid arrow) arising from distal branches of the internal iliac artery (arrowheads). For anatomical reference, the external iliac artery is noted (dashed arrows). (B) Selective angiogram through a microcatheter localises and confirms the pseudoaneurysm (arrow). (C) Following gelatin sponge embolisation, the pseudoaneurysm has occluded with no residual flow noted. There is 'pruning' of distal branches (open arrow) indicating embolisation of non-targeted branches as expected.

PELVIC TRAUMA

High-speed and concussive injuries, and, on rare occasion, penetrating injuries, lead to pelvic fractures. The most common cause is motor vehicle accidents. Severe pelvic fractures are often associated with pelvic vascular injuries, and death from pelvic trauma is commonly due to vascular extravasation within the first 24 hours. Pelvic fractures lead to bleeding directly from bone and associated venous and arterial injury.

Prior to the advent of IR, these injuries were often fatal. Surgical repair of the deep pelvic vasculature is exceedingly difficult and ligation of the proximal pelvic arteries results in only a 50% reduction in pelvic blood flow due to a rich collateral network. Trauma surgeons would pack the pelvis with lap pads and gauze in hopes of stopping the bleeding with limited success when arterial injury was present. Now, urgent consultation to IR offers a better and minimally invasive method of stopping the haemorrhage. Steve Scalise, a US Congressman recently attacked by an armed gunman, presented with a bullet injury to his hip, a location not commonly associated with a mortal wound. However, the bullet lacerated blood vessels in his pelvis producing massive haemorrhage, placing him in life-threatening critical condition. This required emergent intervention and embolisation by IR and surgery and necessitated numerous blood transfusions.

Management of pelvic vascular injury is dependent on the patient's haemodynamic status at presentation and response to resuscitative efforts of repletion with blood and intravenous fluids. Patients that are unstable at presentation should be treated urgently with pelvic ring stabilisation including external fixation or binding to help stabilise venous bleeding originating from bone fractures and their nearby tissues. Open surgical packing of the pelvis remains widely used for venous bleeding if stabilisation is not successful. If arterial bleeding is suspected, embolisation should be provided immediately (Figures 16 and 17).

Bleeding is typically from a small branch vessel of the hypogastric (internal iliac) artery. If time allows, selective angiography and coil embolisation can successfully eliminate bleeding from the small vessel(s). In the more acute setting, embolisation of the entire hypogastric artery can be performed with gelatin sponge. Vascular recanalisation of the hypogastric artery occurs in several hours to weeks after the damaged vessel has healed. Arterial embolisation of pelvic bleeding provides a minimally invasive solution to life threatening, traumatic pelvic bleeding.

SUMMARY

Management of acute traumatic injuries has changed dramatically over time. The development of minimally invasive, image-guided techniques has led to a revolution in the treatment of traumatic bleeding. By pioneering innovation through endovascular management, interventional radiologists are now at the forefront of trauma care and provide a minimally invasive means for life and limb saving therapy.

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accomplished his medical studies at Louisiana State University Health Sciences Center at New Orleans from 2000 to 2004 and residency training in radiology at the same university in the following year and at University of Pittsburgh Medical Center, Pennsylvania, USA from 2005 to 2009. He did a fellowship training at Baptist Cardiac and Vascular Institute at Miami, Florida in affiliation with the University of South Florida, Vascular and Interventional Radiology of the Department of Radiology in 2010. Dr. Schiro became board certified by the American Board of Radiology, with a Subspecialty Certificate in Interventional Radiology in 2011. Dr. Schiro has been practicing interventional radiology at Miami Cardiac and Vascular Institute from 2010 to present. He is lead investigator and principal investigator of research projects in the domain of interventional radiology and was Program Director of the Washington Health System Tumor Board in 2015. Dr. Schiro has conducted research in retrievable biliary stents and tissue-engineered blood vessels focussing on abdominal and thoracic aortic aneurysm. He is a member of various American professional organisations, and has authored scientific publications and given presentations at scientific meetings and congresses in various radiologic subspecialties.

DR. CONSTANTINO S. PEÑA

accomplished his medical studies at Yale University School of Medicine, New Haven, Connecticut, USA, from 1990 to 1994. After a one-year internship in internal medicine, he underwent his residency training in diagnostic radiology at Massachusetts General Hospital, Boston, from 1995 to 1999 and completed a fellowship in vascular and interventional radiology from 1999 to 2000. Dr. Peña was a Clinical Fellow of Radiology at Harvard Medical School from 1996 to 2000, and instructor of radiology from 2000 to 2001. He has been Affiliate Assistant Professor of Radiology at University of South Florida College of Medicine at Tampa, Florida, from 2006 to present and a Clinical Assistant Professor of Radiology at Florida International University College of Medicine at Miami, from 2010 to present. Dr. Peña became board certified in diagnostic radiology in 1999 and certified in added qualifications in vascular and interventional radiology in 2001 and 2011. He was Director of Interventional Radiology at Mercy Hospital from 2003 to 2005 and has been Medical Director of Vascular Imaging at Baptist Cardiac and Vascular Institute, Baptist Hospital, in Miami from 2005 to present. Dr. Peña is a member of numerous American and international medical societies and associations. He has authored a long list of publications, including book chapters, lectured regularly at scientific meetings and congresses and delivered invited lectures in the USA and abroad, predominantly in the field of vascular diagnostic and interventional radiology.

DR. BARRY T. KATZEN

got his medical education at University of Miami School of Medicine, Miami, Florida, USA from 1966 to 1971, followed by an internship at Jackson Memorial Hospital in 1970 and 1971. He had his residency training in radiology at Cornell Medical Center, New York Hospital, as well as at Memorial Hospital; Sloan Kettering Cancer Institute; and Hospital for Special Surgery, from 1971 to 1974, followed by a fellowship in cardiovascular radiology at St Vincent's Hospital Medical Center, New York, from 1974 to 1975. Dr. Katzen was certified by the American Board of Radiology in 1974, with added qualifications in vascular and interventional radiology in 1994. He was a Clinical Assistant and Chief of Cardiovascular Radiology at St Vincent's Hospital and Medical Center from 1974 to 1976 and Chief of Cardiovascular and Interventional Radiology at Alexandria Hospital, Alexandria, Virginia, from 1976 to 1987. Dr. Katzen founded the non-invasive Vascular Lab at Miami Cardiac & Vascular Institute, Baptist Hospital, Miami in 1987 and was the Medical Director until 2014. He was appointed Clinical Professor of Radiology at George Washington University Medical Center in 1981 (to 1987), Professor of Radiology at University of Miami School of Medicine in 1987 (to present), Clinical Professor of Radiology at University of South Florida in 2005 (to present) and Associate Dean for Clinical Affairs, Clinical Professor of Radiology and Surgery at Herbert Wertheim College of Medicine, Florida International University at Miami in 2010 (to present). Dr. Katzen is an advisor to many companies producing interventional tools and founder of the Endovascular Forum. He is founding editor of Techniques of Vascular Interventional Radiology, *chief medical editor of* Endovascular Today, *and was a senior editor of* Cardiovascular Radiation Medicine *in 2003 and has been consulting editor and associate editor to other scientific journals. He was a Gold Medal Recipient of the Society of Interventional Radiology in 2002 and Gold Medal Recipient of the Cardiovascular and Interventional Radiological Society of Europe in 2006. He was distinguished with the Iron Arrow Award from the University of Miami in 2007 and received a Distinguished Achievement Award from the American Heart Association Council on Cardiovascular Radiology and Intervention in 2008, the Cor Vitae Heart Award from the American Heart Association for his Lifetime Achievement in 2010 and the Lifetime Achievement Award by Dade County Medical Association in 2010. Doctor Katzen has held the position of Founder and Chief Medical Executive of Miami Cardiac and Vascular Institute at Baptist Hospital of Miami from 2014 to present. He is a gifted educator and lecturer at scientific meetings and congresses in the USA and throughout the world and a prolific writer.*

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THE VISIBLE, THE INVISIBLE AND THE INVINCIBLE CLINICAL RADIOLOGIST

THE VISIBLE, THE INVISIBLE AND THE INVINCIBLE CLINICAL RADIOLOGIST – WHERE DOES TELERADIO-LOGY FIT?

BY **DINESH VARMA** AND **MILO MACBAIN**

A COMMON SCENARIO

It's 12 a.m. in a regional hospital in rural Australia. A 75-year-old lady presents to the emergency department two hours after first noticing that she was unable to hold her pen properly while trying to do her crossword puzzle in bed. Her husband then noticed she had slurred speech and a droopy face. She is rushed to the local emergency department where on first assessment by the emergency department (ED) doctor, she is found to have dysarthria, right-sided facial droop and right upper-limb weakness. It is suspected that this patient is having a stroke.

The next step in management depends largely on the cause of the stroke: is it due to a blockage in a blood vessel in the brain by a blood clot (ischaemic stroke)? If so medication to break down the clot (thrombolysis or clot retrieval) can be administered; or is it due to a haemorrhaging blood vessel in the brain (haemorrhagic stroke), which would be made worse by thrombolysis and hence must be ruled out? If this is in fact an ischaemic stroke, caused by a blood clot, then time is of the essence – the sooner the patient is given thrombolysis the less likely the permanent damage to the brain … 'Time is brain!'

The only way to be sure as to the cause of the stroke is to request an urgent CT scan (computerised tomography) of the patient's brain, which will either show bleeding, if there is any, or signs of a blood clot. The ED doctor requests the CT scan, which is performed immediately at 12:25 a.m. in the hospital's CT scanner. The only issue is that there is no clinical radiologist on site to interpret the results of the CT scan.

THE 21ST CENTURY

In the past, this would have meant phoning a radiologist who is at home asleep, waking him or her up and asking them to come in and review the scans, or review the scan from home if they have the possibility of doing so. However, this rural hospital has enlisted the services of a teleradiology company, so that there is no need to have a radiologist on call overnight. Rather, the CT images are sent electronically to the teleradiology company, who have offices round the world, which means that a clinical radiologist, trained and registered in Australia, can review the scans on a computer in an office in London, where it is currently 3:30 p.m. The radiologist reviews the images promptly as they are marked urgent, given the clinical diagnosis of stroke. The radiologist reports the scans as showing no sign of a bleed in the brain but there is evidence of a blood clot in the left middle cerebral artery, meaning ischaemic stroke which is consistent with the patient's symptoms. He or she immediately phones through the result to the ED doctor who requested the scan, to notify of the finding. The ED doctor, now equipped with the knowledge that the patient is having an ischaemic stroke, organises thrombolysis medication for the patient that will aim to break down the blood clot and reduce the damage to the brain. Within 60 minutes of presenting with a stroke, this patient who lives in a regional town was given treatment that may save her from significant long-term brain damage. The off-site clinical radiologist (the invisible expert) played a key role in allowing this to happen safely and quickly.

Emergency medicine is an ever-changing field, and as it evolves, so does the field of emergency radiology. In recent years, expanding populations and the push for access to high quality healthcare 24 hours a day, 7 days a week, has put increasing pressure on radiology departments – they're being asked to perform more diagnostic tests, for more patients, in less time, as highlighted by the above scenario. This has led to the development of the field of teleradiology.

WHAT IS TELERADIOLOGY?

To understand the concept of teleradiology, it is first important to understand the role of the clinical radiologist in general. Clinical radiologists are medical practitioners who have undertaken broad medical training as well as comprehensive specialist training in performing and interpreting diagnostic imaging tests and imaging-guided procedures or treatments that involve the use of a range of imaging modalities.

Diagnostic imaging uses plain x-ray radiology, CT, magnetic resonance imaging (MRI), ultrasound, nuclear medicine imaging and other techniques to obtain images which are then interpreted to aid in the diagnosis of illness and injury.

Those practicing interventional radiology, a subspecialty of radiology, undergo further rigorous training in providing various treatments through minimally invasive techniques. The procedures they perform vary from draining abscesses, opening up narrowed or blocked arteries to emergently removing blood clots in the arteries of the brain that cause stroke as exemplified in the case above.

The vast majority of clinical radiologists will provide the services on site where the patients undergo their imaging tests and are employed either by the health service or are in private practice. However, the growing demand for round-the-clock, rapid and high quality diagnostic imaging, even in rural and remote facilities, is making it less and less feasible to have on-site clinical radiologists performing every imaging interpretation. For this reason, the concept of teleradiology has been born and there has been rapid growth in this area allowing radiologists to work 'normal hours' taking advantage of the global time zone differences (convenient for some).

Teleradiology is defined as the transmission of patients' radiological images electronically from one location (acquisition site) to another for either viewing or reporting purposes. Radiologists utilise this technology to provide an assessment and report on these images remotely (reporting site). What this means is that rather than needing to have a clinical radiologist on site or on call for 24 hours a day, a health service can outsource some of their diagnostic imaging reporting services.

HOW DOES TELERADIOLOGY WORK?

Over the past 15 years several companies that offer teleradiology services in Australia have emerged, all of who pride themselves on 'following the sun'. Their general business model is that they have Australian-trained and registered clinical radiologists working from offices around the world, so that no matter what time it is in Australia when a scan is performed, there will always be a consultant radiologist working in their respective daylight hours, ready to report the scan. In the example scenario above, the CT scan is performed on site by a trained radiographer (an imaging technician). The teleradiology company utilised by the health service has an office in London. The CT images that are produced on site are immediately transferred using a secured data-sharing method to the London office, where an Australian consultant radiologist, working a standard daytime shift, reviews the scan. All the while, the on-site clinical radiologist in Australia who is expected to be at the hospital at 8 a.m. that morning, is not woken up to report the scan, and therefore awakes

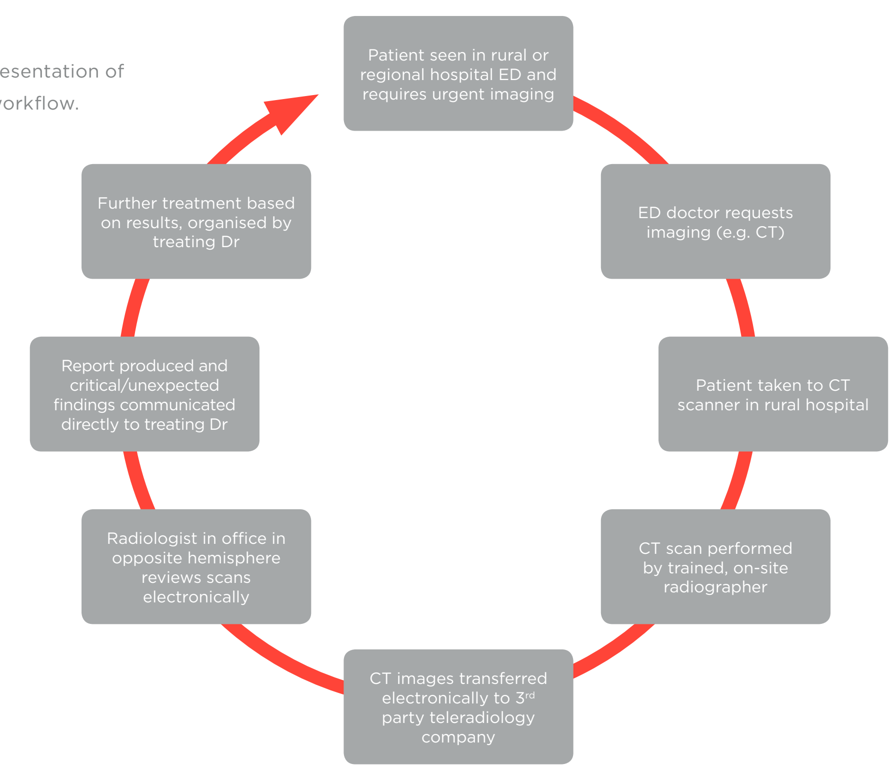
well-slept and ready to perform his or her duties that day in a safe and timely manner. (Figure 1 shows the workflow schematically.)

APPLICATIONS AND POTENTIAL BENEFITS OF TELERADIOLOGY IN AUSTRALIA: THE EMERGENCY SETTING

Teleradiology can help to alleviate pressure on radiology departments in multiple ways. The most obvious area where teleradiology is useful is in the emergency medicine setting. As described earlier, for multiple reasons it can be difficult or impractical for hospitals to have a clinical radiologist on site or on call 24 hours a day, 7 days a week. Despite this fact, the need for access to a timely, high-grade, consultant-level diagnostic imaging opinion around the clock cannot be denied, even in rural and remote regions. Having a consultant radiologist on site is costly and requires a sufficient number of radiologists to share the workload and simply cannot be justified by some health care services. The on-call aspect is economically costly, with clinicians being rightfully paid overtime rates when they are

FIGURE 1

Schematic representation of teleradiology workflow.



called in after hours. The remuneration for the on-call radiologist is dependent on the health service they are employed by and will take into account the time they are expected to be on call and available to provide the service and not simply on an 'on-demand' basis.

This also undoubtedly has an impact on the clinician's well-being and their ability to function safely the following day after a night of being on call.

Teleradiology companies alleviate this strain on the individual clinicians, by eliminating the need for an on-call radiologist. They also potentially reduce costs, as when engaging a teleradiology company, the health service usually pays on an 'as needed' basis, based on the service level agreement. The common model is 'fee for service' depending on the modality e.g. plain x-ray, ultrasound, CT, or MRI scan. There is then the initial cost of setting up appropriate connectivity with the hospital and radiology IT infrastructure.

It is not just rural and small health facilities in Australia who are utilising teleradiology. Some larger, metropolitan tertiary centres have commissioned teleradiology companies to provide reports on some or all of their after-hours diagnostic imaging. These centres have traditionally had a radiology registrar (a junior doctor in training) in house overnight, with a consultant radiologist on call if needed. Some have decided that either their workload overnight is too excessive to be handled by a single registrar, or that it is of benefit to the health service as a whole to be getting finalised consultant reports overnight. Hence the justification to 'outsource' and utilise teleradiology services. Teleradiology no doubt has enabled health service providers to significantly improve the turnaround time of the final radiology reports after hours and therefore provide timely care for their patients.

This model is not restricted to the public sector. There are some private radiology facilities that serve large private hospitals and also use another private teleradiology service provider for after-hours and particularly overnight reporting.

DAY-TO-DAY OVERFLOW

Teleradiology has applications beyond after-hours reporting and emergency reporting. Several companies offer an 'as-needed' overflow service, whereby health services can send scans done within normal working hours for teleradiology reporting. This can be utilised, for example, on days that are busier than anticipated or to cover sick leave for on-site staff. This may also be of use when a particular radiology department doesn't have a subspecialist radiologist for a certain body region, as some teleradiology companies offer subspecialist support. The financial modelling of fee for service is usually similar to after-hours reporting.

PEER REVIEW

It's recognised that peer review is a key to maintaining high standards in diagnostic imaging as it is in any other field of medical practice. This means having a certain percentage of scans reported by a second consultant

radiologist to ensure that each radiologist's work is being reviewed and that any systematic mistakes can be identified and learned from. This type of peer review is essential to quality assurance and, as highlighted by a Price Waterhouse Coopers analysis published in 2013, may be the most important factor in improving the economic efficiency of diagnostic imaging for the Australian healthcare system as a whole. Even with this in mind, on an individual health service level, and particularly the individual clinician level, peer review is still a time consuming process, and prevents consultant radiologists from performing other tasks such as reviewing new scans, performing interventional procedures, teaching trainees and attending multidisciplinary clinical meetings. Recognising the impact of peer review on the on-site radiologist, some teleradiology companies offer peer review services whereby a certain percentage of scans from a hospital are re-reported by an off-site consultant clinical radiologist with similar expertise. If the cost of this second read being done by a teleradiology company is less than the overall cost of having an on-site radiologist doing a second read, then this service stands to improve the cost efficiency of the radiology department, through freeing up on-site radiologists to perform other tasks.

IS TELERADIOLOGY A SUBSTITUTE FOR ON-SITE CLINICAL RADIOLOGISTS?

Radiologists must have an active role in determining whether a patient requires imaging and if so, which imaging is most appropriate: the visible radiologist. Teleradiologists – the invisible radiologists – unfortunately cannot substitute for the advantages a clinical radiologist provides by being physically present where the patients are. The value of the face-to-face discussion between treating clinicians and radiologists cannot be underestimated – it streamlines the process of getting a patient the imaging they need in a timely manner. In many emergency departments, the on-site radiologist will be located in an office in the emergency department and will be in constant discussion with the lead doctors in the ED, coordinating and triaging workflow based on medical urgency. They will be working closely with the emergency medicine physicians on how to best achieve the common goal of providing all patients with timely, quality care. The on-site clinical radiologist often gives the treating doctor advice on which type of imaging will best answer their clinical question, which is a function that could be achieved by an off-site radiologist over the phone, but with much less efficiency and convenience. The on-site radiologist also supervises complex or difficult scans, and assists the technical staff in performing such scans. An off-site clinical radiologist simply cannot perform this function.

International teleradiology poses some difficulties concerning language and regional practice differences. Certain terminology may be used and understood by doctors in a certain region that is not utilised and understood by those in another region or country. With cultural and health system differences, there are also differences in the way that medical imaging is applied and reported, and in the ways that clinical radiologists interact with other medical and allied health staff. It is important to recognise these issues when utilising teleradiology, to ensure that all involved healthcare providers are using standardised language and procedures in order to provide high quality, safe patient care that complies with local standards.

Teleradiology has some inherent delays – the transfer of images electronically from the site of acquisition to the reporting site takes time, and in some cases this can be of critical importance. The system also opens more potential for technological glitches to get in the way of timely and quality diagnostic imaging.

Imaging is largely protocol driven, however in complex cases radiologists advise the radiographers of any variation to protocol and occasionally tailor the test while the patients are still in the radiology department. Unfortunately, teleradiology does not offer the opportunity to review the images while patients are still in the scanner in case further imaging needs to be performed. An off-site radiologist cannot perform interventional procedures, which is a significant part of the workload performed by the on-site clinical radiologist. As such, teleradiology is applicable only to diagnostic imaging.

Multidisciplinary meetings, involving members from various medical and allied health teams, including a radiologist, involving getting together in one physical location all at the same time have become an important part of high level care for difficult or complex cases. The benefit of having all treating specialists in one room together for a real-time discussion cannot be underestimated and an on-site clinical radiologist is central to this process, often taking a lead role.

An important role for the on-site clinical radiologist is that of teaching radiology trainees (registrars). This requires face-to-face mentoring, which gives the trainee the opportunity to directly observe the diagnostic and analytical approach employed by the consultant, and to receive on-the-spot feedback on their work. This teaching role is something that would be very difficult to fulfil without a consultant radiologist on-site.

LEGITIMACY AND GOVERNANCE OF TELERADIOLOGY

Your first impression may be that teleradiology is fraught with legal barriers and poses risks to quality assurance and patient safety and privacy. For example, significant legal issues are posed by the concept of having a doctor in another country providing health care services to patients in Australia. The Royal Australian and New Zealand College of Radiologists (RANZCR), the primary body advancing patient care and quality standards in clinical radiology in Australia and New Zealand, has released several position statements on teleradiology and its implementation in Australia which can be found on their website. These guidelines outline the accepted principles that need to be adhered to by teleradiology companies and the health services that utilise them.

One guideline is that in order to report imaging in Australia, a clinical radiologist must be a doctor who is registered to work in Australia and whose specialist radiology training is recognised in Australia. Furthermore, the clinician must be appropriately credentialed to work in the hospital where the images are acquired. All clinical radiologists must also be fully indemnified in Australia. This is of key importance, as it is recognised that a patient should never be put in a position where they experience a medical mishap and are left having to deal legally with a doctor who is based overseas and who doesn't have legal obligations in Australia. It is recognised that all patients must be given the right to undertake legal action in their home country, under the laws that govern where the acquisition site is located.

RANZCR states that radiologists working for teleradiology companies should assume ultimate responsibility for the diagnostic imaging and for patient safety. The teleradiologist should also ensure adherence to appropriate quality standards, at both the transmitting end and the receiving end. RANZCR also recommends that clinical teleradiologists be registered and qualified to work as clinicians in the country from where they are reporting.

Teleradiology companies have worked with Australian governments and health services to ensure that the services they provide comply with local health board and government regulations, and they have also initiated quality assurance measures in order to comply with RANZCR standards. Other OECD countries have similar regulations that govern the delivery of teleradiology services. Other radiology specialist colleges and societies have also developed their jurisdiction-specific policies and guidelines with the common intent to protect the rights of their patients.

QUALITY ASSURANCE

Responsibility for the quality of imaging services is an essential component of the clinical radiologist's role. Clinical radiologists have responsibilities related to all aspects of the imaging process: equipment selection and maintenance; proper training and supervision of allied health staff; the design of imaging protocols; policies and procedures for patient management and safety; and reporting standardisation and techniques.

Each teleradiology company enters into a specific agreement with each health service that utilises its services. Specific expectations and guarantees are outlined for the partnership, including expected time frames for receipt of both urgent and routine reports, and for the expected quality of reports as well as for the processes that will be put in place for quality assurance. The teleradiology companies currently offering services in Australia have quality assurance programmes in place, including peer review of the accepted percentage of cases, continued medical education, and regular teleconferences between clinicians in order to maintain the high quality of their services.

Teleradiology companies are required to provide reporting stations for their clinical radiologists that meet the same minimum standards as the on-site reporting stations utilised in Australian health services. This includes stipulations regarding screen size and resolution, and the method by which the data is transferred. Essentially, it is not acceptable for there to be any loss in quality of the images that an off-site clinical radiologist is to review compared to the quality of those available on site. Teleradiology companies manage this by taking responsibility for the installation of the infrastructure required both at the acquisition site for transferring the data, and at the reporting site for reviewing.

SECURITY, DATA PROTECTION AND PRIVACY

The same privacy and data security laws that govern other health services in Australia also govern teleradiology companies. They are responsible for keeping patient privacy and safety top priorities, and therefore there are specific requirements on the technological systems used to transfer and store data. The health service and the contracted teleradiology company must also predetermine their contingency plans for any technological issues that may prevent a transfer of data.

THE ENDURING INVINCIBILITY OF THE CLINICAL RADIOLOGIST

Whilst it is recognised that teleradiology is a means to bridge the gap between workload and workforce, it is difficult to argue that it will substitute the multifaceted role of a clinical radiologist as defined by organisations such as RANZCR, which does so in its position paper 'The Role and Value of the Clinical Radiologist':

Radiologists are trained to add value beyond just image interpretation. Working alongside other doctors and healthcare practitioners, radiologists are integral to the care of patients by making accurate diagnoses, monitoring response to treatment, performing imaging-guided treatments and advising on how best to use imaging in the care of patients.

Radiologists, as key members of multi-disciplinary teams, take a greater role in clinical decision-making and patient management, while maintaining the focus on optimising patient outcomes through higher quality, appropriate and timely imaging-based care.

Radiologists oversee the clinical journey of a patient from access to appropriate imaging modalities, patient interaction before and after imaging, to communicating the knowledge gained. Radiologists are also involved in directly providing care to patients through clinical procedures, often referred to as interventional radiology.

There are however, situations where teleradiology is invaluable in the timely and appropriate management of patients and in progressing their care. In those circumstances 'the invisible' becomes more 'visible' but the clinical radiologist remains invincible.

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Dr. Varma's research and academic involvement include 40 publications including peer-reviewed articles, book chapters and abstracts as well as being a supervisor of post-graduate degrees (Master's and PhD).

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CLINICAL DECISION SUPPORT

CLINICAL DECISION SUPPORT AND REFERRAL GUIDELINES IN EMERGENCY RADIOLOGY

BY **BORIS BRKLJAČIĆ** AND **LUIS DONOSO**

Medical imaging is a ubiquitous diagnostic tool in medicine, part and parcel of the standard operating procedure for caring for patients in an enormous number of clinical scenarios.

Since the discovery of x-rays by Wilhelm Conrad Röntgen in 1895, the scientific and technological development of imaging has been nothing short of astounding. Particularly since the 'digital revolution' in recent decades, the pace of technological innovation has accelerated exponentially, and at the same time radiologists are increasingly becoming (sub-)specialists in fields focused on a particular modality or body area.

With this ever-increasing complexity in terms of technological applications, medical knowledge and professional skills, along with the awareness of the importance of radiation safety, it is more important than ever to ensure healthcare processes are organised to ensure that patients receive the imaging examination with the highest diagnostic value for any given clinical indication.

This is where guidelines and clinical decision support systems come in. Imaging referral guidelines are a way to systematically organise knowledge about the appropriateness of the different imaging modalities and their diagnostic value for a given clinical scenario. These guidelines tell doctors in which cases an x-ray is the best option for diagnosis, for example, or whether a magnetic resonance imaging (MRI) exam is preferable over a computed tomography (CT) scan for a particular condition. Given the complexity of medical imaging, guidelines are an essential tool to support doctors in deciding what is best for their patients. In Europe, the availability of evidence-based referral guidelines is mandated by the EURATOM Basic Safety Standards (BSS) Directive, the European Union's radiation protection legislation, while the United States has gone a step further by requiring the use of guidelines via a decision support mechanism starting in 2019.

Every imaging exam needs to be medically justified, and the justification process has several steps. In the case of modalities using ionising radiation, such as plain radiography and CT, the responsibilities and process for justifying the patient's exposure to radiation are defined by law. Justification in medical imaging means that the expected medical and diagnostic benefit is greater than the associated risk. Making sure that the referral is appropriate for the patient and his or her condition is the first step in the justification process. Referral guidelines are the knowledge base that help doctors determine how appropriate various modalities are in a given situation, and clinical decision support systems are the IT tools that make guidelines user-friendly.

CLINICAL DECISION SUPPORT SYSTEMS

At the most basic level, clinical decision support is a system that utilises a knowledge base of indicators to guide the user in making a decision based on certain parameters. In the context of medical imaging, the knowledge base consists of the imaging referral guidelines, the user is the referring doctor (usually primary care physicians or specialists such as cardiologists or orthopaedists, etc.), and the parameters relevant for the decision are the patient's characteristics including age, gender, and the signs and symptoms which he or she has presented with.

Imaging referral guidelines have been available for around 25 years in many countries. They have traditionally been available as structured but narrative text documents available in print or as PDF files, and more recently also in static, searchable digital applications. Maintaining and updating the vast knowledge base composed of these guidelines is a complex and lengthy task involving dozens, or even hundreds, of radiologists and consultants from other specialties. One downside to this is that it can take a long time before a new version of comprehensive guidelines is published, while the current document slowly but continuously becomes outdated. Their narrative style can make these guidelines ill-suited for the quick decisions that are necessary in modern medicine when, on average, general practitioners in Europe only have 7 to 15 minutes to spend per patient.

CDS can go a long way in addressing these issues. One of the first steps in developing a CDS mechanism for imaging referrals is to turn the guidelines for appropriate referrals into actionable rules in an algorithmic, software-compatible format. These guidelines are often supplemented with additional recommendations based on expert consensus to broaden the coverage of clinical scenarios, and to increase the amount of structured information that is used in the process and captured by the system, which can be analysed to further improve the guidelines over time. The digital format also allows updated guidelines to be brought to the user in much shorter intervals. In addition, the system's recommendations can be adapted to reflect national regulations, local guidelines or institutional circumstances, for example taking into account the availability of certain types of imaging equipment. If an evidence-based guideline recommends the latest technology as the most appropriate option, this is of little use in practice to doctors and patients if the equipment is not available at their location.

IMPLEMENTATION AND USE OF CDS SYSTEMS

CDS systems can be used as stand-alone portals that doctors consult similarly to text-based guidelines, with the already noted advantage of being dynamic taking into account particular parameters. However, using a separate portal without access to the patient's record as well as other IT programmes the doctor would otherwise use, is not an efficient way to embed referral guidelines in clinical practice. An important condition to facilitate the use of CDS systems is the existence of an electronic referral workflow into which they can be integrated. Speed is an important factor in healthcare delivery – even more so in emergency scenarios, as we shall see later – and doctors do not have the option of spending extra time consulting guidelines to fill in forms. The widespread adoption of hospital information systems, electronic patient records, and computerised physician order entry (CPOE) systems has led to the development of streamlined IT workflows into which CDS systems can be seamlessly integrated.

In its integrated form, a CDS system does not interrupt the clinical workflow; it simply changes an existing process and adds valuable information for the doctor. By communicating with, for example, a hospital information system, CDS automatically pre-selects key patient parameters such as age and gender that are relevant for selecting the appropriate exam, while the doctor selects a structured indication based on the patient's symptoms, which previously was done as free text. In most referral forms, the doctor still has the option to add further observations that may help the radiology department carry out the examination, but the use of structured indications makes referrals much more consistent and clear than a free text request. With this information, the CDS system returns feedback on the appropriateness of the examinations that are available at the radiology department the patient is to be sent to. Usually, this information is presented by grouping the available exams into categories in descending order of appropriateness, perhaps aided by colour coding in green, yellow and red to make it visually clearer (Figure 1).

FIGURE 1

Example of how CDS displays actionable appropriateness recommendations within existing workflows.

Different configurations are possible. For example, a common way of incorporating CDS alerts is to only display them if the doctor is about to request an exam that is not appropriate to the patient's condition according to the guidelines. It should be noted that it is always the healthcare professional that makes the final decision, as CDS has a strictly advisory function in supporting this decision. Needless to say, no software is perfect, and a doctor may be able to take into account information that a digital record cannot. However, the fact that users are being made aware of guidelines, in real time and at the point of care, is a significant improvement, providing doctors with important additional information to take into account when making healthcare decisions for their patients. Hospitals that have implemented CDS in the United States have experienced a significant change in referral patterns, as doctors can now make their decisions using evidence-based recommendations either by selecting a more appropriate exam or by concluding that in a given case imaging is not justified at all. Having up-to-date evidence at doctors' fingertips has important educational benefits while making medical practice more consistent and reducing variation and the risk of medical errors. Requesting the right test the first time saves resources, time and money.

This leads us to another crucial advantage of embedding referral guidelines digitally through CDS: it makes reliable data on appropriateness available for analysis. The data gained from this process can be analysed, and findings can be used to reduce unnecessary radiation exposure, improve the efficiency of workflows, reduce waiting times, or even support long-term investment decisions in healthcare systems by giving a clearer picture of the need for different imaging modalities.

Because it affects imaging referrals from all departments, the implementation of a CDS system is an endeavour for a whole enterprise or hospital, not just for a radiology department alone. A shared understanding is needed and the leadership of the project has to be jointly agreed from the beginning with the hospital management and the clinical departments involved.

CDS IN RADIOLOGY – ACR AND ESR EXPERIENCE

The use of CDS for radiology referrals was pioneered at Massachusetts General Hospital in the United States almost 15 years ago. The experience at MGH, where the introduction of CDS led to a reduction in medically unnecessary CT scans of 12 percent between 2003 and 2007, was the starting point for a development that eventually culminated in the 2014 Protecting Access to Medicare Act (PAMA) that mandates the use of CDS and accredited appropriateness criteria for Medicare and Medicaid patients across the United States starting January 2019.

The Appropriateness Criteria of the American College of Radiology (ACR), first developed over 25 years ago, are currently the most widely adopted set of guidelines in the country. In 2012, the ACR partnered with National Decision Support Company (NDSC) to transform the Appropriateness Criteria and make them available in a CDS platform called ACR Select. As a qualified provider-led entity under the terms of PAMA, the ACR's Appropriateness Criteria are a national standard for imaging referrals, and the widespread adoption of ACR Select has afforded the ACR and NDSC a wealth of experience in delivering CDS.

This is part of the reason why the European Society of Radiology (ESR) in 2014 decided to enter into a partnership with the ACR and NDSC, which were collectively selected as the best platform provider in an open bidding process, to realise its plan to introduce a CDS system for referral guidelines in Europe. In cooperation with the ACR, the ESR 'Europeanised' the Appropriateness Criteria to create referral guidelines adapted for use in Europe. These guidelines have been available through the decision support system ESR iGuide in Europe since 2016, when the first pilot projects started in European countries.

CDS IN THE EMERGENCY DEPARTMENT

The emergency department is different from other departments in a healthcare organisation not only because of the types of patients that they see and their pathologies but also because of the issue of time which impacts healthcare delivery in two ways. First, emergencies can happen at any time of day (or night), any day of the week, any time of the year. It is obviously a significant difference if a patient comes to a hospital during regular working hours on a weekday, or whether an injury occurs during the early hours of a Sunday morning, both in terms of the staff that is present and potentially in the facilities that are available. For example, some community hospitals may switch off their MRI machines on weekends or public holidays.

The second way time makes a difference is in the speed with which an emergency has to be dealt with. In some cases, stroke being an example, mere minutes can literally make all the difference in the world. This means that the margin for delays in the emergency department is infinitely smaller than in 'regular' healthcare situations.

The editorial of a *British Journal of Radiology* edition dedicated to emergency radiology identified the major challenges for radiology in the emergency department (ED) as, inter alia, finding a common language between different groups of physicians, finding the human, economic and technical resources for round-the-clock coverage, and reducing costs by choosing the appropriate technique for each case. CDS helps address each of these challenges. The clinical indications in a CDS system are structured and based on coherent terminology, and the introduction of CDS therefore necessarily creates a common language between radiology and other departments, including the emergency department. In addition, each exam associated with an indication has an appropriateness rating, creating a standard framework in which medical decisions for radiology referrals are made. And if a decision that is not in line with the guidelines is taken, it can be discussed and justified in reference to this common framework.

CDS supports consistent coverage round-the-clock as it is continually available independent of the time of day or staff on duty. What is more, CDS can help alleviate fluctuations in the number, experience and expertise of the staff available at any given time, helping to guide imaging referrals towards the most appropriate option, thereby also contributing to the optimal use of the available technical resources. This in turn leads to optimisation of costs by improving the appropriateness of referrals and, consequently, the diagnostic yield of the exams carried out, improving the cost-benefit ratio for healthcare organisations, professionals and patients.

In recent years radiology exam volumes in the ED have increased significantly compared to long-term trends. While the benefits of emergency imaging and its impact on physicians' diagnoses and treatment decisions are well-documented, it is not clear whether this increase is entirely justified for medical reasons or whether imaging is being overused, and if so what the reasons for such overuse are, and if there is room to slow this growth by avoiding unnecessary exams. In fact, there is no evidence that the higher number of imaging exams being carried out lead to a corresponding improvement in patient outcomes. Some studies have identified the concept of 'defensive medicine' – doing a medical examination for fear of adverse legal consequences without medical justification – as part of the reason for the increase in exam volumes for certain modalities which are not clinically justified. The use of evidence-based medicine and the application of referral guidelines have been suggested as possible remedies. Therefore, with it being the most effective tool for the incorporation of evidence-based guidelines in clinical practice, CDS can help optimise the quality of care, safety and outcomes for ED patients.

To do so effectively and in a coordinated way, evidence-based knowledge is a prerequisite. This is something CDS can help provide thanks to the structured information captured in the process, which provides a much clearer picture of what imaging is used for and it enables doctors to detect trends that warrant closer inspection, and this can in turn lead to the optimisation of clinical decision rules. Secondly, as a tool that ensures that the match between an indication and the prescribed exam is appropriate according to validated guidelines, the core function of the system is to ensure each referral is done for a medically sound reason. One European study uncovered an overuse of x-ray and went on to establish that a decrease is possible for certain injury types such as limb injuries or abdominal pain without negatively affecting patients' treatments, thereby easing problems with crowding and cost in the ED.

IS THERE ANY REASON NOT TO USE IT?

For most common emergencies, there are certain pre-defined, well-tested and routine procedures in place to ensure the process is as smooth, fast and efficient as possible. To effectively use CDS in the ED, it is important to understand in which cases it provides added value, and how possible disruption can be kept to an absolute minimum.

There are some obvious advantages. The ED is not specialised for a certain body area or a particular type of disease. Therefore, the range of possible scenarios and patient pathologies is unlimited, and no doctor can be an expert in every type of situation. By making comprehensive guidelines available within the native workflow, CDS can be an extremely useful support tool in cases where, e.g., a junior doctor is on duty during a night shift, or even if a more experienced doctor encounters a patient with a condition where there is no pre-defined pathway in place and the most appropriate imaging exam may not be immediately clear. It also helps with regard to consistent practice, making sure patients with the same condition are sent to the most appropriate imaging desk regardless of whether they visit the fully staffed ED during peak hours or in the middle of the night.

In addition, using CDS in the ED has the already familiar benefits of being able to monitor what is taking place. Being able to detect trends or patterns and optimising processes based on this information can streamline the cooperation between the ED and the radiology department to the benefit of patients.

A few things need to be considered when implementing CDS in the emergency department. For example, there needs to be an option to bypass the system if necessary. The doctor is always best placed to decide if time is of the essence, and appropriateness may be of secondary importance in a given set of circumstances. However, even though CDS may be seen as an extra step in the referral process, it does not necessarily add time to it; on the contrary, it can actually save valuable time. In the ED it is even more important than in other departments that staff is well-trained in using CDS to make sure the referral process is completed as quickly as possible. An experienced user will be just as quick in completing a CDS referral as they would otherwise be, and, as we have seen in cases in which the doctor on duty may be less familiar with a particular situation, CDS can be a valuable advisory tool significantly speeding up the decision making process. As for the radiology department, referrals that went through the CDS process are guaranteed to have a clear indication

associated with them, along with information on the appropriateness of the requested exam. In many cases, this can avoid the need for consultations with the referring physician to clarify an unclear reason for the exam, and it reduces the time spent on vetting referrals or approving examinations.

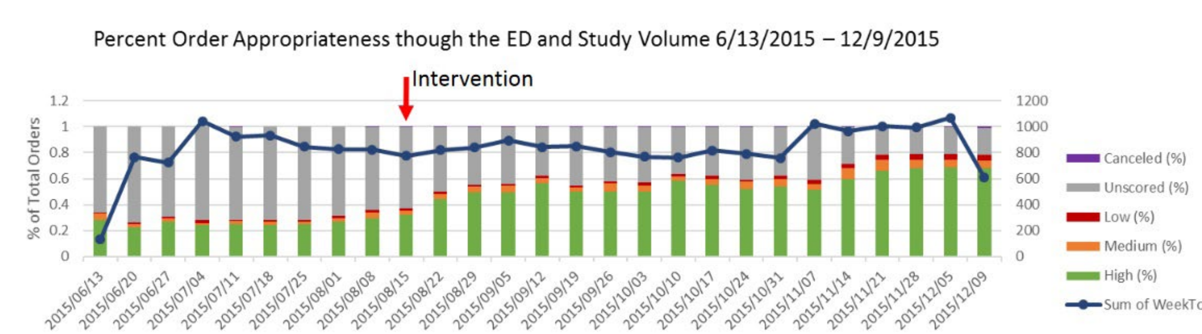
In the United States, where CDS systems have been in use for a number of years, including in emergency departments, studies have demonstrated that they can have a significant impact on the improvement of patient care. A study on the introduction of CDS using the ACR Appropriateness Criteria in Los Angeles compared the appropriateness of referrals before and after, and results showed that the amount of appropriate referrals increased, reaching a consistently higher appropriateness score baseline towards the end of the study period. This study is significant as it looked at all referrals that occurred in the ED of a whole health system during the trial (Figure 2).

Many studies on CDS in the ED have focused on pulmonary embolism as the clinical indication to evaluate the impact of CDS. It has been shown that the introduction of CDS has decreased the volume of CT in these scenarios, while increasing the yield of the exams actually carried out. This means that CDS makes the use of CT in evaluating acute PE more targeted, avoiding radiation exposure for patients that do not need it (Figure 3).

Other studies have shown that an option to bypass or override CDS – even though this may be necessary in certain exceptionally urgent cases – can have a negative effect on the appropriateness of imaging. One study analysing the effect of overriding CDS concluded that the yield of CT for acute PE was more than twice as high with CDS compared to referrals without decision support. The odds of surviving acute PE were more than 50 percent lower when providers overrode rather than followed the decision support guidelines.

FIGURE 2

CDS can significantly improve the appropriateness, and consequently the diagnostic yield, of ED Referrals.

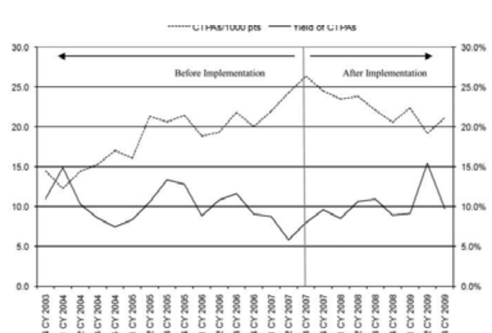


SUMMARY

Guidelines and other tools supporting evidence-based medicine in practice are becoming more and more important as medicine in general, and the specialty of radiology in particular, is becoming ever more complex. The sheer endless amount of scientific information and medical data coupled with the rapidity of technological innovation make necessary the ability to collate and maintain huge amounts of medical knowledge, and to make it available in a meaningful, practical and concise way within healthcare workflows. This is essential in order to maximise the benefits made possible by these developments. Clinical decision support systems are the most effective tool to help healthcare organisations carry out this function.

FIGURE 3

Pulmonary embolism is a good example to demonstrate the benefits of CDS: through more targeted use of CT, diagnostic yield is increased while unnecessary radiation exposure is reduced.



The emergency department is a clinical setting with unique challenges, and healthcare organisations meet these challenges in different ways. Due to these unique circumstances, the delivery of healthcare in emergency situations sometimes does not make optimal use of the available resources. Staffing issues, lack of availability of equipment, variability and lack of standardisation, defensive medicine, time pressure, financial constraints and other factors can negatively affect the quality and safety of patient care. The use of imaging in the emergency department is one important part of the complex processes at work, and the introduction of CDS in different settings has shown promising results for quality of care and patient safety in emergency radiology. The implementation of a decision support system for radiology referrals needs to be tailored by the radiologists and referrers to the particulars of emergency medicine in order to be successful. The following aspects including technical integration, the quality of the guidelines, training and educating staff on using CDS, the seamless introduction of CDS as a normal part of the IT workflow, and how to make it an accepted element in the overall cycle all need to be considered. If done properly, implementing CDS to utilise referral guidelines in the emergency setting can be valuable for improving the quality and safety of healthcare for patients.

This article was commissioned by EuroSafe Imaging, the ESR's flagship campaign to support and strengthen medical radiation protection across Europe.

Visit **www.eurosafeimaging.org** *for more information, and become a Friend of EuroSafe Imaging to support radiation safety!*

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Prof. Brkljačić has actively represented the radiology profession at the national, European and international levels, having served as president of the Croatian Society of Radiology from 2008 to 2012, chairing the Advisory Committee of the Croatian Ministry of Health on Radiology since 2004 and being a member of the International Society for Strategic Studies in Radiology since 2011. Following a number of committee-level positions in the European Society of Radiology, most recently as Chairman of the Communications and External Affairs Committee from 2014–2017, Prof. Brkljačić was elected to a five-year term on the Board of Directors in 2017 and is the ESR's incumbent 2nd Vice-President (2017–18).

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Prof. Donoso was born in Sabadell (Barcelona) in 1955. He received his MD from the School of Medicine of the Autonomous University of Barcelona in 1981. He completed his residency in radiology at the Hospital de Sant Pau in Barcelona, in addition to earning a PhD in medicine from the Autonomous University of Barcelona in 1992. Prof. Donoso was appointed Chairman of the Radiology Department of the UDIAT Diagnostic Centre in 1992, becoming its Executive Director in 1998. Since 2006 he has also led the Diagnostic Imaging Department at the Hospital Clinic of Barcelona and has served as Professor of Radiology at the University of Barcelona.

Prof. Donoso has been involved in many research projects. Early in his career, his research activity focused on abdominal imaging, especially regarding liver disease. His emphasis has shifted to digital imaging and the development and implementation of IT in diagnostic radiology. Under his leadership, a large R&D team was built at UDIAT, leading to several patents and products widely used throughout Spain. Prof. Donoso has given numerous lectures at prestigious universities, congresses, and courses. Altogether he has published over 90 articles and seven book chapters.

Prof. Donoso has always been active in the professional societies, from the regional to the international level. He served as Vice-President of the Spanish Society of Radiology (SERAM) from 1998 to 2002 and as president from 2002 to 2006. From 2008 to 2016 he was the President of the Spanish Foundation of Radiology. He was the Secretary General of the International Society of Radiology from 2012 to 2014 and president-elect from 2016. Since 2000, he has served the European Society of Radiology (ESR) in various capacities, including as ESR President from 2015–2016. Recently he was nominated president-elect of the International Society of Strategic Studies in Radiology (IS3R).

Prof. Donoso has received numerous honours for his contributions to the discipline, including the Gold Medal of the Spanish Society of Radiology and the Gold Medal of the Interamerican College of Radiology (CIR) as well as honorary memberships in the Argentinean Society of Radiology, the Chilean Society of Radiology, the Mexican Federation of Radiology, the Italian Society of Radiology, the French Society of Radiology, the German Society of Radiology, the Mexican Society of Radiology, the Serbian Society of Radiology, the Swedish Society of Radiology, the Radiological Society of North America, and the Honorary Fellowship of the American College of Radiology.

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TEAM-WORKING WITHIN THE EMERGENCY DEPARTMENT

TEAMWORKING WITHIN THE EMERGENCY DEPART-MENT: THE DEVELOPING ROLE OF THE RADIOGRAPHER

BY **BEV SNAITH** AND **PETROS SOULIS**

EMERGENCY IMAGING AND THE RADIOGRAPHY PROFESSION

Radiographers are the health professionals responsible for acquiring images for diagnosis or providing dynamic imaging during intervention. Although the role's title varies between countries with many using terms such as radiologic technologist, the European Federation of Radiographer Societies (EFRS) recognises 'radiographer' as the official title and describes the key responsibilities as patient well-being and justifying and optimising imaging investigations, with particular regard to radiation safety. Radiographers work closely with their radiologist colleagues and the wider multi-professional team.

Imaging has a long history of use in the emergency setting, with x-rays used to visualise bony trauma within months of their discovery. With the advent of World War I (WWI) the drive to establish emergency imaging intensified and across Europe the opportunities for imaging in military medicine were quickly identified. Both horse-drawn and motorised vehicles were adapted for use and field equipment and radiographers were deployed to the front line. One of the most famous operators was Marie Curie, who led the establishment of the French WWI x-ray service and over one million x-rays were obtained by her mobile facilities known as 'Petites Curies' (Figures 1 and 2). Over the last century imaging has become a mainstay of patient care in emergency situations in the hospital setting, as well as having pre-hospital, military field and forensic applications.

As the technological advances have enshrined imaging as a tool for diagnosis and treatment of a wide range of conditions, the radiographer's role has also evolved. Building on their responsibility for direct patient care, their technical expertise has provided a unique skillset. From a predominantly technical function, radiography has developed as a profession with the educational requirement of a Bachelor's degree (European Qualification Framework – EFQ – level 6) in most countries, with an increasing expectation of specialist postgraduate training at Master's level (EQF level 7) and many now undertaking doctoral studies. With such educational advancement, radiographers have naturally developed their roles from pure image acquisition to include clinical and service leadership.

Radiography has embraced the rapid changes in technology and the ability to transmit images across the world for review and reporting, however the workforce still

FIGURE 1

Marie Curie at the wheel of a Renault transformed into a mobile x-ray unit, 1914 (Source: lelivrescolaire.fr).

FIGURE 2

Irène Curie stepping out of one of the mobile units named after her mother, 'Petites Curies', 1916 (© Musée Curie).

continues to deliver bedside care 24 hours a day, 7 days a week, 365 days a year.

A UNIQUE SITUATION

Imaging in the emergency environment remains unique because of the competing pressures of time, the acuteness of the patient's condition, and the need to multitask and make critical decisions. Radiographers are involved throughout the diverse range of emergency services, from minor to major trauma, from initial receipt to discharge to ongoing assessment of outcomes. However, rarely do they have the opportunity to become 'emergency' specialists unless they work in a large trauma centre, although many develop a specific interest in the field. Due to the requirement of delivering services day and night, many radiographers continue to engage in emergency imaging throughout the extent of their career.

Radiographers work alongside doctors and other healthcare professionals to provide accurate and timely diagnoses to ensure that the correct treatment can be initiated as quickly as possible. Examinations need to be fast and accurate and radiographers require highly specialist image acquisition skills as well as experience in the care and techniques required for dealing with acutely ill patients. The ability to work quickly and calmly under extreme pressure is crucial in this environment. Dealing with distressed patients and their relatives, together with the demands of different clinical groups, can give rise to challenging situations. The radiographer's role is to manage every situation and ensure that the needs of the patient are paramount whilst acquiring images.

RADIOGRAPHER SPECIALISATION

Whereas radiologists tend to specialise in body systems, e.g. thoracic or musculoskeletal imaging, radiographers commonly develop their expertise around the technologies, e.g. computed tomography or ultrasound. In the 21st century there is a wide range of imaging modalities, with new applications continuing to emerge. Although some centres require radiographers to maintain skills across multiple imaging modalities, the complex nature of the equipment and imaging protocols has led to the development of these as specific radiography fields.

Radiography (x-ray)

Still the mainstay of the emergency department, radiographs continue to be the primary diagnostic tool for many emergency patients. A rapid and low cost imaging modality, x-ray equipment technology has remained essentially unchanged, but the field took a technological leap in the 1990s when images began to be captured digitally. This change revolutionised this modality and enabled more rapid diagnoses and image transfers, but the technical skills required to position patients who are in distress with potentially life-threatening or at least life-changing injuries, is not to be underestimated.

The portability of the equipment also means that it is available in the resuscitation room and critical care unit, meaning there is immediate access to the images to support decision-making. Even though the radiation dose is low, radiographers have a primary responsibility to protect the public. Justification of exposures is an important element of the examination, ensuring that the mechanism of injury, clinical presentation and referral criteria are appropriate and likely to produce images of benefit to patient diagnosis.

Computed tomography

Computed tomography (CT) uses an x-ray source linked to a detector in a ring configuration which, when rotated around the patient, demonstrates both bony and soft tissue anatomy in cross-section and 3 dimensions (3D). Modern CT scanners use multiple detector rows and slip ring technology to produce whole body imaging in a few seconds. CT therefore plays an essential role in emergency diagnosis and is the gold standard for major trauma. It is also the investigation of choice for imaging head trauma due to its ability to demonstrate fresh bleeding and bony injury. To enhance the diagnostic visualisation of vascular injuries, radiographers may inject intravascular contrast media during scans, ensuring patient safety before and after administration.

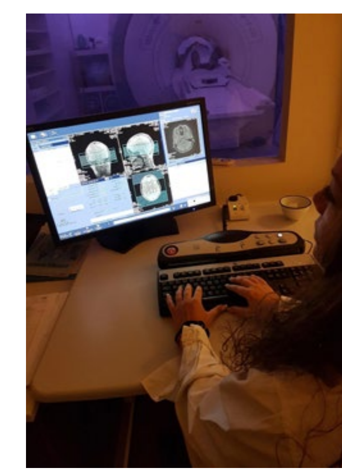
Newer more widely available applications have seen CT leaving the confines of the department and being employed as a mobile unit. Radiographers can now be deployed alongside specialist medical teams in ambulances specially equipped for the investigation and treatment of stroke, so-called 'scanbulances'. Developed in Germany, these units have now been introduced in Norway, the United States

FIGURE 3

Anterior view of the shoulder demonstrating dislocation of the glenohumeral joint. Provided by the Mid Yorkshire Hospitals NHS Trust.

FIGURE 4

MRI scan operation. Provided by the General Hospital of Nikea-Piraeus.



and Canada but their role in improving clinical outcomes remains controversial.

Radiographers have embraced this technological revolution, but have a significant ongoing role to play in managing the radiation risks associated with this high dose modality. This includes advising and investigating appropriate imaging techniques to optimise anatomical visualisation whilst minimising patient exposure. The acquisition of images is not the end of the examination and manipulation of data and images intro multiple planes produces complex 3D visualisation often guiding immediate treatment and reconstructive surgery.

Magnetic resonance imaging

Magnetic resonance imaging (MRI) uses strong magnetic fields and radio waves to generate cross-sectional images of the body. Different imaging sequences can be applied depending on the clinical question. MRI is less used in the initial emergency imaging setting because of relatively long scan times of up to an hour. Other barriers to its use include the need to screen patients, to exclude any MRI incompatible devices such as pacemakers or metallic foreign bodies, and the need to ensure the compatibility of monitoring and anaesthetic equipment with the very high magnetic field strengths.

However, MRI has an important role in head trauma, following initial imaging for more detailed classification of injury, and for further patient management. Following spinal trauma, MRI is useful to evaluate all the soft tissue structures surrounding the spine to detect, for example, damage to ligaments and to assess the spinal cord. MRI does not involve radiation and has particular relevance in paediatrics, where it may be used earlier in patient assessment.

Fluoroscopy

Fluoroscopy utilises a continuous x-ray beam to image moving structures or is used for direct treatment in the operating theatre, interventional radiology (IR) or cardiology setting. Increasingly utilised as a first-line treatment of vascular and cardiac emergencies these take place in what are now akin to operating theatres in terms of equipment and safety. As a result of these treatments, radiographers have developed wider clinical and specialist patient care skills in addition to their technical knowledge.

Ultrasound

Ultrasound use varies internationally, whereas in some countries it is only undertaken by medical professionals, in others radiographers provide the majority of ultrasound imaging and reporting. Completely operator dependent, sound waves emitted and received by a probe provide dynamic images of soft tissue structures. Its application in emergency imaging has grown, particularly in abdominal and musculoskeletal trauma and the relatively portable nature of the equipment allows imaging to be carried out at the bedside in the emergency department. Radiographer specialists in the ultrasound field, usually termed sonographers, can play a vital role in immediate decision making. Furthermore, ultrasound is increasingly being used by emergency medicine physicians and paramedics in the resuscitation room or pre-hospital setting and sonographers play a key role in their training

and in providing advice to the multi-professional team.

Information technology

Underpinning the development of all imaging modalities has been advances in information technology (IT). This has been crucial not only in reducing the duration of imaging examinations but also in the distribution of images. Picture archiving and communication systems (PACS) have played an important role in improving the efficiency of health services and in emergency imaging in particular. Their use allows greater clinical collaboration, simplifies procedures, improves working conditions and most importantly, significantly reduces the waiting time for patient treatment decisions.

In addition, radiographers have a role in supporting teleradiology, which utilises telecommunications and IT-services to support the local, regional, national and international transmission of images. Teleradiology enables access to specialist advice, improving patient outcomes by facilitating decision making particularly for remote medical services.

TEAMWORKING

Nowhere is teamworking more evident and relevant than in emergency imaging. To deliver an excellent, efficient and safe service, the workforce needs to be highly skilled with an ability to work together as a team. This requires building relationships, working with others and knowing the requirements and boundaries of individual roles. As a result, important characteristics of the radiographer include:

- *Being able to work co-operatively*
- *Being able to communicate (both giving and receiving)*
- *Having a sense of responsibility*
- *Having excellent decision-making skills*
- *Having respect for different opinions, customs, and individual preferences*

The size of the emergency team can vary depending on the facility and the clinical situation, but radiographers will interact with a whole range of other professional groups. This can be at different stages of the patient pathway, including referral, imaging, diagnosis and treatment and therefore effective communication is essential.

When clinical teams work together to accomplish a goal, everyone benefits. Employers might expect to see this in action in different ways, for example, advance planning and working co-operatively to assign tasks. Consensus is wonderful, but not always possible, and in the emergency situation an assigned leader should facilitate the decision-making.

Although the radiographer works in a multi-professional team, their primary responsibility is patient well-being and, during first contact, assessment of the patient and communication of the requirements and examination-specific details can ensure cooperation and minimise distress. Unlike many other imaging settings, prior knowledge of the patient, their condition and capabilities is limited and therefore radiographers are required to ‘think on their feet’ and respond to situations as they arise. This will include adapting standard imaging protocols and techniques to achieve quality diagnostic images whilst often minimising patient movements. Whatever the imaging examination, an overview of the patient's condition is critical and decisions to limit or abandon examinations may have to be taken on a case-by-case basis in the interests of patient safety.

THE EVOLVING ROLE OF THE RADIOGRAPHER

As new technologies and imaging modalities have emerged, radiographers have embraced these changes and opportunities. However, the educational advancement of the profession has both challenged and supported developments in the clinical setting with individual radiographers taking on greater responsibility for patient care and decision making. Having evolved to streamline clinical pathways or improve patient safety, radiographer roles are no longer limited to image acquisition. Initially supported by in-house training, university postgraduate education now underpins advanced practice specialist roles, with individuals developing their knowledge, skills and competence as an expert in their chosen field.

One of the earliest recognised uses of the radiographers' expertise was the flagging of abnormal radiographs to referring clinicians in the emergency department. The colloquially termed 'red dot' system was initiated in the UK in the 1980s with the examining radiographer affixing a red sticker to images demonstrating abnormalities. This initial review of the images assisted the junior emergency physicians and nurse practitioners and reduced the incidence of overlooked injuries by providing a double read. Although use of the red dot system has spread internationally, its limitations are recognised: the flag does not indicate the location or number of abnormalities. As a result it is being superseded by a more formalised preliminary evaluation which encourages radiographers to communicate any abnormalities they discover in a more informative and helpful way as a written comment. This does not replace or reduce the relevance of the definitive report, but does raise the stakes for the radiographic profession in terms of education and clinical responsibility, and it will remain crucial for a radiographer to communicate critical findings to the individuals managing the patient.

The intervening three decades since the advent of the red dot have seen clinical and academic education in image interpretation develop with specialist postgraduate education at EQF level 7 enabling radiographers to undertake definitive reporting in their chosen modality. Although more focussed than a radiologist's reporting remit, the UK has established radiographer advanced practice in the emergency setting with immediate reporting of x-rays or CT head scans enabling rapid decision making.

As a result of the increased knowledge base and close working-relationships with the emergency department, some radiographers have grasped the opportunity to span the boundaries between patient assessment, imaging and management. Emergency clinical practitioner roles are still relatively rare for radiographers, but many now use skills in clinical history and/or patient assessment to refer for and justify imaging examinations as well as support their clinical reporting. Recognising the benefits of providing immediate reports for emergency examinations has also enabled radiographers in the UK to take responsibility for the onward referral and eventual discharge of patients, streamlining care and relieving the time of other professionals. Such roles are possible and have demonstrated improved outcomes and patient satisfaction but need the initial and ongoing support of the multi-professional team and the employer.

Radiographer roles are dynamic and although image production remains at their heart, the scope of the role and its responsibilities continue to develop, particularly within emergency imaging. The need to make rapid, but thoughtful, decisions and respond to competing demands makes this a unique but rewarding field.

The EFRS, as the umbrella organisation for 37 national radiographer societies and 57 educational institutions, representing over 100,000 radiographers and over 8,000 radiography students across Europe, strongly supports these emerging roles for radiographers within the multi-professional emergency team. Through its statements on education and role development and ongoing work on establishing EQF Level 6 and Level 7 benchmarking documents for radiographers, the EFRS continues to highlight the need for the wider consideration of role development, role extension and advanced practice.

Radiography has changed and continues to change rapidly and radiographers have to be proactive in this process to survive. The subject is now too broad and complex for an individual to remain a comprehensive provider. As a result, radiographers will need to group themselves as specialists in particular systems or disease-based areas while finding a mechanism to provide high-quality service. Emergency imaging continues to be a dynamic and evolving field and radiographer roles will continue to evolve to add value to the imaging examination and whole patient pathway.

Further information on the EFRS and its statement can be found at **www.efrs.eu**

FIGURE 5

Mobile image intensifier unit in action. Provided by the General Hospital of Nikea-Piraeus.

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PATIENTS CAUGHT BETWEEN FEAR AND FASCINATION

PATIENTS CAUGHT BETWEEN FEAR AND FASCINATION: THE PATIENT'S PERSPECTIVE ON EMERGENCY RADIOLOGY

BY **IAN BANKS** AND THE **ESR PATIENT ADVISORY GROUP**

It may sound trite to say that emergency radiology is of utmost importance to patients.

However, it is indeed true that, depending on the nature of the problem and especially after accidents, most people need and desperately want an x-ray. The reason for this is obvious: people want to understand the root of their pain. Simply put, they want to know what is wrong with them. To patients, radiology is thus a means of shedding light on their problem – and this can even be taken literally.

FROM FASCINATION TO FEAR

Being able to see your organs and bones meticulously displayed on a computer screen from one second to another is somehow fascinating to most patients and, to some extent, still makes radiology some sort of 'space age technology'. This fascination may, however, fade when it comes to accidents and emergencies. In fact, people usually feel scared in such cases.

There are innumerably different reasons for such fears: Patients might be anxious about the severity of their injury. Others might be anxious about the examination itself. For many people, the sight of a CT scanner, MRI or even a simple x-ray machine might be a new experience. Suddenly finding yourself strapped down, warned not to move a single muscle might cause panic and render the examination a nightmare.

Emergency radiologists and radiographers are thus often confronted with extraordinary situations, where they not only need to prove their expertise in stressful situations but also take the time to show an interest in individual patients and their fears.

Given the ever-increasing workload and pressure under which emergency radiologists and radiographers find themselves, this certainly poses a huge challenge. It might be tempting to have the examination completed as quickly as possible and then have another staff member communicate the result in order to be able to help the next patient already waiting in the crowded waiting area.

TALK TO THEM

What emergency radiology staff always have to bear in mind is how much it means to the patient to talk to a radiologist directly and perhaps even receive some motivating words in a situation which is most likely unfamiliar and frightening. As a matter of fact, reassurance from the 'true expert' can work wonders for the patient. The important role of communication between patients and healthcare professionals in the field of radiology is also a key issue addressed by the ESR Patient Advisory Group (ESR-PAG). ESR-PAG strongly advocates a patient-centred, human approach in the field of clinical radiology, which takes into account the patients' emotional and social needs.

In its so-called Driver Diagram for Patient-Centred Care in Clinical Radiology, ESR-PAG not only defines the opportunity for patients to talk to radiological staff as a key concept for change and improvement, but goes even further by saying that radiologists need to find the right words in accordance with the level of understanding of each patient. This also requires respecting and acknowledging different cultural backgrounds, values and beliefs, which might not only affect communication but planning and delivery of service itself.

Generally speaking, emergency radiologists need to be experts in a variety of areas and the value patients place on the radiologist's knowledge, training and expertise should never be underestimated. In addition, it is important to understand the exceptionality in the eyes of the patient of a situation, which probably seems only too ordinary to radiologists and radiographers in their daily routine. Reflecting on the situation from the patient's perspective, or 'living the journey' of the patient as the ESR-PAG phrases it in its Driver Diagram, might help in recognising and ultimately understanding the patient's fears and worries, which very often translate into confusion, frustration or at times even aggression.

It is thus often the patients themselves who add to the difficulty of the radiology staff's job and the examination itself. Nonetheless, – and at least once the examination is over and people are undergoing recovery – patients are truly thankful that there are emergency radiologists and radiographers who dedicate their professional lives to their well-being. In some cases, this might mean relieving your pain, in others, it might even mean saving your life. In any case, emergency radiology practitioners are doing a tremendous job and make a vital, profound difference!

DR. IAN BANKS

is a retired accident and emergency doctor and general practitioner and has been the President of the European Men's Health Forum since its launch in 2001. He is a former president of the Men's Health Forum (England and Wales), past vice president of the International Society of Men's Health (ISMH), past deputy editor of the Men's Health Journal and for six years the medical editor for Men's Health magazine. He was a trustee of Developing Patient Partnerships (DPP, formerly Doctor Patient Partnership) for six years. Ian is a founder member of the Self Care Forum (UK) and chair of the Patient Advisory Committee of the European CanCer Organisation (ECCO).

ABOUT THE ESR PATIENT ADVISORY GROUP

It is not always easy to find useful and clear information about radiology, and patients often have questions about radiological examinations. The ESR has recognised this need, and in 2013 began taking its communication with patient groups to another level with the launch of the ESR Patient Advisory Group (ESR-PAG). The goal of the ESR-PAG is to bring together patients, the public and imaging professionals in order to positively influence advances in the field of medical imaging to the benefit of patients in Europe.

EUROPEAN SOCIETY
OF RADIOLOGY