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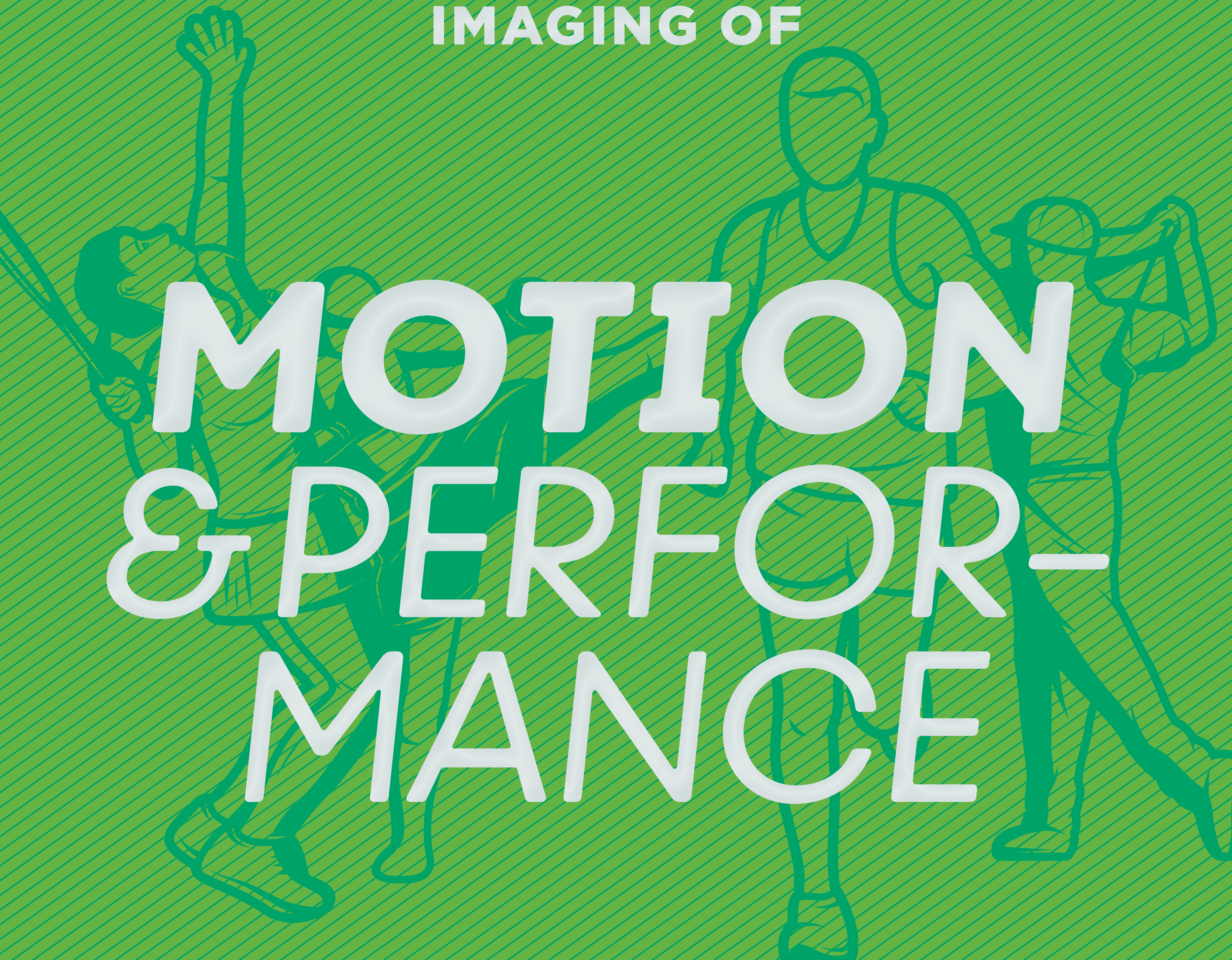

Stress & Strain

EDITORS

ALBERTO VIEIRA | LUCA SCONFIENZA | FRANZ KAINBERGER

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PUBLISHED BY
ESR
EUROPEAN SOCIETY OF RADIOLOGY

Table of Contents

Foreword

By **Maximilian F. Reiser**

… it became possible to display all structures of the musculo-skeletal system (bone and bone marrow, ligaments and ten-dons, cartilage, nerves, muscle) with previously undreamt-of accuracy …

To celebrate the 8th International Day of Radiology (IDoR 2019), renowned scientists and representatives of international skeletal radiology have written this book, which provides an excellent overview of many aspects of this increasingly important field. The editors Alberto Vieira, Luca Sconfienza and Franz Kainberger have been able to recruit proven experts from many European countries and beyond. In informative and readable essays, the history and the current state, as well as research and fascinating trends, are presented.

Even when Wilhelm Conrad Röntgen discovered x-rays, the focus was on the representation of the skeleton. In connection with the wars at the beginning of the 20th century, the imaging of bone injuries was given a high priority. With the introduction and increasing refinement of new imaging techniques such as CT, MRI and ultrasound, it became possible to display all structures of the musculoskeletal system (bone and bone marrow, ligaments and tendons, cartilage, nerves, muscle) with previously undreamt-of accuracy. This made diagnosis incredibly accurate and enabled different disease entities to be detected early and analysed accurately during their courses.

Using modern imaging techniques, it has even become possible for the first time to describe a large number of illnesses and injuries, such as stress reactions of bone, and to make differential diagnoses.

Due to increasing life expectancy and the importance of high-performance and popular sports, imaging and competent assessment have become increasingly important. Diseases of the musculoskeletal system are the most common cause of sick leave in industrialised countries. In the case of many top athletes, the findings of MRI in muscle tears, for example, determine whether they can continue to participate in competitions, how long the competition break must be and which therapy is chosen. Older people also often engage intensively in sports and are therefore not immune to accidents and damage caused by overuse. In allusion to the 'Baby Boomers', the authors speak amusingly of 'Boomeritis' in this context.

In a chapter on 'Sports: overuse and injury in athletes and the general population' a large variety of topics are tackled in informative and highly readable essays: tendon overuse, muscle injuries, stress fractures, shoulder, elbow, hand and wrist, hip, knee, ankle and foot and spine overuse, as well as imaging at major sporting events.

However, the field of activity of skeletal radiology is not limited to injuries and damage caused by overuse. Important topics such as bone and soft tissue tumours, rheumatic and metabolic diseases, as well as diseases and tumours of the peripheral nerves are also covered here.

As in other areas of imaging, musculoskeletal radiology has benefited from the dramatic technical and methodological advances in imaging modalities and has systematically tested and evaluated them.

Important topics related to education, social responsibility and cooperation with other medical disciplines are also mentioned. 'Patient empowerment' is an important task that must be recognised and carried out in order to guarantee acceptance by our patients and to optimise the success of treatment. As in other areas of radiology, it is important to fulfil the role of a clinically active physician who is visible to the patients.

Musculoskeletal radiology is a highly scientifically active and exciting field with which a number of contributions are concerned. In addition to highly accurate morphological imaging, functional, metabolic, biochemical and prognostic parameters can increasingly be obtained. The aim of all these efforts is to generate measurable added value for patients and society.

This book provides an excellent overview of the fascinating field of musculoskeletal radiology, which plays an invaluable role in patient care and will continue to gain in importance.

I would like to congratulate the editors and authors on this successful work, which is a worthy celebration of IDoR.

PROF. MAXIMILIAN F. REISER, MD

received his medical degree from the Ludwig-Maximilians-Universität of Munich in 1973. He completed his residency at the diagnostic radiology department of the Technical University of Munich in 1983, where he later served as an assistant professor, before moving on to become an associate professor at the University of Münster in 1986. He took up the post of professor and chairman of radiology at Bonn University in 1989, before he returned to his alma mater in 1993. There he served as professor and chairman from 1993 to 2017, and as dean from 2008 to 2015.

A long-time and active member of the European Society of Radiology (ESR), he served as president of the society's congress in 2008, went on to serve as president of the society in 2010–2011, and was Editor-in-Chief of the society's main scientific journal European Radiology *from 2014 to 2017. He has also served as president of the German Radiological Society, the European Society of Musculoskeletal Radiology, and the 2001 joint congress of the German Radiological Society and Austrian Röntgen Society.*

With more than 500 original publications to his name, Prof. Reiser has authored extensively throughout his clinical and academic career. His main research interests include skeletal radiology, magnetic resonance imaging, and oncologic interventions.

Editorial

By **Alberto Vieira, Luca Sconfienza** and **Franz Kainberger**

… radiologists will report findings with a strong focus on the interpretation of how to restore movement disorders …

When designing this book, the idea was to find answers about how musculoskeletal imaging will appear within the next decade. The discussions on this topic can be summarised under the title of this book: 'Imaging of motion and performance' means that radiologists will report findings with a strong focus on the interpretation of how to restore movement disorders so that the patient's performance in daily life can be improved efficiently. In other words, all details of lesions due to trauma, degeneration, inflammation, tumours, neurogenic and congenital disorders, osteoporosis and metabolic diseases will be quantified with regard to their biomechanical impact and consideration of preventive aspects, as well as patients' and social outcomes. Radiologists will not only write their reports to explain patients' pain or function impairment, but will also be able to give personalised information about pending risks of worsening conditions and advice for lifestyle changes.

Imaging findings, more than before, should be regarded as indicators or biomarkers of the patient's lifestyle and as values for patient management. Their quantification may be used for personalised treatment planning and, in sports and rehabilitation medicine, for training, patient empowerment and other instruments of preventive medicine.

Looking back at the history of musculoskeletal imaging, these aspects are not new, but the focus of a radiologist's report seems to have shifted from a simple listing of abnormalities towards such a holistic approach with biomechanical impact.

This trend will be facilitated by improvements in both the technology of available imaging equipment and in the workflow of radiology units. It will be influenced by a new and positive understanding of radiation protection, here with a shift in focus from reducing risk towards increasing the chances of imaging, i.e. specifying the pre-test probability of referrals to musculoskeletal imaging with detailed guidelines, computer-assistance and, based on this, artificial intelligence.

The sense of 'imaging of motion and performance' is also very well represented in the setting of sports imaging. Musculoskeletal radiology has always played a pivotal role in the diagnosis and treatment of most sport-related conditions. However, in the past, radiologists were only reporting the ongoing damage already well visible on conventional images. At present, radiologists can use newer imaging techniques to detect damage well before it becomes visible on conventional images. This enables the correction of potential risk factors to prevent further damage. Imaging has also been largely demonstrated to be crucial in the guidance of local therapies, the success of which is strictly dependent on the correct injection technique.

Accomplishing such tasks relies on certain prerequisites: one is that radiologists and radiology technicians closely collaborate with orthopaedic surgeons, rheumatologists, sport physicians and specialists in rehabilitation medicine. Turf battles among these disciplines should be abandoned; to avoid such fights, radiologists need to be specialised and educated, by taking part in high quality educational events, and by using the latest technologies of hybrid e-learning. With this in mind, it has to be clear that musculoskeletal radiology as a sub-discipline needs strong support from the whole community of imaging specialists. Another prerequisite is that for the huge workload of reporting the biomechanical, preventive and prognostic impact in a personalised fashion, we will need refined imaging informatics applications. In such a scenario, narrative reporting might not be replaced, but rather enhanced with multimedia structured reporting, which in turn will be indispensable for transmitting information from the images to the referring physician and the patient. The radiologist will not be replaced by artificial intelligence but again a shift in focus might occur towards enhanced quality management and a personalised workup of the constantly growing amount of image information that non-radiologists can no longer keep track of.

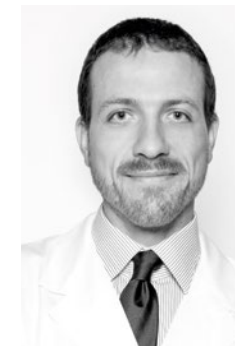
The European Society of Musculoskeletal Radiology (ESSR) has initiated activities to develop solutions for all topics presented in this commemorative book, published to mark the International Day of Radiology 2019. The editors and the authors are happy to support the radiological community in this way and to contribute to the discourse for defining the role of imaging in the era of digital and personalised medicine

DR. ALBERTO VIEIRA, MD

is a consultant MSK radiologist and chief of the MRI and MSK unit at São João University Hospital, Porto, Head of the radiology department at CUF Porto Hospital, and Coordinator of the MSK Section of the Portuguese Society of Radiology. He is currently the President of the European Society of Musculoskeletal Radiology and is Past-president of the Portuguese Society of Radiology.

Alberto Vieira is an invited assistant at the Faculty of Medicine at Porto University. He has authored and co-authored several book chapters and papers in peer-reviewed journals.

He is also a reviewer for Eurorad and various MSK specialty journals and has presented more than 300 invited lectures.



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1 HISTORY & FUTURE

HISTORY & FUTURE: Trends in musculoskeletal imaging

By **Franz Kainberger, Luca Sconfienza, Filip M. Vanhoenacker** and **Alberto Vieira**

The imaging of the bones has been an integral part of radiology since the discovery of x-rays because of the high contrast difference between calcium-containing osseous structures and soft tissue.

The first x-ray image taken by Wilhelm Conrad Röntgen on December 22, 1895 was of the hand of his wife, who, when recognising her bones, is supposed to have said in surprise "I have seen my death". Four weeks later, the first images obtained for medical purposes, again mainly relating to musculoskeletal diseases, were presented in the *Billrothhaus*, the headquarters of the *College of Physicians in Vienna*[1]. With this pioneering work in mind, major trends may be identified which have influenced musculoskeletal (MSK) radiology in the past and might influence the future of this imaging sub-discipline. Radiologists and other physicians, radiographers, other healthcare professionals, and, last but not least, patients, should be given the opportunity to play an active role during the current period of transition towards more computerised applications.

1st TREND

Technical advances in high-resolution, 3D imaging and computer-assistance have been used primarily for musculoskeletal applications

Even a few weeks after the discovery of x-rays and then later during the first and second world wars, with high demand for the diagnosis of fractures and other injuries, tremendous improvements in resolution and in the practical use of x-ray equipment were achieved, again with bone imaging as the central focus of research[2]. Later technical advances relating to MSK imaging included high-resolution and 3D imaging techniques for displaying the structure and architecture of the bones, the description of fibre anisotropy in ultrasound and MRI, and computer-assisted diagnosis (CAD)[3, 4]. The first radiological application of CAD was the characterisation of bone tumours in 1963. In the 1980s, a major advance was achieved with the computerised calculation of bone mineral density and some years later that of body composition by using dual-energy x-ray absorptiometry (DXA)[5]. DXA may become a useful tool for digital anthropomorphometry, which might also be done with 3D CT. Today, imaging informatics with a special focus on artificial intelligence (AI) has become the current disruptive technology in imaging. With the integration of AI into daily practice, refinements can be expected in workflow (applying appropriateness criteria, image reconstruction) and in the quantitative interpretation of fractures, osteoarthritis, bone age and bone strength.

Another driving force is radiation protection with new sensitive hardware and software tools for performing low-dose and even ultra-low-dose examinations[6]. Together with a new patient safety culture and a culture of patient empowerment, there is the potential to improve patient service and offer new opportunities in clinical radiology, research and education.

Along with these technical advances, a continuous increase in knowledge has been achieved through close collaboration with orthopaedic surgeons, underlining the need for sub-specialisation in musculoskeletal imaging. Furthermore, it was only possible to carry out such research thanks to cooperation with medical physicists, engineers, and later with medical informatics specialists. Another important set of relationships have been those between musculoskeletal radiology and the other 'morphologic' disciplines of anatomy, pathology, forensic medicine, and anthropology. Many musculoskeletal radiologists have a special interest in these topics and can bring new knowledge from these fields into our discipline. Additionally, significant progress has been made in functional and molecular imaging, as well as in hybrid imaging, with an expanding armament of technologies becoming available or in development[7].

2nd TREND

Musculoskeletal imaging is indispensable for understanding the pathogenesis and course of bone and soft tissue diseases

The pathogenesis of many bone and soft tissue diseases has been explained with the help of radiologists and some entities have been defined on the basis of imaging research. Robert Kienboeck (1871–1953), Albin Koehler (1874–1947), Heinrich Albers-Schoenberg (1865–1972) and Louis Milkman (1895–1951) were early radiologists whose names became eponyms for bone diseases. Some of them died from radiation injuries. Especially in the early days of radiology, many radiologists had originally been trained in other fields of medicine and later specialised in imaging, and many non-radiologists have influenced musculoskeletal imaging research. This underscores the close relationship between MSK radiologists and their clinical partners. Some major outcomes have been a deeper insight into overuse injuries in sports, the classification of fractures, the definition of the various forms of osteonecrosis, and the grading of degenerative joint diseases. Since the Olympic Games in Atlanta in 1996, MSK radiologists have been directly involved in medical services at top sporting events by providing ultrasound in the field, with multimodal imaging conducted in the nearby hospitals and with teleradiology services[8].

3rd TREND

The indications for MSK imaging are expanding

As musculoskeletal diseases are the worldwide leading cause of chronic pain, impaired movement and reduced quality of life, their diagnosis constitutes a large part of radiological services. Sport is a major reason for making use of imaging, with increasing demand due not only to young athletes but also the older population. The latter has been referred to as the 'boomeritis' effect, due to the baby boomer generation continuing their lifestyles into old age[9].

Regarding sports and rehabilitation medicine, the preventive aspect of imaging is gaining importance because, independent from pain and functional impairment, imaging has an important prognostic impact in terms of reducing the risk of degenerative diseases, trauma and, as recently shown, rheumatic disease[10, 11]. The estimation of the fracture risk in osteoporosis is a domain of DXA. This modality and other forms of measuring the body composition have prognostic impact on metabolic, nephrologic, cardiovascular and oncologic diseases. These techniques are under continuous development towards a three-dimensional digital in-vivo anthropometry.

Neurography is a term mainly used for diffusion tensor-weighted MR imaging of the nerves, but it may be used to define all types of nerve imaging, mainly with ultrasound. Ultrasound is often used for interventional pain management and is an expanding field that is becoming an integral part of interventional radiology besides vascular and oncologic applications.

Forensic radiology has become another increasingly common application, which is mainly performed by MSK radiologists. Together with other legal requests for imaging, including age determination in immigrants, requests by athletes because of financial interests, and biomedical research, it is summarised under 'non-medical exposures' according to the Basic Safety Standards (BSS) Directive (2013/59/Euratom) in radiation protection.

4th TREND

The radiology report should be redesigned

The radiology report is the result of the diagnostic process and is different from the orthopaedic surgeons' or rheumatologists' expert opinions when they view the images. With respect to the potential and efficient treatment options, this opinion may be of higher clinical relevance than the legally more important written radiology report. Solutions for overcoming this problem have recently been described by the European Society of Radiology (ESR) in a summary about value-based imaging: radiologists can add value for referring physicians by having daily consultants in every subspecialty or embedding reading rooms in the specialty clinics of referring physicians[12].

Another challenge is that the 'product' of the radiology service may not only be the report, because the referring physician's request is to use the images for computer-assisted surgical planning with or without template devices, to have 3D prints generated, or in the near future to use artificial intelligence schemes. Patients might be happy if they can understand the report and if actionable information can be provided, for instance in the form of cooking recipes for a calcium rich diet as provided by DXA companies.

Outcomes-oriented and value-based radiology reporting as expected by the recipients will mean that the report is readable and accessible for all target groups (findings compiled in a clear structure and described in an understandable way, provided with multimedia, apps and other tools), that it contains both a diagnosis and a quantitative assessment with imaging biomarkers (similar to the rheumatologist's assessment of arthritis and the orthopaedic surgeon's clinical scoring), that radiologists feel responsible for the quality management of the whole process (including management of the patient during their stay in the radiology department, quality of 3D prints, and others), and that they use AI and other CAD schemes for augmenting the report, which includes the integration of the latest medical knowledge.

CONCLUSION

In conclusion, the value provided by radiology goes beyond the volume of services delivered. Subspecialisation is becoming the major driving force in the development of musculoskeletal radiology, as orthopaedic surgery, rheumatology and physical medicine practices are demanding quality, convenience, and efficiency in imaging services[13, 14]. The combination of new technologies, mainly in the area of AI, improvements in radiation protection, close collaboration with clinical and non-clinical partner disciplines, and outcomes-oriented and value-based reporting will be the driving force for MSK imaging during the coming years.

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Imaging of MOTION & PERFORMANCE STRESS & STRAIN

2

SPORTS IMAGING

SPORTS IMAGING: *The pivotal role of MSK imaging*

By **Alberto Vieira**

Increasing participation in sports and the inevitable rise in sports related injuries have turned musculoskeletal imaging in sports medicine into a rapidly growing and developing field.

Imaging plays a key diagnostic role in sports medicine and in the management of sport lesions, not only in the diagnosis and grading of injuries and in determining the prognosis of a lesion, but also setting the time needed to recover before returning to activity. Nowadays imaging also has an important role as a guiding technique for accurate needle placement for the delivery of therapy.

Continuously advancing technology, which has seen new imaging techniques emerging over recent decades, has greatly expanded our ability to evaluate complex anatomical structures non-invasively and to diagnose and understand the disabilities that may result from sporting injuries.

Sports imaging has a pivotal role that can influence the management of the athlete. This applies to elite and recreational athletes, independent of their age. It must never be forgotten, however, that imaging should not replace or reduce the need for a thorough clinical evaluation.

The common sense rule of ordering an imaging test which is likely to influence management of the athlete should always be borne in mind.

Some general indications for imaging are: (a) when the clinical diagnosis is uncertain and management of the patient may be affected; (b) when the clinical diagnosis is obvious, but the extent of injury or presence of complications need to be determined, because that may influence management; (c) when treatment has failed and no clear reason is seen (was clinical diagnosis correct?); (d) when objective evidence is required to document the existence, progression or resolution of disease (e.g. medicolegal issues); (e) when high negative predictive value rule-out is needed (e.g. professional elite players); (f) when preoperative localisation of the lesion or planning is demanded.

The sophisticated array of imaging techniques currently available means the sports physician sometimes faces a challenging and confusing choice regarding exactly which test to order and when.

The choice of the best imaging technique may vary, depending on (a) the provisional clinical diagnosis, (b) available guidelines, (c) local availability of appropriate radiological equipment and expertise, (d) patient considerations such as cost, convenience, and compliance, (e) safety considerations such as patient age, radiation dose and contrast sensitivity, and (f) other costs such as that to the tax payer or insurance company.

The sports physician should know the available imaging techniques (geographical differences may exist), their indications, contraindications, sensitivity, specificity, how invasive or innocuous the techniques are, and even their cost implications. All are important issues in ordering the correct examination.

Advances in musculoskeletal imaging have led to a tremendous improvement in the ability to detect minor abnormalities in bones, joints, and soft tissue sports injuries. A thorough and wise application of imaging techniques to the appropriate setting and musculoskeletal condition is critical to optimise treatment of the injured athlete, both conservatively and surgically.

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3

SPORTS OVERUSE & INJURY

IN ATHLETES AND THE GENERAL POPULATION

SPORTS OVERUSE AND INJURY

Tendon overuse

By **Maria Tzalonikou**

Classically, injuries have been divided into two categories: acute and overuse.

Acute injuries result from single traumatic events while overuse injuries are related to repetitive microtrauma to an anatomic structure, possibly in association with inadequate recovery time. Overuse injuries may occur among the general population but are most commonly associated with sports.

Tendon injuries are a common sports-related problem, accounting for approximately 50% of all sports-related injuries and including the full spectrum of tendon pathology from tendinopathy and tenosynovitis to partial and complete tendon tears. Sports-related tendon injuries affect both the upper and the lower extremities but most commonly affect the rotator cuff, the medial and lateral elbow epicondyles, the patellar tendon and the Achilles tendon. Upper limb injuries are most commonly encountered in throwing athletes and Paralympians, while tendon injuries in the lower limbs are seen in sports that require running and jumping.

TENDON ANATOMY

In order to understand the effects of overuse on a tendon, review of the basic tendon anatomy is helpful. Tendons form part of the musculotendinous unit and are responsible for the transmission of force from muscle to bone. Tendons are composed of collagen fibres, primarily of collagen type 1 but also of type 3 and 4, as well as of elastin, proteoglycans and lipids. Individual collagen fibrils form collagen fibres that make subfascicles, which in turn compose fascicles. Subfascicles and fascicles form an epitendon and epitendons form tendons, which are enclosed by synovial sheaths. The epitendons contain the tendon's neurovascular supply. Some tendons are not covered by a synovial sheath but with dense connective tissue.

PATHOLOGY

Tendinopathy is the clinical condition that describes tendon pain and dysfunction and is a non-inflammatory degenerative process. Tendinosis describes the structural disorganisation and degeneration of the tendon without signs of inflammation. Tenosynovitis represents inflammation of the synovial sheath that surrounds tendons and is often associated with fluid accumulation within the tendon sheath, which may occur with or without tendinosis. Tendon tears can be partial or complete. Tendon tears due to overuse usually occur at the level of the osteotendinous junction, since tendons are rather hypovascular proximal to the tendon insertion.

IMAGING OF TENDON OVERUSE

The imaging modalities that can be used for non-invasive tendon evaluation include radiography, ultrasonography, and magnetic resonance imaging, with ultrasonography and magnetic resonance imaging actually indicated.

Radiography

Plain films are suitable for the demonstration of hydroxyapatite disease or, as it is commonly known, calcific tendinopathy, but also for the revelation of co-existing bony abnormalities such as bony spurs and osteoarthritis, or loose bodies that may be the cause of the patient's complaints.

Ultrasonography

Ultrasonography is a fast, low-cost and widely available examination method. Its advantages are greater spatial resolution, the possibility of dynamic evaluation during passive and active movements, colour Doppler imaging, and the fact that it can be used to provide guidance for percutaneous treatment. The main disadvantage of the method is that is operator-dependent.

Normal tendons appear on ultrasound as multiple bright echogenic lines that are parallel to one another on the longitudinal plane, while they appear as multiple echogenic dots on the transverse plane. As tendons are rather avascular, no Doppler signal changes are noted in a normal tendon. The tendon sheaths are seen as thin echogenic lines.

Tendinopathy is seen as tendon thickening, loss of the normal fibrillary pattern and change in the tendon echostructure,

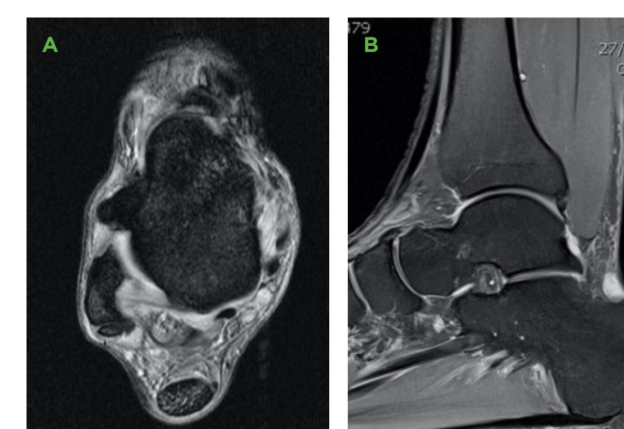


FIGURE 1

Chronic Achilles tendinopathy. (A) axial T2 GRE and (B) sagittal PD FS images. Fusiform swelling of the Achilles tendon with intratendinous signal change – high T2/PD signal is seen. The signal change is not as high as fluid.

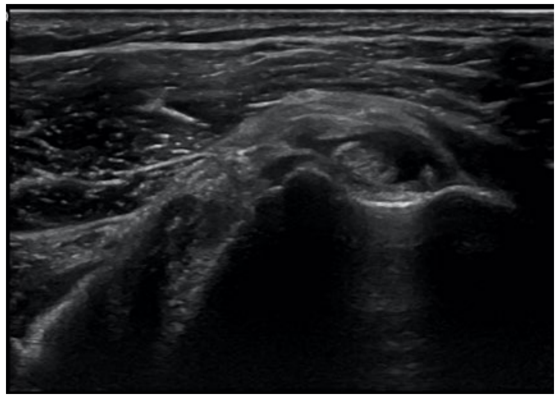
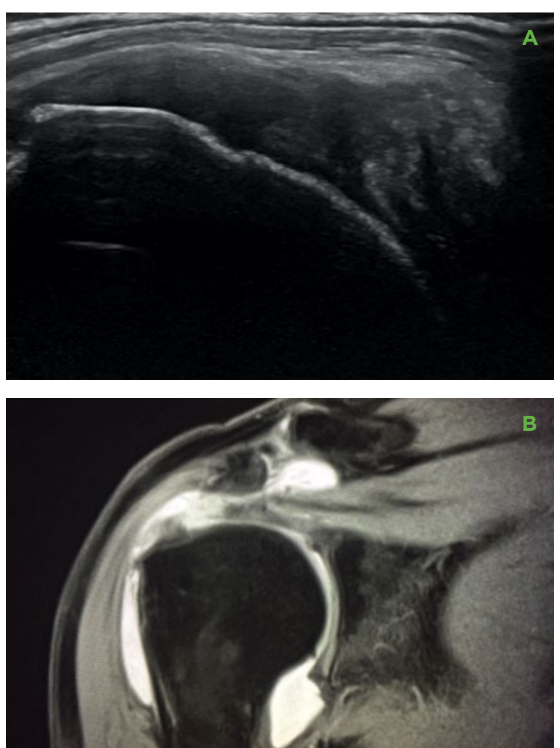


FIGURE 2

Long head of the biceps tenosynovitis. Transverse image through the LHB tendon along its course within the bicipital groove. Fluid is seen within the LHB tendon sheath. Furthermore, surface irregularity of the tendon can be seen.

FIGURE 3

Complete supraspinatus tendon tear. (A) ultrasonographic and (B) coronal PD FS. Complete tear of the supraspinatus tendon, fluid-filled gap and tendon retraction at the level of the humeral head.



with the tendon becoming hypoechogenic. These changes can be focal or more extensive. Colour Doppler imaging can be used to assess hyperaemia and neovascularisation.

Ultrasonographic imaging of the tendons needs linear transducers of high frequency (9–17 MHz) to enable optimal visualisation of the tendon's structure. The sonographic beam should be perpendicular relative to the tendon examined in all scanning planes so that anisotropy can be avoided. Anisotropy is an angle-related artefact that occurs in ultrasound when a fibrillar structure is scanned in a non-perpendicular way; in the case of tendon imaging, the tendon may appear hypoechogenic, giving the false impression of tendinopathy.

Magnetic resonance imaging

Magnetic resonance imaging is considered the imaging modality of choice for tendon imaging. This is because of the method's inherent capability for tissue discrimination, multiplanar imaging, non-operator dependence and, thus, reproducible results. The disadvantages of MR imaging include the high cost of the exam, the relatively long examination time and its more limited availability.

Normal tendons on MRI demonstrate low signal intensity on all pulse sequences because of their low water content. The magic angle phenomenon may lead to signal change of a normal tendon. The magic angle phenomenon happens when a tendon is oriented at approximately 55° relative to the magnetic field; it is seen in the low TE sequences and is corrected with the use of long TE sequences.

Tendinopathy on MRI is seen as signal change/heterogeneity on T2/PD sequences. The tendon presents a high T2/PD signal but not as high a signal as that of fluid. The tendon may appear thickened but no tendon fibre disruption is noted.

Tendon tears due to overuse are usually associated with a background of tendinopathy. In both ultrasonography and magnetic resonance imaging, partial or complete tendon tears are seen as tendon fibre disruption. The tendon gap may be filled with fluid, with haematoma in acute cases, or with scar tissue in chronic tendon tears.

CONCLUSION

In conclusion, overuse tendon injuries are common injuries both in athletes and in the general population. The preferred imaging modalities are ultrasonography and magnetic resonance imaging, which are considered to be of excellent accuracy for examining tendon pathology. Ultrasonography is widely available and can both focus on the area of suspected pathology and give us a more global view. Magnetic resonance imaging is still considered to be the imaging modality of choice, which can provide reproducible images of high quality and display a global view of the anatomic area of concern, especially if the clinical diagnosis is unclear and the ultrasonographic exam inconclusive. Magnetic resonance imaging also provides information related to a relatively large anatomic area and may be used to assess co-existent injuries or reveal other types of injuries as the source of a patient's symptoms.

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SPORTS OVERUSE AND INJURY
Muscle injuries

By Apostolos Karantanas

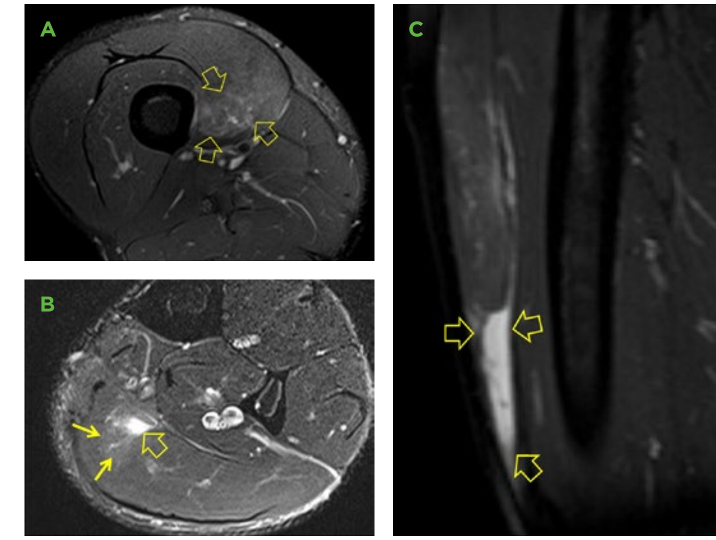


FIGURE 1

Muscle strain. (A) Grade I injury of vastus medialis, demonstrated with a poorly defined high signal intensity area on a fat-suppressed PD-w image (arrow). (B) Axial fat suppressed T2-w MR image showing a grade II injury of the medial head of the gastrocnemius with oedema (thin arrow) and haematoma (open arrow). (C) Sagittal STIR MR image in a 16-year-old male football player with an injury three months prior to imaging, showing the complete disruption of the distal myotendinous junction of the rectus femoris with retraction of the muscle and haematoma formation (arrows).

INTRODUCTION

Skeletal muscle can be affected by trauma, inflammation, infection, ischaemia-necrosis, neoplasia and congenital and metabolic diseases. Muscle injuries (MIs) include strain, contusion, delayed onset muscle soreness (DOMS) and sequelae such as denervation-atrophy, fascial herniation, scarring-fibrosis and myositis ossificans[1-5]. Most injuries can be diagnosed clinically. The indications for imaging are related to the assessment of extent, the healing process and risk of recurrence. In addition, there are cases, such as chronic exertional compartment syndrome and DOMS, in which clinical examination needs the contribution of imaging in order to clarify the exact pathology and, in elite athletes, to guide management to achieve the earliest possible return to the previous level of performance. MRI and ultrasound are very sensitive tools for diagnosing and characterising MIs. A detailed medical history of the patient, including the mechanism of injury and the anatomic location of the site of pain (skin marker), is mandatory for tailoring the examination and for accurate diagnosis.

MUSCLE INJURIES

Technique

The basic MRI sequences include large FOV T1w and STIR followed by high-resolution fat-suppressed PD/T2w focused on the site of pain, in both the short and long axis of the muscles under investigation. GRE imaging may provide additional information on the presence of hemosiderin. Contrast injection, as a rule, is not required.

Strain

Strains are a group of non-contact injuries, most commonly of the hamstring, quadriceps, and calf muscles, usually following excessive tension during eccentric contraction during acceleration/sprinting. Strains are located in the proximal or distal myotendinous junction. Strain injuries are graded as follows (Figure 1)[1]:

Grade I are microscopic injuries and they show oedema and blood on MRI without macroscopic discontinuity.

Grade II injuries represent partial tears with variable disruption of the fibres. In acute injuries, oedema and blood can be seen.

Grade III injuries represent complete tears of the muscle, often with a wavy appearance of the ruptured fibres. Signal intensity changes follow the presence of oedema and blood.

In all strain injuries, a high signal is seen on fluid sensitive sequences as for oedema and high on T1w images as for blood. A low T2w signal results from hemosiderin deposition, fibrosis or ossification.

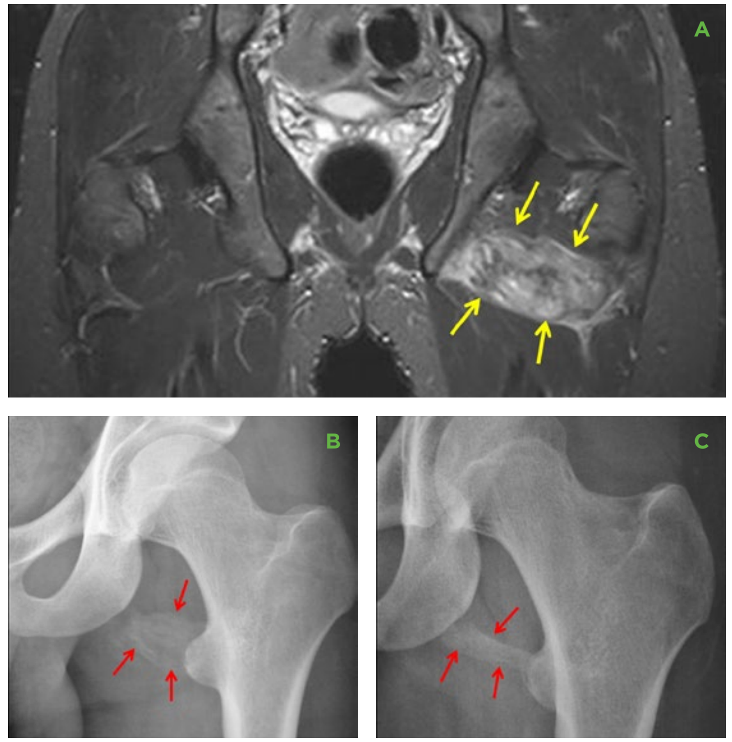
The term 'tennis leg' is specifically used for a partial tear of the medial head of the gastrocnemius muscle and its variable detachment at the aponeurosis interface with the soleus muscle, usually seen in middle-aged racket sports athletes.

Strain-variant injuries are located at the intramuscular myotendinous junction *(degloving),* or at the peripheral part of the muscle, often with involvement of the epimysium and fascia *(myofascial).*

DOMS is a painful syndrome occurring one or two days after intense muscle contractions and is usually seen after long periods without training or following unfamiliar training. In severe cases MRI may show increased signal on fluid sensitive sequences, similar to changes seen with strain grade I. The correct diagnosis is based on the clinical history.

FIGURE 2

A 20-year-old male football player with a history of hip pain radiating to groin and buttock, following an indirect injury eight weeks prior to imaging. (A) The coronal fat suppressed PDw MR image shows an inhomogenously high signal intensity lesion (arrows) at the ischiofemoral area. (B) The corresponding plain radiograph better shows the heterotopic ossification with the typical 'zonal' phenomenon (arrows) which is characteristic of the subacute-pseudotumoral phase of myositis ossificans. (C) The eight-month plain film follow-up shows significant reduction of the lesion size (arrows). No symptoms were reported at this stage.



Contusion

Contusions result from direct-contact injury with subsequent muscle oedema and haematoma formation at the site of maximum impact. As they are exposed to contact, muscles such as the deltoid, gluteus maximus and vastus lateralis, are most commonly involved. The signal changes of the haematoma are related to the time that has elapsed since injury[6]. Acute injuries (<48h) show low to iso-intensity to muscle on T1 and high signal on fluid-sensitive sequences. Subacute (<30d) haematomas demonstrate high signal on T1w images. Chronic haematomas have a cystic appearance with a low signal intensity wall, better seen with GRE sequences, due to hemosiderin deposition. Significant size reduction occurs in a period of up to eight weeks after injury with a pseudocyst/seroma appearance. Typically, besides the clinical and historical information, a contusion usually affects more than one muscle along the axis of the applied force, crossing the fascial planes, which is not the case with strains[3].

Sequelae of MIs

MYOCELE

Myocele is a painless focal muscle protrusion resulting from myofascial rupture or local fascial weakness secondary to muscle hypertrophy. Myoceles are usually located in the lower limbs. As the muscle may be totally normal at rest, dynamic scanning with muscle contraction may be required. Ultrasound is better than MRI at showing the muscle herniation.

MYOSITIS OSSIFICANS

Myositis ossificans represents a heterotopic ossification in muscles and may result from various causes. Previous muscle injury, usually contusion, is common and is characterised by three phases (Figure 2): 1. MRI shows extensive oedema in the acute phase, surrounding a poorly defined space-occupying lesion which may simulate a soft-tissue neoplasm. 2. The subacute phase occurs in a few weeks and on MRI, the oedema shows marked reduction, whereas a zone of peripheral ossification appears. CT shows this phase earlier as compared to MRI. 3. The chronic phase is characterised by mature and stable ossification which shows hyperintensity on T1w images because of fatty bone marrow. No oedema is depicted in the chronic phase. Spontaneous healing has been observed in this phase. *Calcific myonecrosis* is a rare late complication of a closed trauma in the calf *muscles*[7].

DENERVATION, ATROPHY AND FIBROSIS

Denervation in athletes occurs secondary to nerve injury from entrapment due to muscle hypertrophy and is demonstrated with diffuse oedema within a single muscle[8, 9]. Atrophy and fatty infiltration occurs following nerve entrapment or tendon tear and is best seen on T1w images (Figure 3). Muscle atrophy is common in the rotator cuff. Fatty infiltration suggests an irreversible muscle status and a negative prognostic sign for surgical repair.

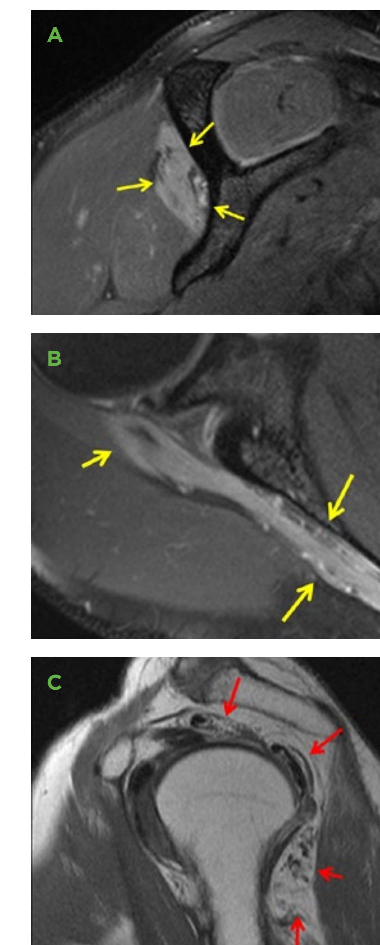
Fibrosis is shown on MRI as an irregular area returning low signal on T2w images. Fibrosis is most commonly located in the muscles vastus lateralis, gluteus maximus and deltoid.

TREATMENT

Treatment decisions are largely based on the initial injury with regard to the extent, grade and rate of healing on follow-up MRI examinations. The evolving application of quantitative diagnostic tools such as blood oxygenation level-dependent imaging, diffusion tensor imaging, T2 mapping, intravoxel incoherent motion techniques, and phosphorus MR spectroscopy, may become useful adjuncts in treatment management[1, 5, 10].

FIGURE 3

Oblique sagittal (A) and axial (B) fat-suppressed PDw MR images of a 30-year-old male professional volleyball player showing diffuse oedema and mild atrophy of the infraspinatus muscle (arrows) in keeping with subacute-chronic denervation. The patient underwent suprascapular nerve neurolysis at the spinoglenoid notch. (C) Oblique sagittal T1w MR image in a patient with a previous massive rotator cuff tear following trauma, shows diffuse atrophy and fatty infiltration of supraspinatus, infraspinatus and teres minor muscles (arrows).



Imaging of MOTION & PERFORMANCE STRESS & STRAIN

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His main research is focused on imaging of musculoskeletal disorders including trauma and emergencies, bone marrow, osteoporosis, sports injuries, osteoarthritis, hip joint disorders, applications of newer MR sequences and advanced models of data analysis focused on imagenomics and precision medicine.

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SPORTS OVERUSE AND INJURY

Stress fractures

By **Üstün Aydingöz**

INTRODUCTION

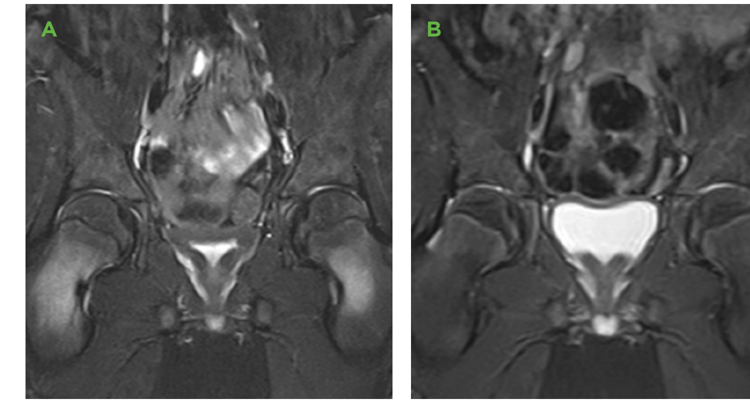
One of the hallmarks of the human mind is the ability to categorise or classify, and assign names to, a group of similar subjects or objects. It is convenient to create short names to describe common occurrences so that each involved party, such as, in our case, radiologists, orthopaedists, emergency physicians, physical therapists and rehabilitation specialists, understands the same thing with the use of a mere couple of words. However, this holistic and simplistic approach has its setbacks.

The term 'pathologic fracture' is a case in point. On the one hand, it denotes the occurrence of a fracture at the location of a pre-existing lesion, be it a metastasis or a simple bone cyst. On the other hand, there is no such thing as a 'physiologic fracture' (or a 'non-pathologic fracture'). The same is true for stress fractures: there is no fracture that occurs without stress on a bone. When a car hits a pedestrian causing a comminuted intra-articular proximal tibia fracture or when someone falls from a height and sustains bilateral calcaneus fractures, we cannot conclude that there was no stress on the bones fractured. Nevertheless, the term 'stress fracture' is quite practical in conjuring up a specific group of fractures: those that happen during daily activities such as walking, running, or climbing up or down stairs. They do not include accidental or incidental 'traumatic' fractures occurring during single episodes, such as motor vehicle collisions, fistfights, or falls.

Stress fractures occur mostly due to overuse or repetitive minor trauma. Each episode of repetitive loading on the bone is individually below the failure threshold of the bone (in contrast, 'traumatic' fractures occur after a single episode of loading on the bone that exceeds its failure threshold). The cumulative imbalance between the development of microdamage due to each episode of loading and the capacity of the bone to repair itself results in stress injury[1].

FIGURE 1

Case of an otherwise healthy, basketball-playing ten-year-old boy with bilateral hip pain. Coronal STIR MR image (A) shows medially located bilateral femoral neck stress fractures (more prominent on the right and tiny on the left) with surrounding bone marrow oedema and overlying periosteal reaction that completely resolved in the seven-month follow-up (B).



The term 'stress injury' encompasses a wide range of poorly defined alterations in the bone architecture, including cortical or trabecular microdamage, focal bone resorption, asymptomatic remodelling, and overt fracture[1]. Magnetic resonance imaging (MRI) can clearly depict bone marrow oedema or contusion of stress injury. To call the stress injury a 'stress fracture', cortical or trabecular disruption in the form of a line, which on MRI is usually hypointense in the medullary bone and hyperintense in the cortical bone, needs to be identified. Although routine radiography and standard computed tomography (CT) usually show stress fractures, dual energy CT, radionuclide examinations or MRI make earlier detection of stress injury possible. Lack of ionising radiation, along with superb depiction of bone marrow, renders MRI especially useful in this regard. Although most stress fractures are perpendicular to the long axis of the bone, unusual longitudinal stress fractures involving the femoral or tibial cortex are also reported[2].

Stress fractures are most commonly seen in the lower extremities and the spine. They are divided into fatigue and insufficiency subtypes, primarily depending on the quality of the bone and somewhat on the quantity of microtrauma. Repetitive loading on the healthy bone exceeding the

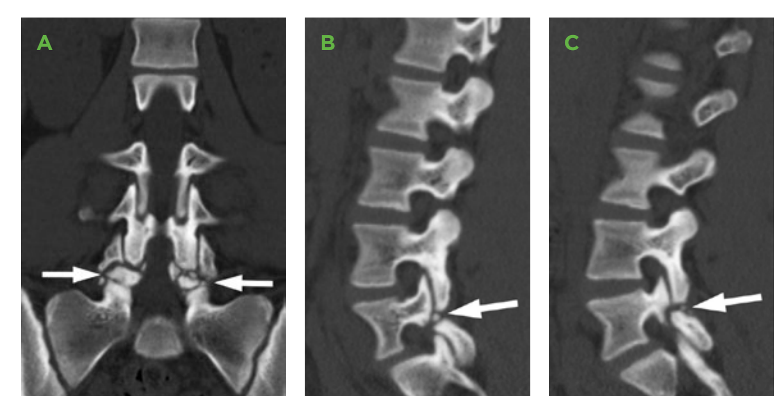


FIGURE 2

Case of an otherwise healthy 13-year-old girl with back pain. Coronal (A) and sagittal (right side, B; left side, C) CT reformats show fragmented fatigue subtype stress fractures (arrows) at bilateral pars interarticularis of L5.

FIGURE 3

Case of a 65-year-old woman with osteoporosis. Coronal fat-saturated proton-density MR images (A–C) show a subcortical insufficiency subtype stress fracture (arrow, A) at the weight-bearing section of the medial femoral condyle surrounded with bone marrow oedema. Note that the medially extruded (arrow, B) medial meniscus displays posterior root avulsion (arrow, C).

normal range of daily activities causes fatigue fractures. Repetitive stresses within the normal range of daily activities applied to abnormal bone result in insufficiency fractures. The former are usually seen in the younger population, while the latter are more common in the older. However, stress fractures with features of both fatigue and insufficiency categories are also encountered. On the one hand, the increasing engagement in our times of middle-aged people and the elderly in fitness-related or recreational activities that entail vigorous exercise or motion can result in fatigue injury[1]. On the other hand, the occurrence of nutritional or metabolic disorders in the young renders bones weaker, predisposing them to insufficiency fractures[1].

FATIGUE FRACTURES

Cortical bone is the initial site of involvement in fatigue fractures, which are commonly seen in the second and third metatarsal bones, the tibial shaft and the femoral neck. Periosteal reaction, intracortical resorption cavities and reactive subcortical marrow oedema follow with subsequent extension of the fracture line into the medullary cavity[1]. Fatigue fractures are generally considered to be the result of new (or different than the usual) or strenuous activities. They are usually encountered in young and active individuals, such as athletes or military recruits, as well as in children (Figure 1)[3–5]. What is known as spondylolysis, which denotes a defect in the pars interarticularis of the neural arch (usually at the level of L5), is most likely a fatigue fracture[6]. This condition, too, is more common in otherwise healthy adolescents (Figure 2) or young adults. The so-called ‘distal clavicular osteolysis’ is also considered to be an overuse injury in the form of cortical and subchondral bone stress reaction or fracture[7].

Muscles can play a causative or a protective role in fatigue fractures. The case of rowers, in whom stress fractures of the ribs occur more as a result of muscle torque than of external forces,

favours the former role. The ability of muscles to absorb 100 times more shock than bones of the same length favours the latter[8].

INSUFFICIENCY FRACTURES

The most common entity predisposing to insufficiency fractures is osteoporosis (primary or secondary). Corticosteroid or bisphosphonate therapy and prior irradiation are additional causes of iatrogenic predisposing conditions. Vertebral compression fractures associated with osteopenia are typical insufficiency fractures[3]; the sacrum is another frequent location. The pelvis, lateral femoral neck, and subchondral femoral head are among other sites of insufficiency fractures. What was formerly known as spontaneous osteonecrosis of the knee (SONK) is a subchondral insufficiency fracture[9] of the medial femoral condyle (or less commonly the tibial plateau), typically occurring over the age of 50, more common in women, and associated with medial meniscus posterior root tears in up to 80% of cases (Figure 3)[10].

Although the protective role of muscles in fatigue fractures is suggested, the effect of sarcopenia in the development of insufficiency fractures remains to be established.

CONCLUSION

Stress fractures can occur in normal and abnormal bone, in the young and in the elderly. Due to the current emphasis on a more active lifestyle and the increased longevity of humans, along with a wider recognition of nutritional and metabolic disorders affecting the largest organ system of the human body (i.e., the musculoskeletal system), the detection and management of stress injuries are increasingly important. Radiologists have excellent tools and the knowledge base to identify stress injuries to the skeleton ranging from the subtle to the overt.

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He worked as a member (and most recently the chairman) of the Musculoskeletal Scientific Subcommittee of the European Congress of Radiology for four years. He also served in the Education Exhibits Awards Committee of the Radiological Society of North America (RSNA). Dr. Aydingöz is currently the Musculoskeletal Subspecialty Member of the Postgraduate Educational Programme Subcommittee of the European Congress of Radiology 2020.

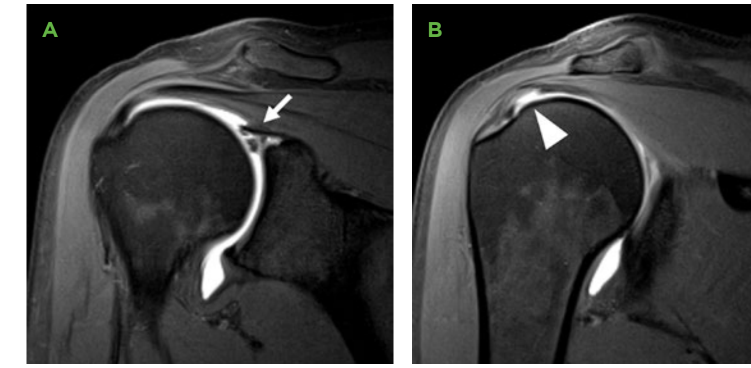
SPORTS OVERUSE AND INJURY

The shoulder

By **Klaus Wörtler**

FIGURE 1

(A, B) Coronal T1-weighted MR arthrograms with fat saturation show a SLAP lesion (arrow) and an articular-sided partial tear of the supraspinatus tendon (arrowhead) in a volleyball player with shoulder pain.



SPORTS INJURIES OF THE SHOULDER

Shoulder pain and injuries are common in both professional and recreational athletes and can be caused by chronic overuse or more infrequently by a single traumatic event. In particular, overhead sports, such as throwing, tennis, volleyball and handball, place great demands on the shoulder joint. Sequelae of overuse include biceps tendinopathy and instability, rotator cuff tears, SLAP lesions, and, if associated with muscular imbalance, extrinsic and intrinsic impingement syndromes. Traumatic shoulder dislocation, lesions of the acromioclavicular joint and fractures of the clavicle are among the most common acute sports injuries of the shoulder.

CONVENTIONAL RADIOGRAPHY

Conventional radiography is still the initial imaging modality to use in athletes with acute or chronic shoulder pain in order to obtain an overview of the morphology of the glenohumeral and acromioclavicular joints and the bony structures. Abnormal positions and degenerative changes of joints, acute and chronic osseous alterations, developmental disorders, and sequelae of previous surgery are often best visualised by radiography.

ULTRASOUND

Ultrasound is used as a rapid and focused modality which can be performed in conjunction with a clinical examination of the athlete's shoulder. It is highly accurate for diagnosis of rotator cuff tears, abnormalities of the extra-articular biceps tendon, and subacromial impingement. Due to its limited value for the depiction of intra-articular pathology, ultrasound is, however, unsuitable for a complete work-up of sports-related shoulder problems.

MR IMAGING AND MR ARTHROGRAPHY

In addition to clinical examination, MR imaging represents the most important modality for diagnosis and treatment planning in athletes with shoulder injuries. Whereas conventional MR imaging is typically used in acute injury cases, MR arthrography appears to be superior in the work-up of chronic shoulder problems due to its increased accuracy for labro-ligamentous pathology, SLAP lesions, pulley lesions, and articular-sided rotator cuff tears, as well as its overall higher negative predictive value. These advantages over conventional MR imaging are also evident at 3 Tesla, and thus, MR arthrography remains the modality of choice in athletes with unclear shoulder pain. The acquisition of additional images in the ABER (abduction and external rotation) position allows exact diagnosis of labro-ligamentous injuries, capsular laxity, and the typical patterns of abnormalities in

FIGURE 2

T1-weighted MR arthrogram obtained in ABER position demonstrates an anteroinferior tear at the base of the glenoid labrum (arrow), glenoid-sided thickening of the joint capsule and subtle decentring of the humeral head in a basketball player with microinstability of the shoulder and pain when throwing.

athletes with internal impingement. At present, MR imaging is still limited in the depiction of articular cartilage lesions as well as osseous abnormalities in patients with acute and chronic shoulder instability.

CT AND CT ARTHROGRAPHY

CT is typically performed to exclude or to define fractures in cases of acute sports injuries. In patients with traumatic shoulder instability, CT is often added following MR imaging in order to describe the exact extent of bipolar bone loss (glenoid and humeral head). On the basis of this information, the glenoid track concept enables the identification of patients who are more likely to fail arthroscopic Bankart repair and therefore helps to guide surgical management.

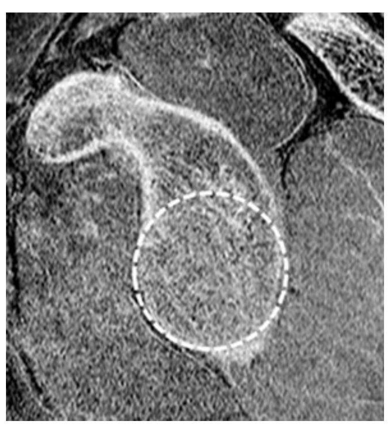


FIGURE 3

Parasagittal CT-like image reconstructed from a 3D GRE MR sequence shows normal anatomy of the glenoid labrum without evidence of bone loss in an athlete with anterior shoulder instability.

CT arthrography represents a valuable alternative to MR imaging and MR arthrography in the diagnosis of labro-ligamentous pathology, but involves the risk of radiation exposure in a group of patients who are generally young.

FUTURE DEVELOPMENTS

At present, imaging of the shoulder in sports injuries and overuse syndromes represents a multimodality approach including radiography, ultrasound, MR imaging, and, if indicated, CT. Current developments aim to provide a comprehensive evaluation of all anatomic structures of the shoulder by a single examination without exposing the athlete to ionising radiation. The only currently available technique which might fulfil this demand in the future is MR imaging. With the use of new coils and new parallel imaging techniques MR imaging and MR arthrography will provide high resolution images with even more detailed visualisation of anatomy than today, including the thin layers of articular cartilage covering the humeral head and glenoid. 3D MR sequences capable of providing CT-like data and simulated radiographs will allow a detailed and quantitative evaluation of bone structures and will obviate the need for additional radiographs and CT examinations. Functional imaging and automatic segmentation techniques will finally give insights into muscle quality, cartilage and bone loss and will allow comparison of these parameters on follow-up examinations.

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SPORTS OVERUSE AND INJURY
The elbow

By **Eugene McNally**

The elbow is a triarthroidal joint. The three surfaces are the radiocapitellar, ulnotrochlear and olecranon humeral joints. This arrangement allows the elbow to flex, extend and rotate the forearm. The bony components are supported by soft tissue structures, including the common flexors, extensors, biceps and triceps tendons. All three major upper limb nerves – the median, radial and ulnar – pass close to the elbow.

RADIOGRAPHY

X-rays are the most important imaging method in acute trauma. Most fractures are readily apparent but some only manifest as joint effusion. An effusion displaces the posterior fat pad, which provides a clue that there is a fracture. In children, this is important as fracture displacement can result in vascular injury. Another important paediatric injury is avulsion of the medial epicondyle, as growth anomalies can result if this is not repaired. In patients with more chronic pain, calcification, bone spurs and cartilage disease can be diagnosed.

COMPUTED TOMOGRAPHY

CT is important in cases of complex fractures, to help plan surgery. In patients with reduced range of motion, CT is used to detect loose fragments and soft tissue calcification.

ULTRASOUND AND MRI

Apart from in trauma cases, ultrasound and MRI are the most important imaging techniques. Whilst equivalent in many areas, each has some advantages; MRI for bone and cartilage disease and ultrasound for dynamic assessment during movement and for guiding treatment.

TENDONS

Tendinopathy results in an enlarged tendon, disruption of internal structure, vascular ingrowth and inflammation in its sheath or lining or paratenon. Damage leads to areas of increased signal on fluid sensitive MRI sequences and loss of normal reflectivity on ultrasound. Ultrasound can be used to guide injection treatment. Advancing disease may lead to partial or complete tears.

A common cause of pain in the lateral aspect of the elbow is 'tennis elbow' (Figure 1), although the condition is more common in others and repetitive rotational movement in manual workers is an important cause. 'Golfer's elbow' is the equivalent condition on the medial aspect of the elbow.

Biceps tendon disease is usually due to overuse injury and medical conditions such as diabetes, arthritis, renal disease and drugs may be predisposing factors. A painful mass simulating a tumour is one presentation. Rupture causes pain, weakness, bruising and a muscle bulge called the 'Popeye sign'. Ultrasound and MRI can be used to demonstrate the tear size and extent, which helps plan surgery (Figure 2). The site may be surrounded by an inflamed bursa, leading to nerve compression.

Triceps injuries are less common. Causes include olecranon bursitis, infection or local steroid injections.

FIGURE 1

Ultrasound of tennis elbow. The increased blood flow seen on Doppler ultrasound is especially helpful for diagnosis and provides a target for various injection therapies guided by ultrasound.

FIGURE 2

Rupture of the biceps tendon demonstrated by MRI. The tip of the torn tendon (arrow) is lax and has retracted from its normal insertion (arrowhead). These are important findings which help the surgeon plan a repair.

FIGURE 3

X-ray of a congenital supracondylar process of the humerus. The median nerve passes under the spur where a tunnel is created by the ligament of Struthers. If the tunnel is particularly narrow, median nerve compression can occur.

FIGURE 4

Sagittal MRI of osteochondritis dessicans of the capitellum. The arrow points to fragmentation of the joint surface.

LIGAMENTS

Ligament injuries affect the medial side more than the lateral. The internal structure of ligaments is similar to tendons but in more tightly compacted layers. Grade 1 injuries cause only haemorrhage around the ligament, grade 2 injuries involve fibre damage and grade 3 injuries are complete ligament ruptures. There is thickening and loss of reflectivity on ultrasound, and high signal on fluid sensitive MRI.

The anterior part of the medial ligament complex is the most important. Injuries can be complete or partial. Partial rupture tends to be distal separation of the ligament from its attachment. Ultrasound and MRI are both used for diagnosis.

Laterally, the annular ligament is the most important in children. An injury, called 'pulled elbow' occurs when the ligament slips over the head of the radius. In most cases, x-rays are all that is needed and the injury is easily treated.

In adults the radial and lateral ulnar components are more often injured, though this is uncommon. Posterior dislocation of the radial head is a known cause.

NERVES

All three upper limb nerves pass close to the elbow and are prone to compression. Ulnar nerve compression is the most common, with nerve swelling behind the medial elbow and denervation of the muscles it supplies. MRI is more sensitive for visualising denervation but ultrasound is best for showing the compression. Many causes are idiopathic with thickening of the walls of the neural tunnel; other causes include enlarged tendons, synovial disease, tumour or haemorrhage.

Ulnar nerve subluxation is present in 15% of individuals and may exacerbate other causes of compression, leading to symptoms. Ultrasound is the only technique that can demonstrate subluxation.

Median nerve compression may occur above the elbow joint due to an accessory bone called a supracondylar process (Figure 3). X-rays show the spur and MRI or ultrasound show the compression, which leads to pronator teres muscle atrophy. Masses in the proximal forearm may lead to compression of the anterior interosseus nerve branch of the median nerve, leading to thumb weakness.

Radial nerve injury should be considered if symptoms are unusual. As with other nerves, the radial nerve should be traced throughout its length from brachial plexus to its terminal branches and only ultrasound can achieve this with ease. The most common cause of radial nerve injury is a fracture of the humerus, as is compression at the lateral margin of the humerus, a condition called 'Lovers Palsy'. More inferiorly the nerve passes under and past a number of fibrous bands, tendon margins and prominent vessels, all of which can lead to compression.

The main branch of the radial nerve is the posterior interosseous nerve (PIN), serving the supinator and wrist and finger extensors. PIN impingement by a thickened ligament of Frohse within the supinator is one cause. Others include trauma and mass lesions.

BONE AND CARTILAGE

Osteochondritis dissecans (OCD) of the capitellum is thought to be a combination of trauma and a vascular susceptibility in children. Pain and locking are symptoms. Large lesions can be seen on x-ray. Ultrasound and MRI can be used to identify smaller lesions; ultrasound has the advantage of being less stressful than MRI for children (Figure 4).

In adults, cartilage damage is most commonly due to osteoarthritis and rheumatoid arthritis. Posteromedial impingement syndrome follows ligament instability when the olecranon articular surface impinges against the posteromedial aspect of the humerus. MRI is preferred for diagnosis of cartilage damage.

OTHER CONDITIONS

Olecranon bursitis is a common cause of swelling behind the elbow. The diagnosis is usually obvious, but ultrasound can assist by guiding injection to treat inflammation, or drainage in cases of infection.

Less common conditions include stress fractures, flange syndrome, posterior plica syndrome and brachialis tendinopathy.

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SPORTS OVERUSE AND INJURY
The hand and wrist

By **Maryam Shahabpour**

Overuse and traumatic injuries to the wrist and hand are commonly seen in athletes, comprising 3–9% of all athletic injuries. Many of the injuries reported in athletic activities are also seen in work-related and occupational activities[1].

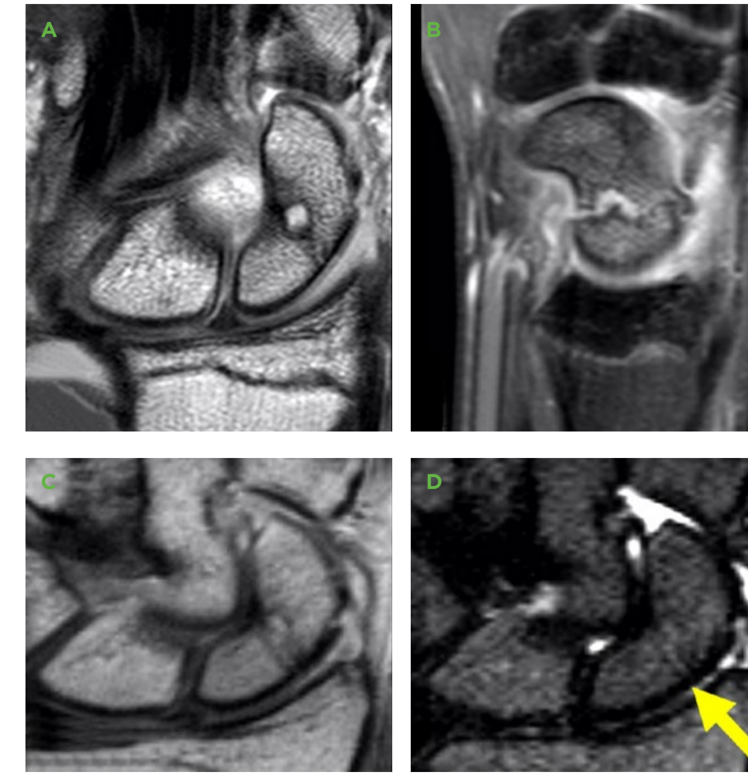
As defined by Rettig, overuse is a level of repetitive microtrauma sufficient to overwhelm the tissue's ability to adapt. Microtrauma represents damage at the molecular level and can be produced by either tension or shear load[2]. While overuse injuries are usually caused by repeated microtrauma without an identifiable event responsible for the injury, they may have a sudden onset as in stress fractures[3]. Wrist and hand overuse injuries are often seen in sports that involve racquet, stick or club use, such as tennis, field hockey and golf, and repeated loading and stresses on the wrist, such as rowing and gymnastics, as well as volleyball and handball.

Overuse and traumatic injuries of tendons, ligaments and nerves are often diagnosed and managed adequately with clinical assessment alone, supplemented by simple clinical tests (such as nerve conduction studies). But imaging is essential for early diagnosis and monitoring of athletes suffering from wrist and hand injuries in order to reduce recovery time and prevent complications.

In this chapter, an overview of the common overuse and traumatic injuries of the wrist and hand encountered in athletes and manual workers will be illustrated with advanced MR imaging and ultrasound. Ultrasonography provides a reliable, non-invasive and dynamic approach for most structures involved in overuse. This review includes bone injuries (acute fractures of the scaphoid, distal radius or ulnar styloid, stress fractures, injury to the hook of the hamate), ulnocarpal impaction syndromes and neurovascular lesions. Tendon disorders such as de Quervain syndrome, intersection syndrome and extensor carpi ulnaris instability are also common overuse lesions related to sports or activity[4].

FIGURE 1

Evolution of a missed scaphoid fracture on first x-rays, complicated by nonunion and healing after immobilisation. Figure shows a 17-year-old male who sustained a trauma with a scaphoid fracture that was not visible on the first radiographs. Coronal proton density (PD) (A) and sagittal fat saturated PD (B) MR images obtained 14 months after trauma revealed an extensive BME of the whole scaphoid, associated with a scaphoid fracture and nonunion. On the control coronal MR images (C, D) obtained three months after immobilisation by cast, the BME was resolved on STIR and the fracture was healed.



Ultrasonography and MRI are used to complement clinical and radiographic assessment in the diagnosis and management of sports-related finger lesions, including closed-tendon injuries (mallet and boutonniere injuries, jersey finger, and boxer's knuckle), flexor pulley injuries, and skier's thumb. These injuries will not be covered in this chapter.

OSSEOUS INJURIES

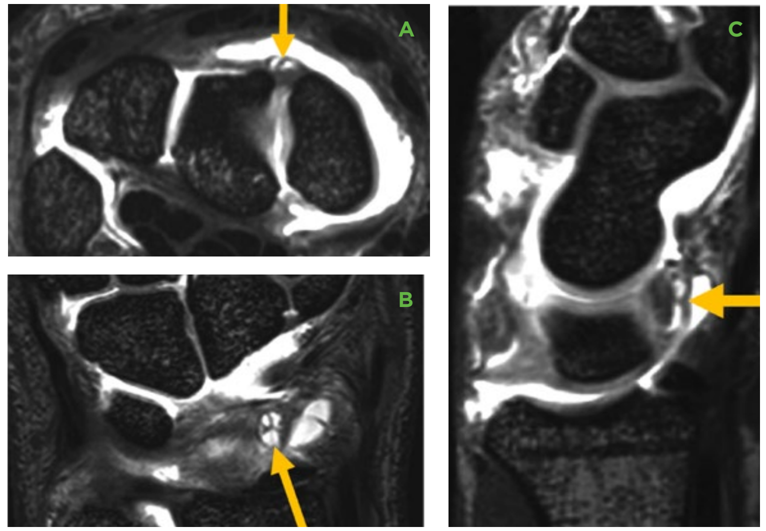
Most of the osseous wrist and hand injuries are diagnosed with clinical assessment and plain radiographs. Dynamic radiographs help to assess carpal instability (in case of associated ligament lesions). In complex fractures, plain CT is often needed for surgical planning. MRI is mandatory for detection of bone marrow oedema in radiographically occult bone injuries, especially scaphoid fractures[6]. However, CT has a higher sensitivity for detection of cortical fractures. Timely diagnosis of scaphoid fractures is important due to the risk of developing complications such as avascular necrosis and nonunion[3, 6] (Figure 1).

FRACTURE OF THE HOOK OF THE HAMATE

Other radiographically occult sports-related wrist fractures such as the fracture of the hook of the hamate can easily be diagnosed on plain CT. This overuse injury is due to repetitive microtrauma caused by direct impact by a racquet or golf club. MRI is the only modality able to show the fracture and potential complications as

FIGURE 2

Small cyst at the level of the dorsal capsuloscapholunate septum (DCSS) after a dorsal scapholunate (SL) ligament sprain. Axial, coronal and sagittal MRA images obtained with a 3D DESS sequence depict the cystic appearance of the DCSS (A, B, C, arrow) within the dorsal midcarpal triquetroscaphoid ligament (A). On the coronal section, the cyst is located within the dorsal capsule (B). The sagittal reconstruction demonstrates the DCSS connecting the SL ligament and the dorsal capsule (C).



nonunion or associated soft tissue lesions, including flexor digitorum profundus tendon rupture, isolated tenosynovitis of the flexor tendon of the fifth finger, ulnar neuritis and ulnar artery injury[2, 3, 4, 6].

STRESS INJURIES OF THE DISTAL RADIUS

Stress injuries of the distal radius often affect the distal radial growth plate in adolescent athletes because it is less resistant to stress than the surrounding bone and ligaments. This condition, caused by chronic repetitive compressive impact and shearing forces, is commonly encountered in young gymnasts and is called distal radial epiphysitis or gymnast wrist. Early diagnosis is essential to avoid premature closure of the physis, resulting in growth arrest of the radius. Coronal MR images can demonstrate epiphyseal and metaphyseal bone marrow oedema, widening and irregularity of the lateral aspect of the distal radial physis and cartilage thickening of the medial aspect of the radial physis. In cases of premature physeal closure, MR images can depict bony bridging across the distal radial physis and anteroposterior radiographs will disclose positive ulnar variance due to the ulna continuing to grow and secondary ulnar impaction syndrome[3, 5].

ULNAR IMPACTION

Ulnar impaction or ulnocarpal abutment syndrome is a degenerative condition at the ulnar side of the wrist that results from repeated contact of the distal end of the ulna with the carpal bones. It is usually observed in the setting of positive ulnar variance, which can be congenital, secondary to trauma, or secondary to premature closure of the radial physis in gymnast wrist. Early presentations of ulnar impaction may have subtle or no radiographic findings, in which case MRI can be helpful. MRI findings include subchondral and cartilage irregularity, bone marrow oedema and cystic changes of the impacting bony surfaces, triangular fibrocartilage complex (TFCC) degeneration or rupture, and lunotriquetral ligament damage; all of which can be associated with chronic wrist pain and dysfunction[1, 3, 4].

DORSAL WRIST IMPINGEMENT

Dorsal wrist impingement describes pain at the dorsal rim of the radius and carpus, caused by impingement of dorsal capsular tissue during repetitive dorsiflexion and axial loading, particularly in gymnasts. This leads to capsular thickening, synovitis and development of dorsal ganglion cysts. It is a clinical diagnosis; however, MRI may be valuable to exclude other causes of dorsal wrist pain such as scapholunate (SL) ligament tears. Ganglion cysts could be associated with partial tears of the dorsal SL band and surrounding extrinsic or midcarpal ligaments, especially the recently described dorsal capsular scapholunate septum (DCSS) connecting the SL to the dorsal capsular ligaments[2, 3, 10] (Figure 2).

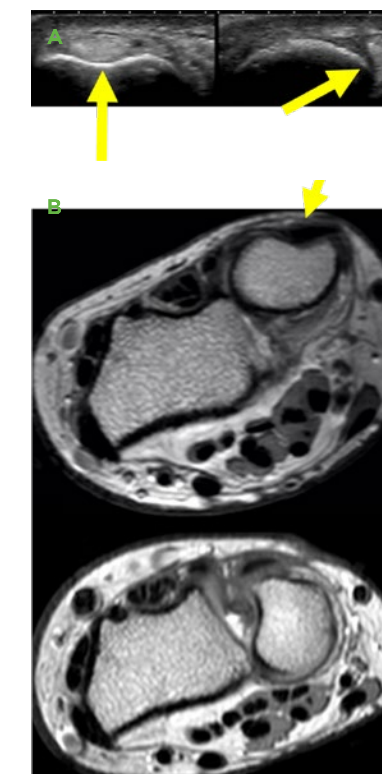
TENDON PATHOLOGIES

Most of the tendon pathologies related to overuse are degenerative (tendinosis, tendinopathy with or without tenosynovitis). The most common sites of tendon pathology due to overuse are the first (abductor pollicis longus and extensor pollicis brevis) and sixth (extensor carpi ulnaris ECU) extensor compartments. First-compartment tenosynovitis and tendinopathy, also known as de Quervain stenosing tenosynovitis, is commonly seen in rowing, racquet sports and weight training. It is also a common workplace-related repetitive-stress injury[4].

Intersection syndrome is due to friction between the first dorsal compartment tendons (APL, EPB) and the radial wrist extensor tendons (extensor carpi radialis brevis and longus) or second dorsal compartment tendons, 4–8cm proximal to the radiocarpal joint, proximal to the location of de Quervain. It occurs in sports that cause repetitive wrist dorsiflexion and radial deviation, such as rowing, racquet sports and skiing. MRI or ultrasound will show oedema or fluid surrounding the first and second extensor compartments, tendinosis, muscle oedema, tendon thickening and/or juxtacortical oedema[2, 3].

FIGURE 3

(A) Ultrasound in neutral position (left image) and in forced supination (right image) demonstrate the ECU tendon in the ulnar groove (left arrow) and an ECU tendon subluxation (right arrow). (B) Static and dynamic axial MR images show an instability of the distal radioulnar joint. In wrist pronation, the ECU tendon is located in the ulnar groove (arrow on upper image). The lower image obtained with the wrist in supination shows an ECU tendon dislocation (out of the ulnar groove) associated with a torn ECU subsheath.



ECU (extensor carpi ulnaris) overuse injuries are encountered in sports requiring repetitive wrist load, such as rowing and tennis. They may also be associated with other ulnar-sided wrist pathologies, including tears of the TFCC. The ECU tendon courses through the sixth dorsal compartment of the wrist, passing through a small fibro-osseous tunnel, which lies on the distal 2cm of the ulna. It is covered by a subsheath, attached on the margins of the ulnar groove, ensuring its stability during pronation/supination. Dislocation and subluxation of the ECU tendon out of the ulnar groove is usually seen in golf, tennis, rugby and weightlifting. Sudden changes in anatomical position explain the onset of traumatic injury to the ECU retinaculum whereby the angle of the wrist constantly changes. Once the fibro-osseous subsheath is torn or detached from the ulna, the ECU tendon can sublux and slide under the intact dorsal retinaculum that covers the six extensor tendons. The mechanism that causes ECU subluxation is often forced supination, palmar flexion, and ulnar deviation; the ECU tendon is relocated with pronation. It is easily palpated and visualised with ultrasound, especially on dynamic ultrasound with the wrist in supination (Figure 3). However, MRI can be useful for the visualisation of other pathologies associated with ulnar-sided pain, such as TFCC tears or ulnolunate impaction syndrome[7–9].

Flexor tendinopathies also occur in golf and racquet sports and most commonly involve the flexor carpi radialis and the flexor carpi ulnaris tendons[1, 4].

CARPAL TUNNEL SYNDROME

Carpal tunnel syndrome (or compression of the median nerve) is the most common nerve injury in the athlete's wrist. It can be the result of flexor tenosynovitis due to repetitive digital flexion, or repetitive flexion or extension of the wrist. It has been reported in body building, wheelchair athletics, cycling and swimming. When there is a discrepancy between clinical and electromyographic studies, ultrasound can be performed. The diagnostic accuracy of MRI in detecting signs of carpal tunnel syndrome (as an increased signal intensity on T2-weighted images or a bowing of the flexor retinaculum at the level of the hook of the hamate) is poor[1–3].

HYPOTHENAR HAMMER SYNDROME

Hypothenar hammer syndrome refers to damage to the ulnar artery caused by repetitive trauma and compression against the hook of the hamate. Repetitive blunt trauma in cycling, volleyball and karate or the repeated impact of a racquet (in tennis) can result in damage to the arterial wall with subsequent thrombosis or aneurysm formation[3, 4].

POST-TRAUMATIC ARTICULAR INJURIES

For assessment of post-traumatic articular injuries (including triangular fibrocartilage complex, intrinsic and extrinsic ligaments and articular cartilage) hand surgeons in many countries still tend to use CT arthrography (CTA), rather than MR arthrography (MRA) and their examination of reference for articular disorders remains arthroscopy in many cases.

With advanced MR imaging techniques and high resolution coils, MRI is able to image most of the relevant wrist and hand structures. Optimisation of MR imaging parameters, such as the use of isotropic three-dimensional sequences with very thin slices and high spatial resolution, seems necessary to detect lesions of the intrinsic and extrinsic ligaments. Direct (with articular injection of contrast material) MRA can be used to evaluate them, including mid-substance tears or avulsions of both ligaments. Sprains, granulation tissue and fibrous scar infiltration of carpal ligaments can be identified in the three carpal compartments (including the midcarpal joint) on indirect MRA using intravenous injection of contrast before the examination. Three-dimensional fat-saturated PD and 3D DESS (dual echo with steady state precession) sequences on 3T MR systems with 0.5mm-thick slices and multiplanar reconstructions allow detailed depiction of many of the extrinsic ligaments affected in carpal injuries. Both techniques may help to determine the precise localisation, size, and extent of dorsal and palmar radiocarpal and ulnocarpal ligament lesions. Further experience with these techniques is needed to define the place of MRI in the management of traumatic wrist injuries[1, 10].

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SPORTS OVERUSE AND INJURY

The hip and sports imaging: never-ending challenges

By **Vasco V. Mascarenhas**

INTRODUCTION

Hip imaging is presently in the spotlight, boosted by both new technical developments and novel clinical conditions discovered in the past decade, such as the recognition of femoroacetabular impingement syndrome (FAIS) as a cause of early-onset osteoarthritis[1] (Figure 1).

Clinically, hip and groin pain ranks in the top six most common athletic injuries, largely depending on sex, age and the type of sport, and mostly related to activities that involve acceleration/deceleration, rapid direction change and kicking. In children and adolescents, up to 24% of injuries affect the hip, as opposed to only 5% in adults. In professional football players, overuse hip injuries are up to three times more common than acute injuries (73% vs 27%)[2].

Interestingly, athletes with hip pain typically consult a large number of different medical specialists, with time to return-to-sport (RTS) often being the main question asked by every stakeholder[3]. Imaging has a pivotal, irreplaceable role in the clinical management of athletes.

AETIOLOGY, DIAGNOSIS AND PROGNOSIS OF HIP AND GROIN PAIN

Aetiology

Hip pain is a common but non-specific symptom that has many aetiologies and is experienced by up to 23% of athletes during a one-year period. These include degenerative joint disease, avascular necrosis, fractures, hernias, osteitis pubis, adductor-related pathology, trochanteric or iliopsoas bursitis, and muscle and ligament tears, all of which have been extensively studied[4]. Interestingly, with the development of newer imaging modalities, several additional causes of hip pain have become apparent, namely FAIS, labral tears and snapping hip[5].

Diagnosis

The complex anatomy of the hip region and the high prevalence of pathologic findings in asymptomatic athletes are likely the main reasons why making a clear diagnosis is often challenging. Accordingly, a myriad of intra-articular and extra-articular lesions can contribute to symptoms. After a thorough clinical examination and close communication between radiologists and referring colleagues, the imaging work-up should begin with a dedicated radiographic series, including an AP view of the pelvis and views tailored to femoroacetabular anatomy. Ultrasound, MRI and MR arthrography (MRA) remain the workhorse imaging tools in sports and pre-arthritic patients. In this setting, MRI protocols combining dedicated hip sequences, as well as sequences covering the pelvis, offer the best chance of identifying all potential sources of symptoms. With MRA, the anaesthetic arthrogram combined with increased diagnostic accuracy can be an extremely useful approach[2] (Figure 2). Although very promising, quantitative MRI cartilage imaging still needs to be further validated.

Prognosis

Accurately predicting an individual's RTS using current strategies is challenging because of

FIGURE 1

The natural history of femoroacetabular impingement disorders; stages, clinical events and goals.

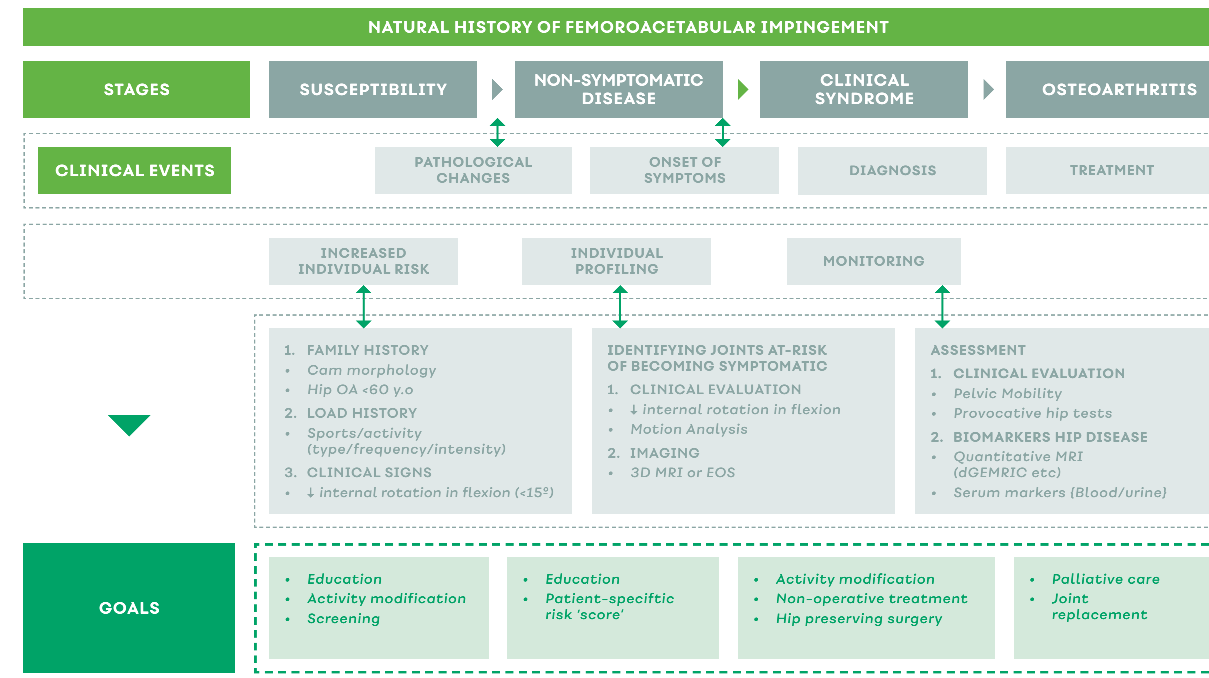
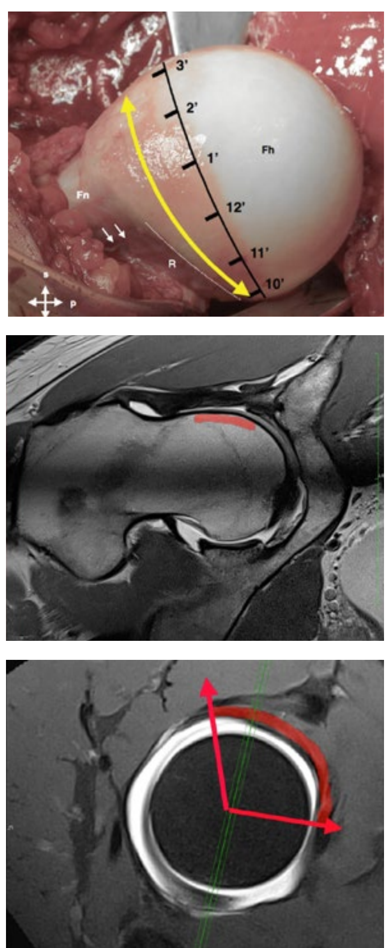


FIGURE 2

Magnetic resonance arthrography and corresponding surgical hip dislocation procedure in a former 35-year-old elite football athlete. Sagittal fat-suppressed proton-density sequence (bottom image), corresponding radial proton-density weighted sequence (middle image) and surgical hip dislocation (top image). Red curved line represents cam morphology assessed on the radial image at one o'clock and corresponding deformity in the sagittal plane extending from 11:30 to three o'clock, later confirmed by direct observation.



the complexity and heterogeneity of such lesions. From an evidence-based point of view, sports physicians and radiologists still cannot satisfy these high expectations[3].

FAIS AND SPORTS

With the acceptance and implementation of the FAIS concept in routine clinical practice, concerns have been raised about overdiagnosis and overtreatment (Figure 3). Imaging and clinical evaluation are now established as the cornerstones of the evaluation of suspected FAIS[6].

Association between FAIS and sport activities

Are sports and FAIS related? Genetics, sex, and physical activity influence whether or not a cam-type morphology develops[7]. Accordingly, there is a strong association between sports and FAIS, with high-level male athletes being two to eight times more likely to develop a cam-type morphology[7]. Specifically, the prevalence of cam morphology is as high as 89% in athletes participating in activities that result in hip impact loading[8].

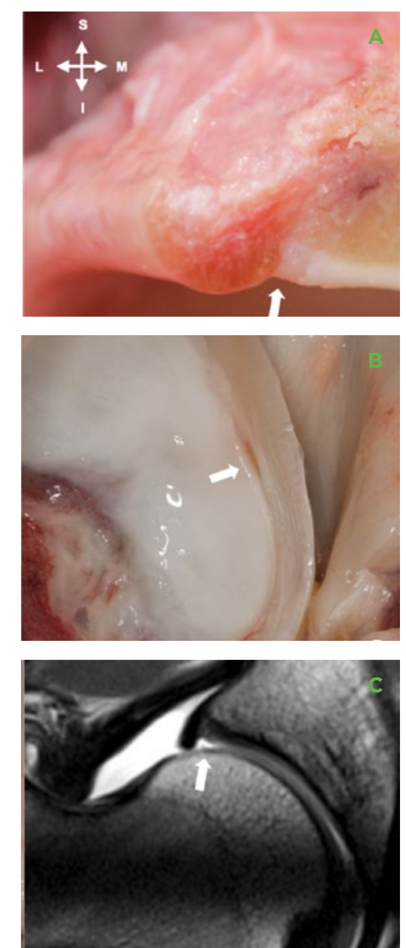
ACTIVITY TYPE

a) Weight-bearing impact sports (hockey, basketball, and possibly football): high-level athletes engaged in activities that require high flexion together with hip rotational movements are at an increased risk of cam morphology at skeletal maturity (e.g. ice hockey players were 4.5 times more at risk than skiers).

b) Extreme and supraphysiological hip motion (ballet dancing, ice skating, or martial arts): high-level athletes engaged in activities that require movement beyond the normal physiological range of motion may not exhibit the typical hallmarks of FAIS but rather develop a type of atypical hip

FIGURE 3

Normal hip labrum variants. (A) Macrophotography of the acetabular labrum section. There is a normal depression in the chondrolabral transition and the continuity of the labral tissue with the bone and cartilage surface (arrow). (B) Detail of the anterior articular surface where we frequently observe a more pronounced depression in the chondrolabral continuity (arrow). (C) Magnetic resonance arthrography image of the same groove (arrow) in a 22-year-old ballet dancer with hip pain. This variant should not be confused with labrum rupture. S: superior; I: Inferior; M: medial; L: lateral.



impingement (resembling that of pincer-type impingement).

ACTIVITY LEVEL

A dose–response relationship exists; elite football players who practiced more than three times a week before the age of 12 years were 2.6 times more likely to have a cam morphology than players who practiced three times or fewer.

WINDOW OF 'INCREASED-RISK'

Particularly between the age of 12 years and the closure of the growth plate, athletes with previously normal hips may develop a cam-type morphology as it mainly develops when the proximal femoral growth plate is open.

Cam morphology is a bony adaptation resulting from the growth plate being stimulated by sporting activities (Figure 2). Accordingly, a personalised training schedule during skeletal growth, adapted to an individual's safe activity threshold (training intensity and frequency), would be the utopian approach. Currently there are no recommendations for how and when to adjust athletic activities[8].

FUTURE TRENDS IN HIP IMAGING

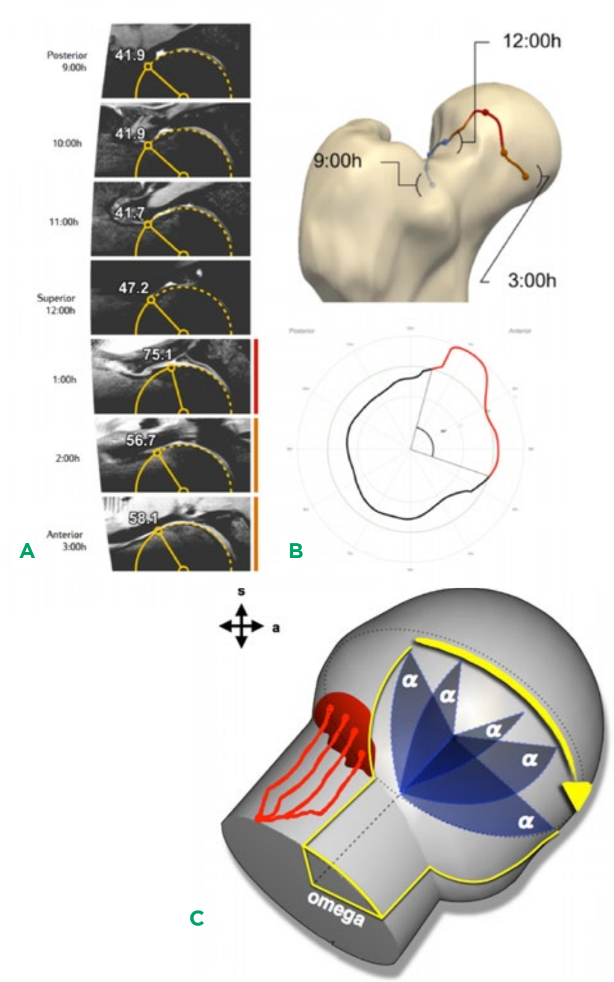
The future of hip imaging will include comprehensive 3D joint imaging, performed within fractions of the time currently spent and multiparametric in nature, allowing for (a) high resolution 3D MRI acquisitions with the potential for replacing MRA and (b) fully automated examinations with algorithms to diagnose and quantify specific biomarkers[9] (Figure 4).

Artificial intelligence

Large clinical databases in the era of value-based healthcare are of paramount importance, ultimately enabling the improvement of patient outcomes while minimising the economic burden. Artificial intelligence in the sports medicine field will certainly set the new

FIGURE 4

Automated segmentation and quantification of femoral parameters based on a 3D MRI dataset of a 30-year-old elite football player. (A) Volumetric 3D MRI alpha-angle (α°) automated measurements made at different points around the femoral head/neck junction. α° measured at nine o'clock (posterior); 10, 11 and 12 o'clock (superior); and one, two and three o'clock (anterior). (B) upper image – 3D generated model representing the radial extension of the cam deformity (orange and red line representing increased alpha angles). Lower image – Polar plot (2D) of the automated 360° α° measurements around the FHN, representing the Ω° angle (grey straight lines) and corresponding perimeter (red line) for a given α° threshold (55°). Red lines represent increased α°s for a given threshold. The Ω° is formed by two lines intersecting the centre of the femoral neck at the level of the head-neck junction. The most posterior line posteriorly intersects the point at which the α° angle begins to be abnormal beyond a best-fitting circle and the anterior line at the point where the α° angle returns to normal. (C) Schematic drawing of the proximal femoral head. Retinacular vessels at the postero-superior quadrant are represented (red lines and dots), with corresponding relationship with the radial angular measurement of the cam deformity (omega- Ω°; yellow lines) defined by increased α° at the antero-superior quadrant (blue lines).



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standard by automatically detecting injury patterns via integration with healthcare big data and then using those patterns to predict a 'personalised' RTS or enable decision making under uncertain conditions[10].

Personalised medicine and biobanks

The original concept of precision sports medicine involves the implementation of treatment and prevention strategies that consider individual variability by assessing large sets of data, including patient information, medical imaging, and genomic sequences. Patient-based imaging data will be implemented and cross-linked to population-based data already held in biobanks, thus allowing a tailored decision[11].

CONCLUSION

Innovation has been the catalyst for the transformation of hip imaging, as the arrival of new modalities and the introduction of MRI have resulted in a paradigm shift from bone morphology analysis to integrated soft tissue, joint and cartilage assessment, resulting in a major impact on therapeutic decision making.

With increasing sports medicine specialisation and rising rates of overuse injuries, major questions have still to be answered, namely regarding RTS-specific predictors and the role played by intense athletic activity in FAIS development. The delicate balance between early preventive measures, conservative treatment and surgical intervention has yet to be clearly defined.

It is time to refine the diagnostic and therapeutic algorithm by incorporating both clinical and imaging data into the medical equation. Looking ahead, imaging and sports will continue to evolve hand-in-hand, with new problems and even greater challenges.

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He has special expertise in non-invasive and invasive hip imaging with CT and MR, with a focus on femoroacetabular impingement and hip preserving imaging. In this capacity, and also as a member of the national MSK committee, he enjoys teaching and promoting hip and MSK imaging to residents and other radiologists through lectures and workshops at national and international meetings.

He was the congress president of the annual ESSR meeting in 2019, held in Lisbon, Portugal, on June 26–29.

Imaging of MOTION & PERFORMANCE STRESS & STRAIN

SPORTS OVERUSE AND INJURY
The knee

By **Filip M. Vanhoenacker**

The knee is one of the most commonly injured joints in top athletes and patients who engage in recreational sport.

Although plain radiographs remain the initial step in the diagnostic setting of acute osseous sports lesions, particularly in children and adolescents, state-of-the art ultrasound is a very useful technique for evaluating superficial structures such as the collateral ligaments and extensor tendons (tendon disorders are discussed separately, in chapter 3.1 of this book). For the evaluation of intra-articular structures, MRI has surpassed all other imaging methods and is currently regarded as the imaging method of choice.

MENISCAL TEARS

Meniscal tears are basically evaluated by analysing the increase in signal and morphologic changes (displaced or missing meniscal fragments). Grading of the intrameniscal signal is summarised in Figure 1. For a confident diagnosis of a significant meniscus tear, extension of the signal changes should be visible on at least two slices (the 'two slice touch' rule).

Meniscal tears can be classified into vertical (often of traumatic origin in young patients) and horizontal tears (often of degenerative origin and occurring at a later age). Further subdivision is explained in Figure 2. Complex meniscal tears consist of a combination of vertical and horizontal tear patterns.

Meniscocapsular separation is a subtype of meniscal tear, which is easily missed on arthroscopy. Meniscal extrusion (>3mm) of the medial meniscus occurs in degenerative tears and complex or large radial tears involving the meniscal root, and may predispose individuals to premature osteoarthrosis.

Imaging of the postoperative meniscus is a particular challenge, in which MR or CT arthrography may be useful if there is a high clinical suspicion of recurrent tearing and inconclusive conventional MRI results. The criterion for a recurrent or residual tear is the extension of contrast into the meniscal fragment or into the site of a meniscal repair.

LIGAMENTOUS TRAUMA

Anterior (ACL) and posterior cruciate ligament (PCL) tears

Ligament discontinuity, failure to identify the normal hypointense anteromedial bundle and loss of the striated appearance are primary signs of an acute ACL tear. A chronic tear may undergo complete atrophy. Table 1 summarises the secondary signs of anterior cruciate ligament rupture.

The diagnosis of partial ACL rupture remains difficult on imaging.

PCL tears occur less frequently in the sporting population and are often associated with other intra-articular lesions.

Medial collateral ligament (MCL) tears

MCL tears typically result from valgus trauma and may be associated with injury of the menisci and ACL. They most often involve the femoral insertion.

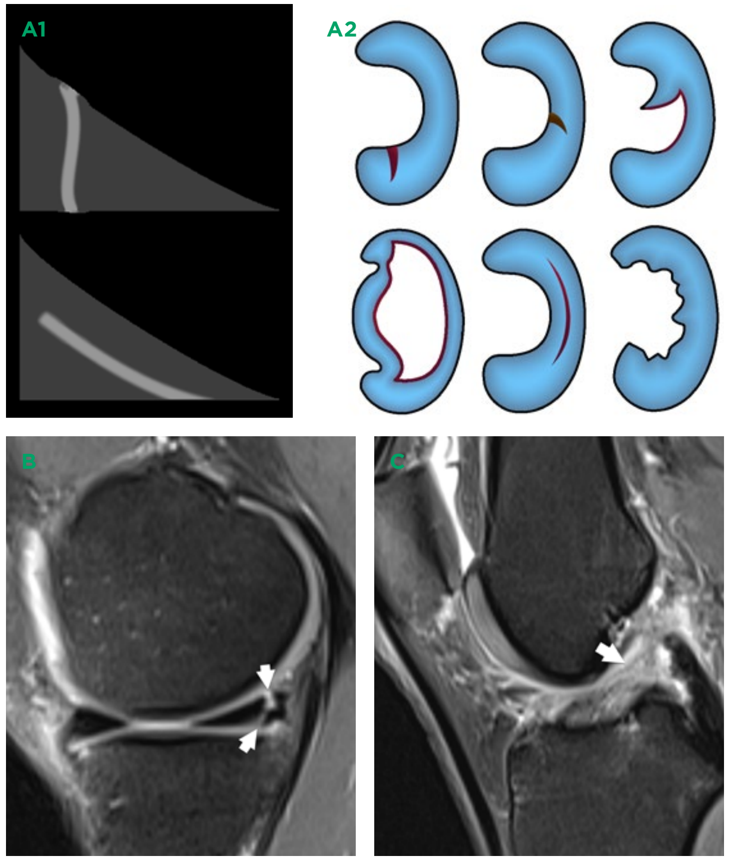

FIGURE 2

Classification of meniscal tears (A) and clinical example of a vertical medial meniscal tear (B) and a complete ACL tear in a 26-year-old football player (C).

Schematic drawing (A)

Coronal view (A1)
- vertical tear
- horizontal tear

View from above with further subdivision (A2)
- radial tear
- oblique tear
- flap or parrot beak tear
- bucket-handle tear
- peripheral, longitudinal tear
- complex degenerative tear

MRI of a football player with a meniscus (B) and ACL tear (C). Sagittal FS PD MRI of a medial meniscal tear extending to the upper and lower edge of the medial meniscus (B, white arrows). Midsagittal PD MRI shows complete discontinuity of the ACL (white arrow) in keeping with a complete ACL tear (C).

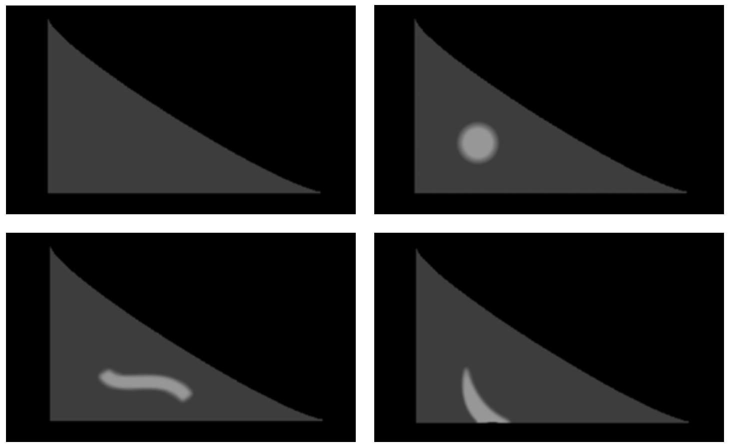

FIGURE 1

Schematic drawing of grading of meniscal signal as seen on MRI.

- Grade 0: Uniform low signal
- Grade 1: Intrameniscal globular-appearing signal not extending to the articular surface
- Grade 2: Linear increased signal patterns not extending to the articular surface
- Grade 3: Abnormal signal extending to the articular surface, representing a true meniscal tear

Other ligamentous structures of the knee

Currently, much attention is given to the role of the posterolateral and posteromedial ligamentous complex, as well as the anterolateral complex of the knee, in maintaining the stability of the knee. For detection of lesions of these thin ligaments, high resolution images and a high level of expertise are mandatory.

BONE MARROW OEDEMA OF THE KNEE

Acute traumatic lesions

Bone marrow oedema (BME) is frequently encountered on MRI following trauma. The location and extent of BME depends on the mechanism of trauma.

Impaction type BME, which is due to the direct impact or impaction of adjacent bony structures, will involve a broad surface of the involved bones. Distraction injuries due to valgus, varus or rotational stress, result in a subtle BME pattern at the point of tendinous, ligamentous or capsular attachment on the bone. It may indicate the presence of an underlying ligamentous sprain, which should be treated appropriately. Small avulsion fractures may be very difficult to detect on MRI. Correlation with radiographs or CT is often mandatory.

Typical BME patterns encountered in sports injuries are the pivot shift injury, hyperextension injury, clip injury, dashboard injury and (transient) lateral patellar dislocation (Figure 3).

Chronic repetitive trauma

FATIGUE AND INSUFFICIENCY FRACTURES

See chapter 3.3 on stress fractures for a full discussion of these.

CHRONIC AVULSIVE INJURIES

Typical examples of chronic avulsive injuries include chronic avulsive irregularity in adolescents due to chronic traction at the insertion of the medial gastrocnemius or adductor longus at the posteromedial aspect of the knee.

CARTILAGE LESIONS

Articular cartilage injury is a common finding in active patients and may be associated with other intra-articular lesions.

Staging of cartilage lesions

The most well-known arthroscopic staging method for articular cartilage is that proposed by Outerbridge in 1961 and modified by Shahriaree in 1985.

Five grades of chondromalacia may be distinguished:

0: normal cartilage

I: slight swelling

II: fissuring or cartilage defects less than 50% of cartilage thickness

III: fissuring or cartilage defects more than 50% but less than 100% of cartilage thickness

IV: cartilage defects and erosion with exposure of subchondral bone

V: penetration of the subchondral bone plate and associated BME

Although advanced MRI sequences for morphological and quantitative evaluation have been developed (delayed gadolinium-enhanced MRI of cartilage or dGEMRIC and T2 relaxation time mapping of cartilage), fat-suppressed intermediate-weighted FSE images are still the workhorse for detecting and grading cartilage lesions in routine clinical practice.

Thin-section volume acquisitions allow segmentation and facilitate accurate 3D reformation of articular cartilage.

Osteochondrosis dissecans in children and adolescents (OCD) and osteochondral fractures are caused by shearing forces. They typically involve the lateral aspect of the medial femoral condyle, the weight bearing portion

FIGURE 3

Bone marrow oedema pattern due to lateral patellar dislocation of the right knee in a 15-year-old football player. Schematic drawing (A) demonstrates lateral dislocation of the patella, resulting in impaction of the medial patella against the ventrolateral femoral condyle, resulting in impaction type bone marrow oedema (black arrows). Fat-suppressed axial T2-weighted MR image (B) demonstrating BME at the medial patella facet and the ventrolateral femur condyle (white arrows). Note also high-grade cartilage defects at the medial patella facet (black arrowheads).

TABLE 1

Secondary signs of ACL tears

SIGNS OF BONE INJURY	SOFT TISSUE SIGNS	ANTERIOR TIBIAL TRANSLATION
BME posterolateral tibia	ACL angle (between anterior aspect of distal ACL and anterior portion of intercondylar eminence) less than 45°	Buckling of the PCL
BME lateral femoral condyle	Blumensaat angle (between anterior aspect of distal ACL and intercondylar roof) more than 21°	PCL line (drawn along the posterior distal portion of the PCL) not intersecting the femur within 5cm of the distal aspect of the femur
BME or fracture posteromedial tibia	Horizontal shearing of Hoffa fat pad	Tangent to the lateral femoral condyle passes more than 5mm from the posterior tibial margin
Deep lateral femoral notch sign (more than 1.5mm)	Buckling of the patellar tendon is rare	Uncovering of the posterior horn of the lateral meniscus: vertical line along the posterior tibial cortex insects the posterior horn of the lateral meniscus
Associated second fracture	ALL lesion	Straight LCL

of the lateral femoral condyle, the patella and the trochlear groove.

In osteochondral lesions MR arthrography or cone beam CT arthrography can be performed to differentiate more accurately between stable and unstable lesions.

Many different surgical techniques have been developed for cartilage repair, which may be divided into three groups: the palliative (lavage and debridement), reparative (stimulation of repair from the subchondral bone) and restorative procedures (replacement of damaged cartilage). MR imaging may be used to evaluate cartilage repair by displaying thickness, edge integration, surface, subchondral bone plate and marrow.

PATELLAR MALTRACKING

Patellar maltracking may be due to several predisposing factors such as patella alta, flat trochlear groove and laterally positioned tibial tubercle, which may be quantified by imaging. The relative position of the tibial tubercle can be assessed by measuring the tibal tubercle-trochlear groove (TT-TG) distance. The upper limit of normal is about 1.7–1.8cm.

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SPORTS OVERUSE AND INJURY
The foot and ankle

By **Davide Orlandi, Matteo Catania** and **Enzo Silvestri**

INTRODUCTION

Foot and ankle pathology, both in the setting of acute diagnosis and follow-up of lesions, is an important aspect of musculoskeletal imaging. The incidence of foot and ankle injuries has been reported in up to 10% of all trauma cases and, moreover, chronic overuse and degenerative changes are commonly encountered in everyday clinical practice[1]. Magnetic resonance imaging (MRI) is often necessary for accurate diagnosis, given the wide spectrum of pathology and anatomical complexity of the foot and ankle. While conventional MRI plays a significant role in diagnosis, contemporary management of sports-related and overuse pathologies increasingly relies upon advanced imaging for early diagnosis of tendons and articular cartilage affections. Moreover, because several ankle, midfoot and forefoot changes are related to particular actions performed by the athlete, which affect joint biomechanics, there is increasing demand for weight-bearing imaging, nowadays achievable with weight-bearing MR and cone-beam CT imaging[1].

STRESS AND STRAIN IMAGING

Ultrasound elastography

Ultrasound elastography (SE) is a recent technology that has seen major developments in the past two decades. The main mechanical properties of tissues can be assessed with this technology by characterisation of their responses to stress. The two major techniques used in musculoskeletal elastography are compression real-time elastography (RTE) and shear-wave elastography (SWE)[2].

The mechanical properties of tendons, particularly their stiffness, may be altered in the case of tendon injury. RTE and SWE have already been used for the assessment of Achilles tendons, sural triceps muscles and plantar fascia. Achilles tendinopathy and plantar fasciitis are the most common pathologies investigated with SE. In relation to conventional ultrasound, SE potentially increases the sensitivity and diagnostic accuracy and can be used to detect pathological changes before they are visible on conventional ultrasound imaging. The main advantage of SWE compared to RTE is the possibility of obtaining a quantitative evaluation of tissue stiffness in a region of interest (ROI). This could be extremely useful for the monitoring of degenerative changes in order to identify the risk of injury and for the follow-up of conservative or surgical procedures. Several technical limitations are still recognised and standardisation is necessary to ensure repeatability and comparability of the results when using these techniques[2, 3].

Weight-bearing imaging

Conventional static imaging is able to provide a vast amount of information regarding the anatomy and pathology of the musculoskeletal system. However, those patients whose pain is dependent on position or triggered by movement can benefit from imaging techniques that enable the acquisition of functional information[4].

Weight-bearing imaging of the foot and ankle can be achieved with particular tilting MR magnets and also with specific CT scanners using cone-beam CT technology. Nevertheless, the acquisition modality that is used and the understanding of healthy joint biomechanics, as well as abnormalities, will help to detect those findings which are detectable only when bearing weight (e.g. hindfoot alignment angle changes; early failure of Lisfranc arthrodesis), enabling the radiologist and the surgeon to evaluate and treat ankle, midfoot and forefoot disorders in their early stages[4, 5].

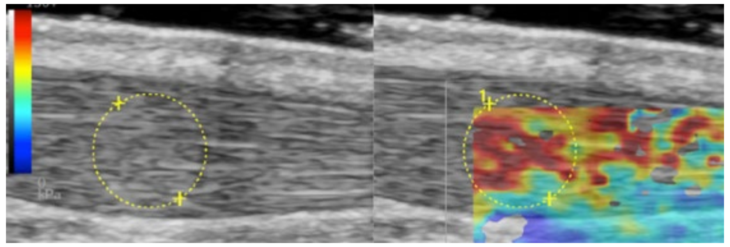


FIGURE 1

Shear-wave elastography (SWE) assessment of Achilles tendinopathy. The circular region-of-interest (ROI) is placed on the most thickened portion of the tendon.

ADVANCED MRI OF ANKLE AND FOOT

In clinical practice, pre-radiographic chondral damage is usually evaluated using semi-quantitative magnetic resonance imaging (MRI) scoring systems based on morphological parameters. More recently, quantitative MRI has been used to quantify different parameters of cartilage composition. Such physiological imaging techniques, like transverse relaxation time (T2) mapping, delayed gadolinium-enhanced MRI of cartilage (dGEMRIC), T1rho mapping, sodium MRI, and diffusion-weighted imaging (DWI), provide insight into the molecular composition of cartilage[6].

T2 mapping of the ankle articular cartilage provides a non-invasive and contrast-free imaging modality that reflects subtle changes in water content and in the collagen fibre network. This is pivotal for the early diagnosis of cartilage derangements but also for the monitoring of a variety of conservative cartilage repair techniques such as microfracturing, mosaicplasty, autologous chondrocyte and bone marrow-derived cell transplantation. In this setting, the molecular composition of repair tissue has been demonstrated to affect long-term clinical outcome of such cartilage regenerative techniques[6].

Another promising MRI technique is represented by diffusion-tensor imaging (DTI). At the level of the foot and ankle, DTI could be useful for tracking Achilles tendon fibres, furnishing a detailed tendon characterisation and providing early detection of tendinopathy-induced

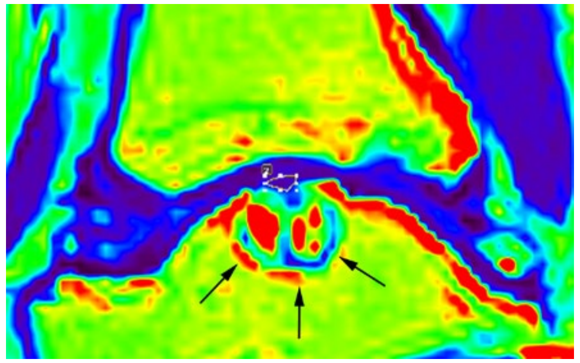


FIGURE 2

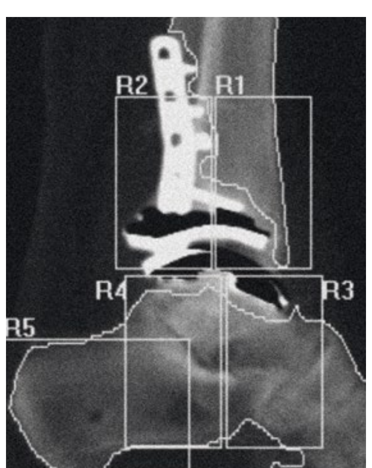
T2-mapping of tibio-talar joint articular cartilage showing a large osteo-chondral defect affecting the talar dome (arrows).

micro-structural disorganisation. This is particularly relevant for the purpose of differentiating between normal tendon repair and irreversible degenerative tendon changes. It has recently been demonstrated that significantly lower mean fibre length and density can be observed in tendinopathy when compared to healthy tendons[7].

IMAGING OF ANKLE PROSTHESES

In the end-stages of post-traumatic or degenerative arthritis, with advances in implant technology, total ankle arthroplasty (TAA) has become an increasingly popular alternative to arthrodesis. This represents a challenging task for the radiologist, who may be asked to perform prosthesis imaging using the most recent artefact-reducing MRI sequences and also to assess the quality of the bone surrounding the implant in order to detect early and subtle signs of intolerance or post-operative complications[8].

MRI is a valuable tool for detecting bone and soft tissue complications related to TAA, but it still suffers from artefacts related to the ferromagnetic properties of prosthetic parts. These artefacts can be reduced with metal artefact reduction sequences in combination with view angle tilting (WARP, MARS) and slice encoding for metal artefact correction (SEMAC)[9].



REGION	AREA [cm²]	BMC [(g)]	BMD [g/cm²]
GLOBAL	66.66	47.58	0.714
R1	7.58	6.41	0.845
R2	0.44	0.59	1.354
R3	12.44	8.94	0.719
R4	15.20	11.72	0.771
R5	20.77	11.08	0.533
NET	49.15	34.34	0.699

FIGURE 3

Dual-energy x-ray absorptiometry (DXA) of total ankle arthroplasty. Bone mineral density is evaluated in five different regions-of-interest (ROIs) showing normal BMD values around prosthesis (case courtesy of Dr. Carmelo Messina, Istituto Ortopedico Galeazzi, Milano, Italy).

Moreover, it is of great importance to accurately evaluate the periprosthetic bone environment, as bone loss may not only lead to loosening of the prosthetic components but can also create difficulties during possible revision. Conventional radiography and computed tomography (CT) are reliable techniques for the qualitative evaluation of bone-prosthesis interfaces, but the quantitative evaluation of periprosthetic bone density is unreliable. Dual-energy x-ray absorptiometry (DXA) with dedicated metal-removal software can be used to evaluate areal bone mineral density (BMD) around TAA implants. A recent study shows that DXA can be used to precisely monitor bone density around ankle prostheses, obtaining high reproducibility BMD values[10].

CONCLUSION

The crucial role of functional and biomechanical-oriented imaging of joints and tendons, together with biochemical imaging in the assessment of cartilage quality, cannot be emphasised enough. These imaging techniques could represent the ideal landmarks to state-of-the-art advanced imaging of the ankle and foot.

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SPORTS OVERUSE AND INJURY

The spine

By **Antonio Leone** and **Victor N. Cassar-Pullicino**

Spine overuse syndrome is a condition that is seen often in sports and occurs when the spine is injured by repeated overuse; especially by repetitive movements of twisting and hyperextension of the lumbar spine. Most painful injuries to the spine resulting from overexertion are sprains of the ligaments or strains of the muscles.

Several more serious conditions, however, can have symptoms similar to a sprain or strain. Repeated stress to the spine and to the pars interarticularis (or isthmus) in particular, can lead to spondylolysis – a developmental or acquired stress fracture of the pars interarticularis, secondary to chronic low-grade trauma – which can be a cause of spine instability, back pain, and radiculopathy[1].

In the primary care setting, an early diagnosis of spondylolysis has important implications regarding management decisions, since stress reactions, incomplete fractures, or complete acute fractures (Hollemberg classification system)[2] can respond to conservative management. Conversely, delayed diagnosis and treatment may progress to nonunion[1, 2].

Imaging is utilised to detect spondylolysis (pars defect), distinguish acute and active lesions from chronic inactive nonunion, help establish prognosis, guide treatment, and assess bony healing. Radiography can often demonstrate spondylolysis. CT with multiplanar reformats is the reference standard for demonstrating complete and incomplete pars defects and may also be used for the few equivocal cases, to clarify the extent of the lesion and for assessment of osseous healing; however, as with radiography, it is not sensitive enough for detection of the early oedematous stress response without a fracture line and exposes the patient to ionising radiation.

The potential for false positive and false negative results, the inability to distinguish between stress reactions and overt fractures, as well as the use of ionising radiation, render nuclear medicine modalities unacceptable as screening investigations for spondylolysis in young patients. Single-photon emission computed tomography in particular, should be avoided except where magnetic resonance (MR) imaging is contraindicated[1, 3]. MR imaging, which has the advantage of not using ionising radiation, should be used as the primary investigative modality for adolescents with back pain and suspected overuse reactions of the pars interarticularis.

The presence of bone marrow oedema on fluid-sensitive images is an important early finding that may suggest stress response without a visible fracture line (Figure 1). However, each MR examination, used with the specific aim of diagnosing spondylolysis, should include at least 3mm sagittal and reverse-angle oblique axial T1-weighted images as well as 4mm sagittal and 3mm reverse-angle oblique axial fluid-sensitive fat-suppressed sequences (i.e., short-tau inversion recovery [STIR] or fat-saturated T2-weighted images) (Figure 2).

A sagittal thin-section 3D spoiled gradient echo sequence is also a useful technique for demonstrating the integrity of the cortex of the pars. Furthermore, Ang et al[4] compared 3T MR imaging using a thin-slice 3D T1 volumetric interpolated breath-hold examination (VIBE) sequence versus CT in the detection and grading of pars injuries. It was found that with use of a 3T magnet and a 3D T1 VIBE sequence, MR imaging can allow accurate assessment of pars morphology and pathology with findings comparable to CT.

For adolescents with unspecific activity-related lower back pain for more than three to four weeks, the goal is to detect impending spondylolysis, which refers to grade 1 (stress reaction) of the Hollemberg classification, characterised by marrow oedema of the pars interarticularis and intact cortical margins, with or without signal changes in the adjacent pedicle or articular process.

An accurate and timely diagnosis is paramount to enable healing, prevent progression and return to sport[5, 6]. We believe the use of MR imaging can help in both the prevention and management of symptomatic spondylolysis. A diagnosed stress reaction, in fact, requires

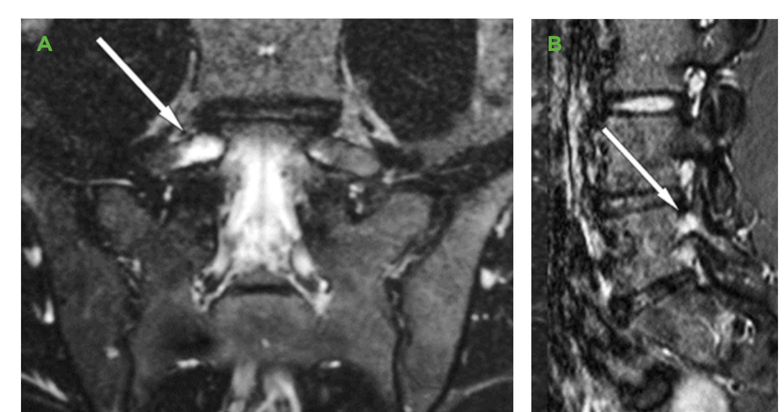

FIGURE 1

17-year-old gymnast complaining of back pain. (A) Reverse angle oblique and (B) right parasagittal fat-saturated T2-weighted MR images show a peri-isthmic area of marrow oedema at the L5 level with no evidence of pars defect (grade 1 spondylolysis) (arrow in A and B).

non-operative treatment consisting of activity restriction, rest, and physical therapy with or without an adjunctive spinal brace with a thoraco-lumbo-sacral orthosis for three to six months, thus avoiding nonunion, listhesis, or surgical intervention[7].

In conclusion, stress reactions and early fractures have a better prognosis than chronic complete fractures. A high degree of clinical suspicion, as well as a greater knowledge of potential causative factors such as incorrect sports techniques, poor preparation, and above all overuse, are desirable, supported by use of MR imaging, preferably with a 3T magnet. MR imaging should be strongly considered as the advanced imaging modality of choice in the evaluation of patients with suspected spondylolysis. The presence of bone marrow oedema on MR images confers a very high risk for bone stress injury; therefore, the hope for the future is to manage the risk with MR screening and monitoring.

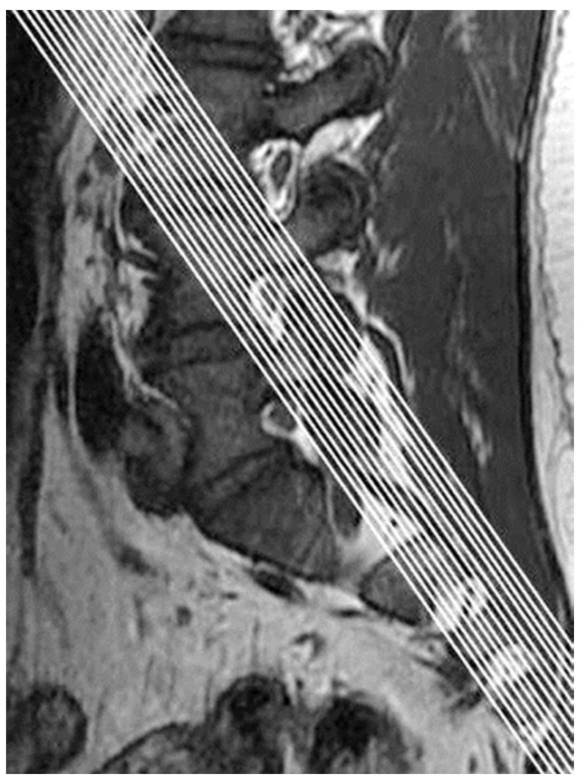

FIGURE 2

Graphical representation of the positioning plane for reverse angle oblique MR images.

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4

PATIENT EMPOWERMENT

PATIENT EMPOWERMENT AND PREVENTIVE IMAGING: The athlete and the patient under rehabilitation

By **Igor Borić**

The primary goal of medical imaging is to establish a reliable diagnosis. But the purpose of radiology should not only be the diagnosis. Everything needs to revolve around the patient; from diagnosis, through follow-up, to the final evaluation of healing and rehabilitation.

Today, radiological imaging should be on the path towards direct contact with the patient. Shared decision making, central to evidence-based medicine and good patient care, begins and ends with the patient. It is the process by which a radiologist and a patient jointly make a diagnostic decision after discussing options, potential benefits and harm, and considering the patient's values and preferences. But, patients' knowledge of their imaging examinations is frequently incomplete. The findings may motivate initiatives to improve a patient's understanding of their imaging examinations, enhancing patient empowerment and contributing to patient-centred care.

Patient empowerment is crucial to shared decision making and occurs when a patient accepts responsibility for their diagnostic procedure, and health in general.

Patient empowerment (PE) is viewed as a key factor for improving health outcomes, enhancing communication between patients and health professionals, bringing about better adherence to treatment regimes, and ensuring the efficient use of health resources. This is outlined as a specific intention by the World Health Organization's (WHO) Regional Office for Europe, in the *Health 2020* European health policy framework. According to this policy framework, which provides main strategies and priorities to support European action for health and well-being, people are increasingly seen as co-producers of their own health, and need to be empowered to take control of the determinants of their own health. The WHO defines PE as a process whereby patients understand their role, are given the knowledge and skills by the healthcare provider to perform a task in an environment where there is an awareness of community and cultural differences, and where patients are encouraged to participate. A recent concept analysis of PE stated that:

"Individual patient empowerment is a process that enables patients to exert more influence over their individual health by increasing their capacities to gain more control over issues they themselves define as important" (WHO: Patient empowerment and health care, p. 1927).

After the establishment of a reliable diagnosis using imaging techniques, patients can then learn how to solve their own problems with information and support from radiologists and other clinicians. Patient empowerment begins with the provider acknowledging that patients are ultimately in control of their care and aims to increase a patient's capacity to think critically and make autonomous, informed decisions about their health. It explores barriers and the potential for improving healing, and self-management of different diseases, including musculoskeletal diseases.

There is a growing interest in patient influence and participation in the rehabilitation process, especially among athletes. Participation in treatment planning is a natural continuation of the patient's participation in the diagnostic process. In managing a life with musculoskeletal disease and the possibility of planning and following a rehabilitation plan, patients' empowerment and self-efficacy are considered important. However, there is currently limited data on levels of empowerment among patients with musculoskeletal disease, and demographic and clinical characteristics associated with patient empowerment are not known.

Continuous radiological monitoring of the progress of rehabilitation and health improvement increases the patient's awareness of the course of rehabilitation. When the patient/athlete is able to visualise the effects of their rehabilitation, it becomes clear how important their engagement in rehabilitation is, and how much the patient can influence their rehabilitation with their additional engagement.

It is important to consider what is needed to get the best results out of rehabilitation, especially in the case of athletes. According to Larsson et al., client participation in rehabilitation planning is the ideal method for decision making in healthcare. Studies that have described the patient's experiences of influence and participation in the rehabilitation process show better results in physical therapy when the influence of each patient in the whole process is higher. But visualisation of the rehabilitation process using imaging methods is crucial.

Client-centred practice can mean different things to different people. Usually, athletes play a bigger part in the decision-making process in diagnosis and rehabilitation than other patients. Patients must be given the tools to take responsibility for their own health. Empowerment means that the patient has learnt enough about their disease, diagnostic procedures and treatment possibilities to be able to decide and choose between different alternatives. Patient empowerment has changed from patient influence to self-control and patient decision making. This will also change the relationship between clinicians/radiologists and patients to involve more exchanges of experiences, thoughts and knowledge. Healthcare must develop an educational role and function as a learning organisation that will help the patient to build up self-confidence regarding their own health values, needs and goals. Prioritising patient comfort, safety and satisfaction may be a hot topic among policy makers in today's radiological environment.

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5

IMAGING IN MOTION

Imaging in motion

By **Jaspreet Singh, Radhesh Lalam** and **Ramy M. Mansour**

A vast proportion of musculoskeletal pathologies arise as a result of abnormal motion or loading of the joints and soft tissues.

Conventional static imaging utilising various different modalities is able to provide a large amount of information regarding these disorders. However, the imaging information obtained is a single static snapshot of the pathology that is a consequence of abnormal joint mechanics. Therefore, whilst interpreting these images, a radiologist has to deduce the underlying abnormal motion or biomechanical stress that may have caused the pathology. The actual abnormal joint motion is often not directly visualised by such imaging and therefore disorders which occur only during activity may not be apparent. Therefore, direct imaging of motion has a huge impact on understanding of the underlying biomechanics of the musculoskeletal system. Dynamic imaging involves evaluation of various soft tissue and bony structures through a specific range of motion. Techniques that allow imaging of the musculoskeletal system dynamically, whilst in motion, under stress, or bearing a load, provide crucial information required for evaluation and treatment of such disorders. Dynamic acquisition can be performed using a variety of modalities, including ultrasound, fluoroscopy, MRI and CT, and each has its advantages and disadvantages. These various imaging modalities are discussed below with illustrative examples.

ULTRASOUND

The benefits of ultrasound are easy accessibility, lower cost and the absence of ionising radiation. In dynamic ultrasound imaging, the examination is performed by holding the ultrasound probe directly over the region of concern whilst the patient performs the manoeuvre that elicits the clinical symptoms. Dynamic ultrasound can be used in the evaluation of musculoskeletal structures to assess snapping of tendons and fascia, impingement or friction syndromes, and muscle herniation through deep fascia, which occurs only during muscular contractions.

Subluxation of the peroneal tendons causes pain and snapping at the lateral aspect of the ankle. On static imaging, the tendons are located in the normal anatomical position and it is not possible to diagnose subluxation without the help of dynamic imaging. The ultrasound probe is placed transversely over the tendons and the patient is asked to perform dorsi-flexion and eversion of the foot, which demonstrates the peroneal tendons to be dislocating antero-laterally over the lateral malleolus (Figure 1).

Dynamic ultrasound is also helpful in assessment of the stability of finger pulleys, which form a fibro-osseus tunnel around the flexor tendons and prevent bowstringing of the tendons during flexion. Conflict between the tendon and the pulleys results in a trigger finger that presents as locking or clicking of the flexor tendons. Dynamic ultrasound reveals the lack of a smooth gliding motion of the tendon and impingement between the tendon and the pulley. In cases of tendon or muscle tears, dynamic ultrasound helps in assessment of the degree of separation, which helps guide clinical management.

FLUOROSCOPY

Dynamic fluoroscopic analysis can be used to investigate motion in various joints of the body. However, as classical fluoroscopy depicts a 2D image, its usefulness can be limited by superimposition of multiple structures overlying the region of interest in areas of complex anatomy such as the wrist or the ankle. Fluoroscopic

FIGURE 1

(A): AP radiograph shows a flake of bone (solid arrow) representing an avulsion fracture at the insertion of the peroneal retinaculum. (B): Axial CT in a resting state shows the fracture fragment and normal location of the peroneal tendons (dashed arrow) are located normally behind the fibula. (C): axial ultrasound image during dynamic dorsiflexion and eversion shows dislocation of the fracture fragment and the peroneal tendons which now lie lateral to the fibular tip.

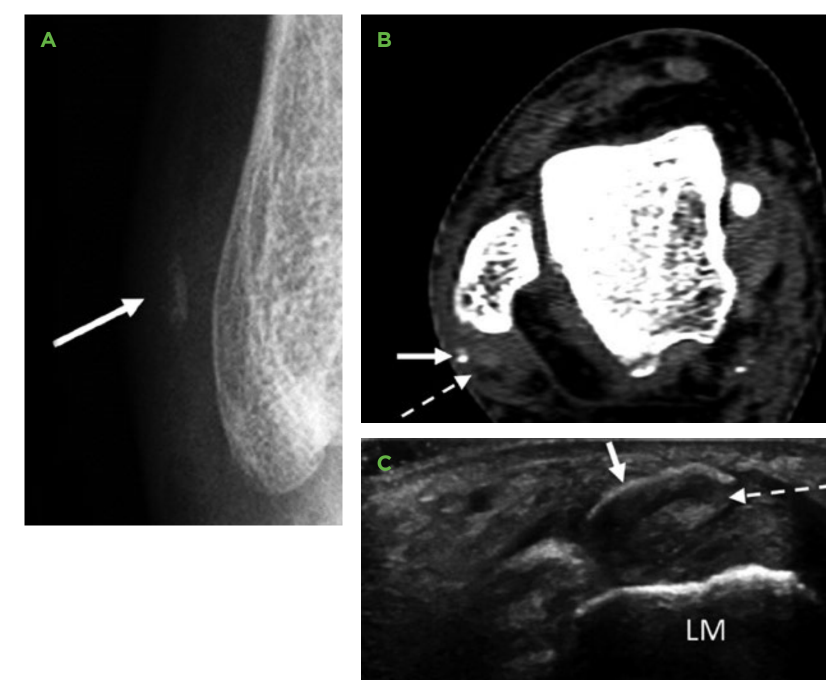
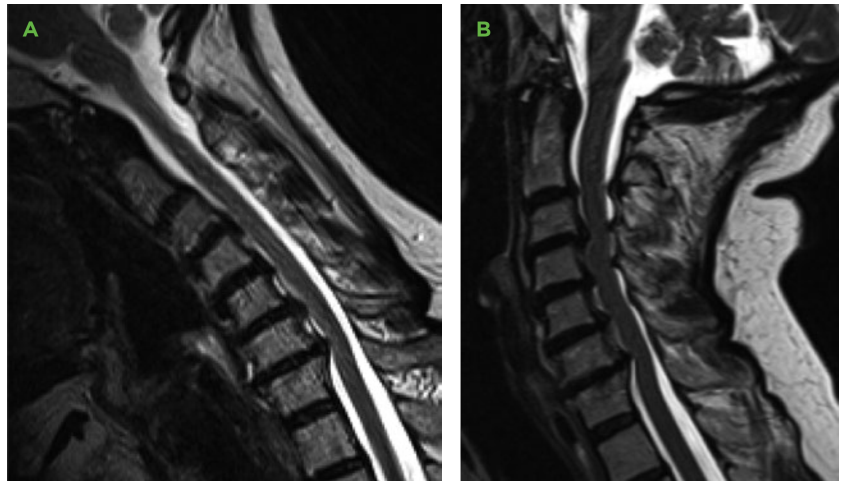


FIGURE 2

An MRI of the cervical spine performed in flexion (A) and extension (B) demonstrating multiple levels of cord compression during the extension phase.



3D analysis is also possible, but not widely available and predominantly used in research and *in vivo* studies. One of the scenarios where dynamic fluoroscopy can be utilised in clinical practice is in the assessment of ankle instability. Mechanical instability cannot be determined solely based on static MRI, even if it demonstrates disruption of the ligaments. Stress radiographs or dynamic fluoroscopy are able to demonstrate talar tilt and diastasis of joint surfaces, which can successfully predict underlying instability.

MAGNETIC RESONANCE IMAGING

Conventional MRI is carried out in non-weight-bearing and static conditions. One of the advances in MR imaging is weight-bearing MRI. This is especially useful in imaging of the lumbar spine, where patients' neurological symptoms may be exacerbated or sometimes only present in a standing position. If these patients were to be scanned by conventional MRI in a supine position, it may lead to a false reassurance that there is no underlying significant pathology, when such a pathology might only be apparent only under load-bearing circumstances. Such an MRI is usually carried out in an upright open-bore MRI scanner, which has the advantages of imaging in a more physiological condition but also has some drawbacks such as low field strength, which results in reduction of the image quality and also increased exam time. Such scanners are also less readily available. Real-time MRI can also be performed and can be useful, for example, in assessing patello-femoral maltracking.

In addition, sometimes useful information can be gathered by obtaining static images in different positions rather than a real-time view of the entire motion. For example, imaging of the cervical spine in flexion and extension can demonstrate cord compression in patients suspected of having cervical myelopathy (Figures 2A, 2B) which is not visible on conventional static MRI in the neutral position.

COMPUTED TOMOGRAPHY

CT can provide functional information in different ways.

The first is a weight-bearing cone beam CT of the foot and the ankle. The foot and ankle comprise a complex anatomical unit that is subject to various biomechanical forces during erect posture as well as walking and running. Therefore, physiological weight-bearing imaging provides more accurate information about underlying ankle and foot pathology. CT is better than plain radiographs as it has additional capabilities of multiplanar reformatting and 3D imaging. Recent CT advances now enable low-dose weight-bearing assessment of the foot and ankle, which can demonstrate alterations in alignment and bony impingement (Figures 3A, 3B).

The second advance in CT is the ability to perform dynamic evaluation of the joints due to the development of wide detector technology. The advantages of CT are that it has high temporal and spatial resolution. Because of the increased volume that can be scanned in one tube rotation, as a result of the wide detector technology, kinematic CT is now clinically available. The predominant applications of kinematic CT are in evaluating pathologies such as impingement and snapping, and also evaluation of the integrity of intra-articular ligaments in the wrist. A dynamic examination can help demonstrate causes of impingement, such as loose bodies or morphological bony changes, resulting in the restriction of joint movement, which would then be useful in guiding any surgical intervention (Figures 3C, 3D, 3E).

FIGURE 3

(A, B): AP radiograph and coronal reconstructed weight-bearing CT image. The CT demonstrates a talar tilt and bone-on-bone contact which cannot be appreciated on the radiograph. (C, D, E): A series of images from a kinematic CT in a patient with osteoarthritis of the elbow during flexion and extension, demonstrating multiple osteophytes and loose bodies. Figure 3C taken at the end point of flexion, demonstrates the anterior loose body responsible for the restriction of full flexion (arrow).

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THE RADIOGRAPHER'S ROLE IN DXA

THE RADIOGRAPHER'S ROLE IN DXA: Sports medicine and MSK

By **Karen Knapp**

DXA BACKGROUND AND UTILISATION

Dual energy x-ray absorptiometry (DXA) has progressed over the last 30 years from measurements of bone mineral density (BMD) at the lumbar spine, hip and forearm, to a range of additional functions including vertebral fracture assessment (VFA) and total body scans providing body composition measurements. The technological advances have underpinned the expansion of the clinical utilisation of DXA and the role of the radiographer in this specialty is expanding with it. In the United Kingdom, radiographers are reporting DXA scans, running fracture liaison services and, in some hospitals, leading one-stop scanning and results clinics for fracture patients[1].

With the advances in DXA, the role of the radiographer has had to change to facilitate the needs of the diverse populations being referred through the services. Appropriate knowledge developed through education and continuing professional development is essential to underpin practice[2]. One area where there is great interest at present is understanding bone inadequacies in athletes, with this group representing a much younger population than radiographers are used to seeing within osteoporosis services.

BONE MINERAL DENSITY MEASUREMENTS IN ATHLETES

Radiographers working in DXA where athlete populations are seen must be aware of the particular musculoskeletal pathologies encountered in this cohort. Stress fractures, traumatic fractures, recurrent fractures and disuse osteopenia are among a multitude of issues. Since many athletes are adolescents and young adults, in their period of bone consolidation prior to peak bone mass being achieved, it is important to identify those with bone inadequacies following injury. The female athlete triad results from athletes undertaking significant training, restricted energy intake and amenorrhoea, with similar hypogonadism seen in some male athletes. This has the potential to compromise bone and has been related to stress fractures; BMD measurement can provide a useful complimentary tool to assess bone health where there is clinical suspicion, and to trigger investigations for secondary causes of low BMD. It is important for radiographers in DXA services to understand the potential benefit of assessing BMD in athletes when there is a concern regarding their bone health.

JUSTIFICATION FOR EXPOSURES AND PREGNANCY ASSESSMENT

Radiographers must ensure there is appropriate justification for the use of DXA in each athlete. In some countries it is commonplace to undertake total body (TB-DXA) scans to measure body composition in athletes, but this remains an illegal practice in the UK due to the availability of other non-ionising radiation methods. In children/adolescents the total body (less head) and lumbar spine should be measured and in adults the lumbar spine and proximal femur[3].

Radiographers must take care when checking the pregnancy status in female athletes with amenorrhoea or oligomenorrhoea who may not have had a period within the previous 28 days. It cannot be assumed that a pregnancy is not possible if the athlete reports unprotected heterosexual activity. Many standard protocols recall patients after their next period, but in this population this may result in an inappropriately long wait. It is therefore possible that pregnancy testing with consent prior to a DXA scan is an option, however radiographers must be trained to do this and to share the results with appropriate support if they are to take on this role. In some hospitals the patient may be rebooked and the referrer can be asked to confirm the pregnancy status of the patient prior to a scan being undertaken.

Radiographers must be aware that the ability of DXA to measure short-term changes in bone, muscle or fat is limited by its precision errors. Precision errors underpin a minimum threshold for detecting changes within an individual,

TABLE

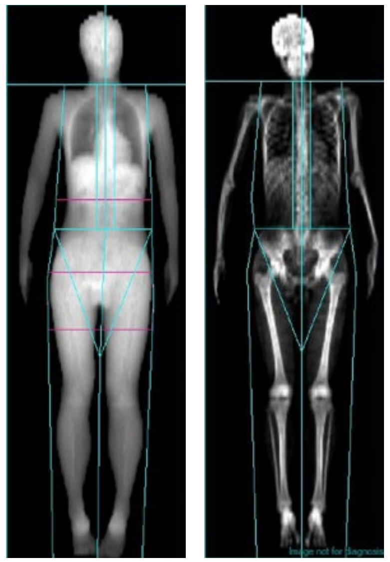
Longitudinal changes in body composition for fat (%) and lean

MEASUREMENT	AGE (YEARS)	FAT (g)	CHANGE VS BASELINE (%)	LEAN (g)	CHANGE VS BASELINE (%)
BASELINE	19.8	6,833	Baseline	53,385	Baseline
6 MONTHS	20.4	6,012	-12.0	51,981	-2.6
12 MONTHS	20.8	4,456	-34.8*	54,263	1.6

* Change exceeds least significant change

FIGURE 1

A total body DXA scan. Bone, lean and fat can be measured from these scans.



referred to as the least significant change (LSC). Furthermore, results from different scanners both within and between different manufacturers cannot be directly compared due to potential calibration differences[4]. Precision errors vary based on the patient's size and body fat, with obese patients having the highest precision errors[3]. If longitudinal DXA measurements have been undertaken, radiographers must remember to compare changes to baseline rather than just to the last measurement (see Table 1) and be aware that adolescents and young adults are likely to be in a bone accrual phase of life.

QUALITY ASSURANCE

Radiographers undertaking DXA scans must ensure that the daily quality assurance (QA) requirements for DXA scanners are fulfilled. Both the operator undertaking the scans and the practitioner reporting results must be assured that the scanner is operating within its recommended limits to ensure the accuracy of the results. The daily QA data must be plotted and assessed for sudden changes or long-term slow drifts as both can impact on the accurate measurement of BMD[4].

DXA INTERPRETATION AND REPORTING

Radiographers in the UK who have extended their scope of practice to include DXA reporting should be aware that the current World Health Organization (WHO) criteria used for the diagnosis of osteoporosis is inappropriate for use in young athletes. The International Society for Clinical Densitometry's (ISCD) definition of a Z-score of ≤-2 is an appropriate diagnostic criterion to identify low bone mass for age, gender and ethnicity, but clinical risk factors should also be considered. Radiographers undertaking these scans also need to be aware that different sports have differential effects on BMD and there can even be differences between amateur and professional populations in the same sport[1]. Athletes with seemingly normal BMD compared to standard reference data may still have bone vulnerability for their particular sport; therefore, it is important that radiographers look beyond BMD.

Clinical risk factors should be considered by the radiographer. Some athletes are reported to have unhealthy behaviours which can contribute to low BMD, such as smoking, excess alcohol use and low energy intake; thus, the radiographer must consider these alongside the BMD results. Vitamin D deficiency or insufficiency should be considered in athletes who predominantly train indoors and supplementation is recommended in the UK with 10μg daily. It is important to also consider calcium intake; calcium food frequency calculators are available. Calcium in this population should preferably be obtained from the diet and supplementation only considered if this is not possible due to the potential of side effects. Radiographers should be able to provide lifestyle advice or recommend for this to be provided in their DXA reports. Collecting relevant information regarding menarche age, menstrual cycles, smoking, alcohol, exposure to sunlight, calcium intake and any drugs or diseases known to affect bone metabolism can help provide a comprehensive clinical picture.

ERRORS, ARTEFACTS AND INCIDENTAL FINDINGS

Radiographers scanning and interpreting DXA results must be able to understand the errors and artefacts which may occur. These range from avoidable artefacts such as piercings, buttons or zips on clothing to unavoidable artefacts such as metal implants or renal calculi. It is important that radiographers understand the impact of such artefacts on the DXA result. For example, in GE Lunar scanners, soft tissue artefacts need to be removed using the software otherwise they will impact on the BMD value, while in Hologic scanners the entire vertebral level where they sit needs to be excluded[5].

Radiographers need to ensure that protocols are adhered to for scanning athletes, particularly for total body scans for body composition. Recent training can result in water retention in the muscles, with acute increases in muscle water content being demonstrated post strenuous resistance training.

While bilateral hip scans in a non-athlete population are well correlated, in the athlete population there may be differences between the dominant and non-dominant sides, which may be sport-related and not pathological. It is important for a radiographer to understand the impact of disuse osteopenia post injury and a reduction in BMD may not only be at the site of fracture or injury, but also proximal to the site. There is evidence that lower limb fractures and resultant off-loading causes a reduction in hip BMD at the ipsilateral hip, which recovers as the limb is loaded during recovery.

Radiographers reporting DXA scans must be aware of potential incidental findings in the athlete

FIGURE 2

Right pincer-type femoral acetabular impingement in an adolescent footballer.

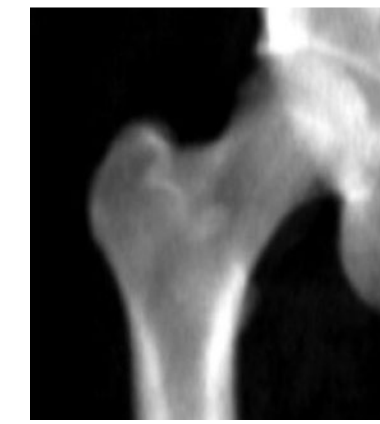


FIGURE 3

Transitional vertebrae in an adolescent footballer.

population. Femoral acetabular impingement (FAI) is a relatively common finding, particularly in footballers (Figure 2) and these findings should be formally reported by a reporting radiographer or radiologist. While the athlete may present as asymptomatic at the time of the scan, they may suffer symptoms at a later date, or may mask their symptoms for fear of not being able to train or play. Transitional vertebrae (Figure 3) may also be detected and these can result in stiffness in the spine. While power athletes tend to have higher than average BMD, in contrast, cyclists, swimmers and other non-weight-bearing athletes may have lower than expected BMD for their age. As with any clinical population blood testing should be recommended to rule out secondary causes when there is concern.

In conclusion, radiographers play a key role in DXA within the athlete population. An extended knowledge-base is required for practice in this population compared to a usual osteoporotic population. Ensuring the safe use of DXA is essential in athletes and the understanding of how precision errors and sports impact on bone and DXA results is essential.

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is a diagnostic radiographer and an Associate Professor in Musculoskeletal Imaging at the University of Exeter. Having specialised in dual energy x-ray absorptiometry and osteoporosis, Dr. Knapp obtained a PhD in Radiological Sciences from King's College London, working with internationally renowned groups in osteoporosis and twin research. During her post-doctoral position, she honed her educational skills teaching medical students and went on to a lectureship at the University of Exeter. She now combines teaching both undergraduate and postgraduate students with research and links the two through research-led education. Dr. Knapp's primary research interest continues to be bone health, osteoporosis and diagnostics.

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7

IMAGING AT A GLOBAL **SPORTS EVENT**

IMAGING AT A GLOBAL SPORTS EVENT, A CASE STUDY:

The pivotal role of radiographers in the London 2012 Olympic and Paralympic Games

By **Carole Burnett**

VOLUNTEERING

Volunteering has become a national 'sport' in the UK since the London 2012 Olympic and Paralympic Games, with the number of individuals volunteering at global sporting events ever increasing[1]. The London 2012 Olympic Games brought volunteering into the everyday vocabulary of the nation, as the United Kingdom and indeed the world, embraced and adopted the 70,000 individuals who proudly became *'Team Makers'* and who gave up their time to ensure that the 30th Olympiad was a success[2].

SPORTS MEDICINE IMAGING

Sports medicine is an emerging medical discipline, with imaging an essential diagnostic component. Dedicated sports imaging radiographers can be found at centres of excellence, as the number of centres increases to provide bespoke imaging services for elite athletes. A new advanced practitioner radiographer role is developing to support care.

Imaging requests for investigations involving elite athletes can be very different to requests seen within a normal hospital setting, with pressure from the athletes' managers or country representatives to undertake imaging. This can be challenging, and specific protocols are required in order to determine whether or not imaging is justified.

Discrete abnormalities which may be considered 'normal' in the general population can have performance affecting results for the elite athlete. Conversely, the result of 'no abnormality' may increase their confidence and therefore their performance.

Indications for imaging elite athletes are broadly subdivided into the following categories:

- Confirmation of injury (acute, traumatic or overuse)
- Additional information that will contribute to an injury management plan
- Information that aids the decision of when to return to play
- Assistance with an intervention, such as therapeutic injection
- Pre-signing screening*
- Cardiac health screening*

*Imaging at global sports events does not include screening imaging and it was not part of the London 2012 imaging remit.

FIGURE 1

The MRI console at the London 2012 Olympic Games.

WHAT WAS REQUIRED FOR LONDON 2012?

A bespoke medical service was built in the athletes' village with comprehensive state-of-the-art imaging facilities. Additional medical services were located at two peripheral sporting locations: the rowing and sailing venues. The service aims were to provide healthcare services to competing athletes, their supporting team officials, the Olympic family and essential workforce.

Volunteer professional team members were recruited for the imaging service. Diagnostic radiographers who were registered with the Health and Care Professions Council (HCPC) and met the requirements of the defined job description were appointed. In line with the European Federation of Radiographer Societies (EFRS) definition of a radiographer, only diagnostic radiographers could be appointed to the limited number of radiographer positions, with others recruited as radiographic assistants. Each had to commit to work a minimum of ten days and attend two additional training days.

There was terrific interest in the volunteer posts, with 482 applicants for radiographic staff positons. Thirty-four radiographers and 23 radiographic assistants were appointed from across the UK and Ireland. Those appointed received no remuneration for their work, with many taking annual leave in order to volunteer at the Olympics. On average, it is estimated that each radiology volunteer used about 40% of their total annual leave for 2012. Their enthusiasm to be part of a unique once-in-a-lifetime event was the motivation for their applications.

The radiology service provided cover over the entire 51 days of the games period (30 for the Olympics and 21 for the Paralympics) from 7am to 11pm each day. The imaging equipment and applications training was supplied by GE medical. This comprised two wide bore MRI scanners (1.5T Optima MR450w and 3T Discovery MR750w), a CT scanner (Discovery 750 HD), two ultrasound machines (Logiq E9 scanners) and digital plain film radiography.

TEAMWORK AND FLEXIBILITY

The underlying success of London 2012's radiology service was the flexibility and teamwork shown by the entire team. The radiographers were required to adapt quickly to a new environment, fine tune their skills on new equipment and work within a changing team in order to provide high quality services. Due to the length of the volunteering period (ten days) and the number of shifts that needed to be covered, this meant that team members would frequently be working with different imaging and polyclinic volunteers on each of their shifts. The seamless service delivered by the imaging team was thought by many of our customers to match that of a paid provider.

The radiology team surpassed expectations, finding solutions to the myriad of problems, barriers and unforeseen logistical issues that arise with new services. The radiology volunteers demonstrated the *'just do it'* mentality, applying their combined experience and skills to every challenge that was encountered.

The reasons for the team's ability to quickly adapt to any scenario were that everyone was committed to delivering the best care and demonstrated all of the core qualities of a professional[3]:

1. **Caring, supportive and able to put patients at ease.** The elite competitors were in London to win, and being chosen to attend the London games was the culmination of many years of practice and dedication. Being sick or having an injury could prevent them from representing their country, and so understandably the stress that the athletes were under was immense. The radiographers showed empathy and were able to support the athletes through their imaging procedures in a professional and kind manner.

2. **Calm under pressure.** The unfamiliarity of one's surroundings and colleagues could enhance an already pressurised situation. On many occasions, team doctors wanted their athletes to be imaged straight away, as the outcome of the scan could affect the individuals' participation in an event. There could be many athletes whose doctors simultaneously wanted them to be imaged immediately for the same reason. The radiographic staff calmly explained the referral and prioritisation processes to the referring team doctors, ensuring appropriate prioritisation based on clinical need, regardless of the country they were representing. It must not be forgotten that an unknown athlete to us could be a national hero in their home country, carrying all the dreams of their nation on their shoulders.

3. **Good at communicating and enjoys working as part of a team.** Spontaneously, a family of likeminded souls formed the teams and supported one another.

4. **Confident working with leading-edge technology.** The state-of-the-art imaging equipment was provided by GE medical. The MRI scanners were the newest models, incorporating new coil technology and

FIGURE 2

Some of the radiographers and technical medical support staff at the London 2012 Olympic Games.

sequences. Using these scanners was an education, even if you were familiar with using GE MRI scanners.

5. **Adaptable, with the ability to quickly learn new skills**. This was one quality that was hard to assess during the recruitment stage. The radiographers and assistants recruited to the London 2012 team showed great character and adapted to everything they were asked to do. Everyone was keen to learn about the new technology being showcased at the games and take an excellent opportunity to learn from the application specialists and each other.

Staff who volunteered at the Olympics loved the experience and many volunteered to return for the Paralympics to fill any vacant rota slots.

STAFF SPECIALITY

Not all of the radiographic staff had experience providing imaging services for the elite athlete.

We were fortunate to have a plethora of experienced individuals who could share best practice, with internationally renowned radiologists specialising in sports imaging. A positive learning environment resulted that was accessible to all volunteers. A lead radiographer was identified for each of the imaging modalities, with responsibility for collaborating with the lead radiologist to produce a comprehensive imaging protocol guide. Links were established with the physics team to ensure that legal and ethical dose restraints were adhered to; justification of every examination was undertaken as per legal requirements[4]. Dedicated standard operating procedures (SOPs) were written to provide frameworks to work within. For example, SOPs for patients whose first language was not English, and SOPs for imaging those taking part in the Paralympic Games.

THE RESULTS

A total of 2,366 radiological examinations were safely performed during the London 2012 Olympic and Paralympic Games. There were no reportable radiation incidents during the games, which is testament to the strong clinical governance and team working. Members of the imaging team have acquired new skills, met new colleagues and made friends for life, and some of the volunteers are seeking new career opportunities. The London 2012 volunteering model was seen as a success, leaving behind a legacy that has shaped the organisation of other global sporting events.

ACKNOWLEDGEMENTS

Thank you to all the members of the 2012 Olympic and Paralympic imaging team. It was truly a once-in-a-lifetime experience that could not have happened without you. I would like to thank GE Medical for all the help they gave us before and during the games, and for providing the infographics used in this article.

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DR. CAROLE BURNETT, PHD

qualified as a diagnostic radiographer in 1989. She specialised in magnetic resonance imaging, gaining experience within the commercial and private sectors as well as the NHS. She was appointed as the lead radiographer for the London 2012 Olympic and Paralympic Games.

Dr. Burnett was awarded a personal fellowship from the National Institute of Health Research to study for a PhD entitled 'Magnetic Resonance Imaging of synovitis without the use of intravenous gadolinium', which was completed in 2015. Currently, Dr. Burnett is the lead clinician for research and innovation for the Radiology Clinical Services Unit and is the lead research radiographer for radiotherapy at Leeds Teaching Hospital NHS Trust, UK.

8

BONE AND BODY COMPO-SITION

Imaging of bone and body composition

By **Carmelo Messina**

Bone imaging is basically as old as radiology itself.

In fact, it was in late 1895 that Wilhelm Conrad Röntgen discovered x-rays, with the first famous applications being the radiograph of his wife's hand. This is mainly due to the intrinsic contrast offered by bone to the x-ray beam, allowing for very nice depiction of skeletal structures. For this reason, plain radiographs still represent the first-line imaging modality for suspected bone pathology (such as trauma, infection, joint pathologies and bone tumours), typically performed before other more advanced techniques such as computed tomography (CT) and magnetic resonance imaging (MRI).

Multidetector CT represents the second line of bone imaging. The introduction of spiral CT imaging with thinner collimation allowed for the acquisition of thin-slice volumes that can reach almost the isotropic voxel. This opened the possibility of producing high quality three-dimensional reconstructions in any plane, with a spatial resolution that is comparable to that of axial images. Dual-energy CT is a new technique with promising applications in musculoskeletal and bone imaging. The presence of two x-ray tubes allows acquisition at two different energy levels simultaneously, and this difference in terms of energy attenuation is used to characterise the chemical composition of bone and surrounding structures (for example, in detecting bone marrow oedema or crystal deposits, or reducing metal prosthesis artefacts).

While the bone components (especially cortical but also trabecular) are best visualised using radiographs and CT, MRI has the advantage of providing information about the medullary part of the bones. The bone medullary cavity is filled with red and yellow marrow, contained within a network of trabeculae. MRI is capable of differentiating between yellow marrow and red marrow, which typically results as hyperintense in fluid sensitive sequences. Many pathological conditions (both benign and malignant) can affect bone marrow and can be depicted using MRI, due to the pathological replacement of fat cells (see Figure 1 for the comparison between a healthy lumbar spine and the spine of a patient with multiple myeloma). The introduction of high-field MRI scans (3T) improved the signal-to-noise ratio (SNR), resulting in better image resolution.

Ultrasound is commonly used to assess musculoskeletal pathology, but it has a limited role in the evaluation of bone, because the vast majority of the ultrasound waves are reflected by bony surfaces. Nevertheless, ultrasound plays an important role in evaluating the bony surface in specific regions, such as joint surfaces, when evaluating patients with degenerative or rheumatoid conditions.

The bony skeleton can be affected by a wide range of pathologies:

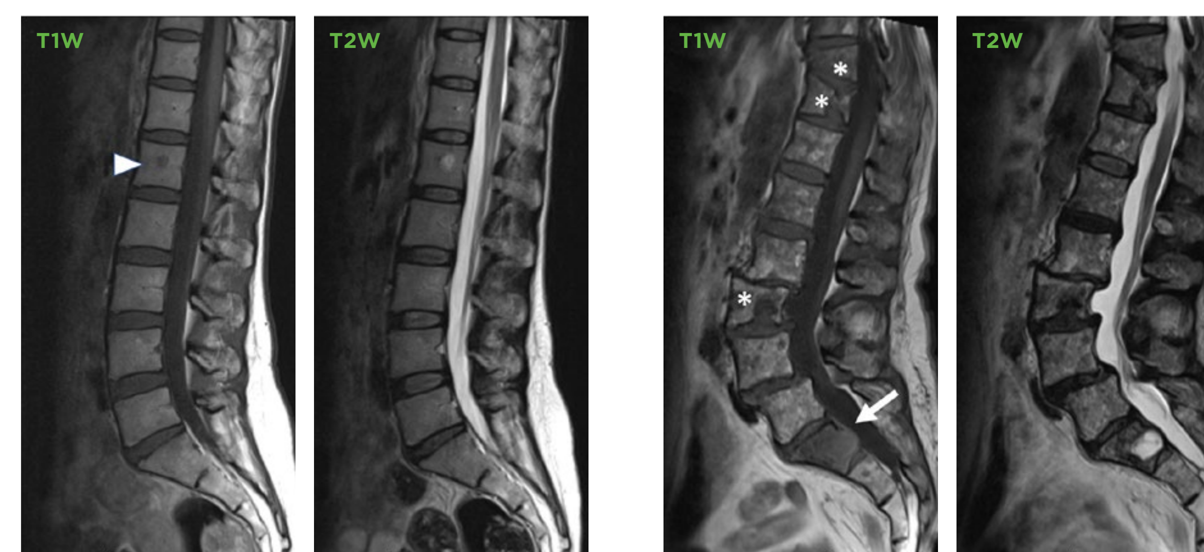
- Skeletal traumatic injuries can result from direct or indirect force on the involved bone. Plain x-ray represents the mainstay for radiological evaluation of fractures, while CT is indicated in complex fractures, or for surgical planning. MRI can help in detecting subtle or occult fractures, by highlighting bone oedema.

- Metabolic disorders typically affect multiple regions of the bony skeleton. These disorders may have different causes, such as endocrinological, biochemical, nutritional or genetic. In some cases, radiographs can show no changes or only subtle changes, making

FIGURE 1

This figure illustrates a comparison between two lumbar spine MR images. On the left, normal fatty marrow is hyperintense on both T1 and T2 sequences. The right side shows the spine of a female patient with multiple myeloma, with extensive patchy bone marrow replacement (hypointense areas) and associated multiple vertebral fractures (asterisks). Pathological involvement of the whole first sacral vertebra is also shown (arrow). There is a benign vertebral haemangioma on the left (arrowhead).

HEALTHY SUBJECT **MULTIPLE MYELOMA**



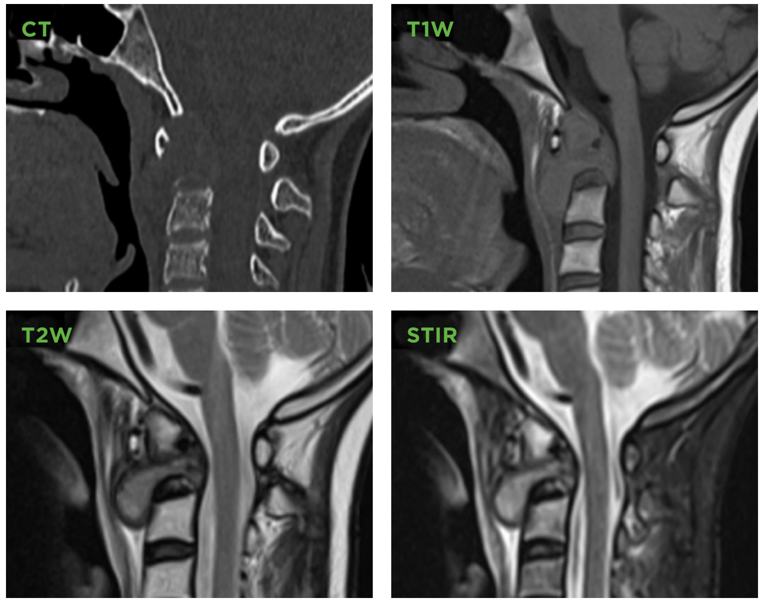


FIGURE 2

Osteolytic lesion of the second cervical vertebra in a young patient, proven to be an osteosarcoma after biopsy.

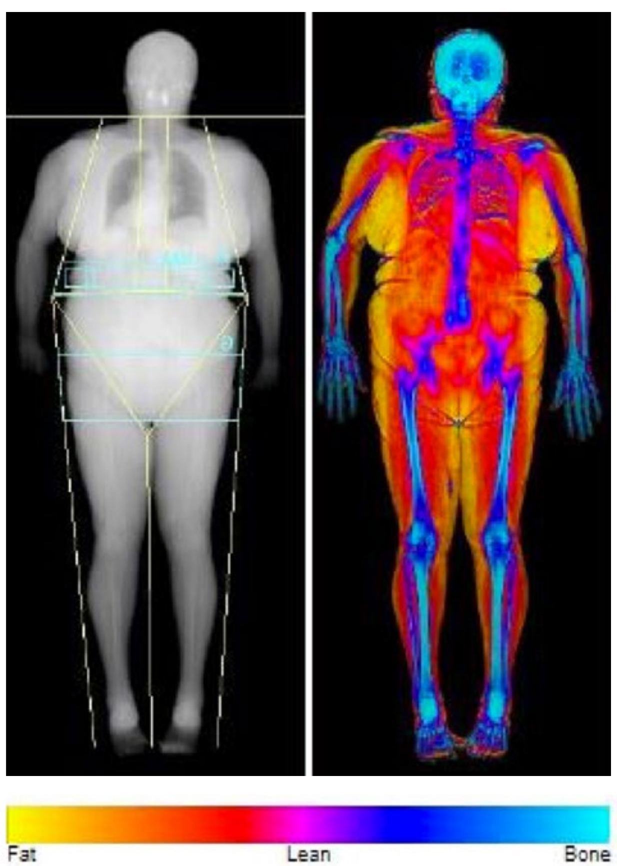


FIGURE 3

DXA body composition image for visual localisation of lean mass, fat mass and bone (illustrated in red, yellow and blue, respectively). The exam provides precise values of each of these components in grams and percentages, as well as several adipose and lean indices.

it mandatory to also include MRI and CT for a better diagnosis. Among these disorders, the most common is osteoporosis, a disease characterised by a reduction in bone mass with impaired bone quality, which leads to an increased risk of fracture. The disease is a major public health problem, as it is associated with increased morbidity and mortality related to hip and vertebral fractures.

– Bone tumours can be primary or related to the secondary metastatic spread of distant malignancies. Primary bone tumours are rare and typically present at younger ages, while metastases are more common in older patients. Such tumours are usually classified according to the WHO criteria, which divides them into different categories (osteogenic tumours, chondrogenic tumours, fibrogenic tumours, lipogenic tumours, etc.) according to the predominant tissue production. Figure 2 shows an osteolytic lesion of the second cervical vertebra in a young patient, proven to be an osteosarcoma after biopsy.

Other techniques can provide quantitative data regarding bone density, with dual energy x-ray absorptiometry (DXA) being the most commonly used in clinical practice. DXA measures areal bone mineral density (BMD) expressed in grams per square centimetre (g/cm^2), which represent one of the major determinants of bone strength and correlates to fracture risk. BMD data from DXA are widely used in the diagnosis and management of osteoporosis. Among the advantages of DXA, it is important to remember the extremely low radiation dose to patients. DXA is typically performed on the lumbar spine and proximal femur, with the forearm being scanned only in specific circumstances (hyperparathyroidism, obesity, etc.).

The assessment of body composition (BC) has the main scope of measuring the amount of fat mass (FM) and lean mass (LM), in order to understand the nutritional status of a specific patient. Several conditions can lead to a status of undernutrition, leading to progressive loss of muscle mass and function. The prevalence of this condition, which is called 'sarcopenia', increases with age and may have a non-negligible impact on daily life activities.

BC assessment can be done with several imaging techniques, such as DXA, CT or MRI. MRI and CT are still considered the reference standard for BC evaluation, because these techniques are capable of producing cross-sectional images that allow for segmental measurements of FM/LM. Nevertheless, DXA has progressively gained popularity as it does not need any image post-processing (as CT and MRI do), it provides accurate data and it is widely available (see Figure 3 for an example of a BC DXA for fat and lean mass estimation).

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THE BEAUTY OF MSK ANATOMY

The beauty of musculoskeletal anatomy

By **Florian A. Huber, Michel O. De Maeseneer** and **Lena Hirtler**

HISTORY OF ANATOMY

Anatomy is one of the oldest scientific fields. Since the very beginning of anatomical studies – which most likely dates back to 1600 BC, with the first reference in an ancient Egypt manuscript, known as the *Edwin Smith Papyrus* (Figure 1) – musculoskeletal structures have always been of interest.

Further anatomical work by ancient Greeks, such as Aristotle and later Galen, followed and mainly developed from theoretical and animal studies. It took many more centuries until anatomical research was dominated by systematic dissection of human bodies. The centre of this movement was Bologna, and Italy in general, represented by Leonardo da Vinci and others. However – as with other scientific specialties – issues with the Catholic church were not to be overcome, and the now well-known drawings of da Vinci were forced to be kept from the public.

Not surprisingly, it was the invention of the modern book press in Europe, in combination with the appearance of Andreas Vesalius (1514–1564), that resulted in a breakthrough in anatomical history and marked the beginning of a modern era. This was a time that shaped modern musculoskeletal anatomy like no other.

Looking at Vesalius' *De humani corporis fabrica* (Figure 2), the essential value of musculoskeletal knowledge at that time (1543 AD) becomes obvious. Within his seven-part masterpiece, the first two books were dedicated to the skeleton, muscles and ligaments. The evolution of anatomical study around this time mainly relied on learning from anatomic dissection of human cadavers and precise documentation through detailed drawing and systematic nomenclature. The importance of

FIGURE 1

Photograph of the *Edwin Smith Papyrus,* the oldest known manuscript regarding surgical treatment of trauma (Public Domain).

FIGURE 2

Cover page of *Andreae Vesalii Bruxellensis, scholae medicorum Patauinae professoris, de Humani corporis fabrica Libri septem,* an anatomic atlas marking the beginning of a new era in human anatomy.

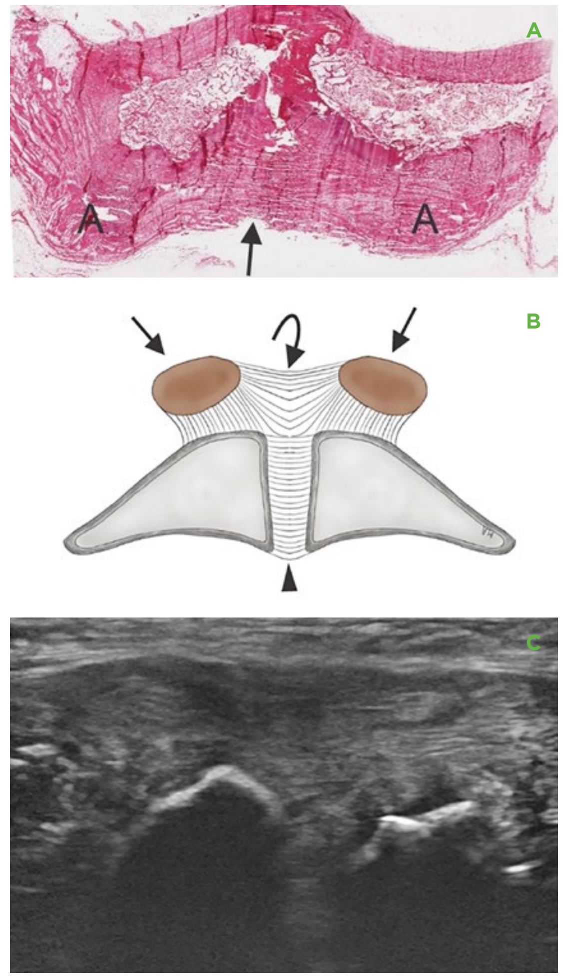
FIGURE 3

Coronal multiplanar reconstruction of a T1-weighted whole-body MRI (Dixon Technique, Water images) of a healthy 46-year-old female.

anatomical dissection is represented by the long line of famous teachers and their publications as well as its entrance into art, as represented by the famous Rembrandt painting, *the Anatomy Lesson of Dr. Nicolaes Tulp* (1632) and similar works.

FIGURE 4

(A–C) Histologic section, sketch and ultrasound image of adductor insertions.



Dissection, a method that still accounts for large amounts of current anatomic research, is implemented in the curriculum of most medical schools and universities worldwide and may have triggered the passion for radiology in many of us.

RECENT DEVELOPMENTS IN MUSCULOSKELETAL RADIOLOGY

Over recent decades, a few trends have made a large contribution to shaping all high-impact journals that deal with musculoskeletal aspects. On one hand, musculoskeletal radiology is one of the big beneficiaries of major developments in image acquisition, imaging methods such as MRI and ultrasound, and spatial resolution, not to forget the advances in interventional radiology[1]. On the other hand, novel computational aspects of radiology, such as applications of machine learning and artificial intelligence in general, and radiomics, have also greatly altered the scientific field of musculoskeletal anatomy[2, 3]. Last but not least, musculoskeletal radiology has had a big impact on clinical subjects, such as orthopaedic surgery and sports medicine.

Radiologists are hence more than ever considered team players in a setting that is typically dominated by primary care providers with long-lasting relationships with their patients. Especially in these settings, it is the radiologist's role to deliver unbiased diagnoses based on profound and detailed knowledge of musculoskeletal anatomy[4].

Nonetheless, the majority of tasks in daily musculoskeletal imaging still require metabolic, functional and exact anatomic data and knowledge as part of an assessment. These applications remain marginal in the clinical practice of musculoskeletal radiology. Articles about anatomical correlations have moved somewhat to the background, despite the fact that techniques such as MRI and ultrasound have improved up to a point where anatomic details can be imaged, which is currently not appreciated.

CURRENT CONCEPTS IN MUSCULOSKELETAL ANATOMY

A systematic diagnostic work-up of musculoskeletal diseases is currently based on understanding of the respective anatomy, but also of the injury mechanism and the underlying biomechanical principles[5]. In order to properly cater to the referring clinician's demands, it is of utmost importance to be able to provide profound anatomic knowledge, as well as constant improvements in imaging techniques and methods in order to perform imaging in an adaptive way[4]. Musculoskeletal radiology has certainly shifted from a mainly radiography-based subspecialty and arrived at a modern and evolving presentation of micro and macro-anatomic structures that is also able to implement functional or metabolic information, e.g. by utilising dual-energy in CT[6] or diffusion-weighted and chemical shift sequences in MRI[7].

THE FUTURE OF MUSCULOSKELETAL ANATOMY IMAGING: CHALLENGES AND POTENTIAL

Looking at the cutting edge of anatomical imaging, current and upcoming imaging techniques offer everything from macroscopic examinations such as whole-body MRI in metabolic questions (Figure 3) up to high resolution MRI and ultrasound of microscopic anatomy in greater detail than has ever before been possible, even in cadaveric dissection. With these innovations, the potential is obviously a spectrum of radiological examinations that almost completely covers the variety of musculoskeletal anatomy and its respective pathologies. However, being able to acquire images in so many ways –macroscopic and microscopic, descriptive, systematic, tomographic and functional ways[8] – brings challenges for the MSK radiologist of the future.

Trends in surgery (e.g. orthopaedics and neurosurgery) already require a more sophisticated understanding of anatomical details (Figure 4). Moreover, current achievements in microscopic imaging methods, such as x-ray micro-computed tomography and x-ray phase contrast imaging will sooner or later demand a basic understanding of pathoanatomic imaging aspects, not only for pathologists, but also for the imaging experts.

No matter how musculoskeletal radiology trends may change throughout the coming years, one must not be forgotten – the beauty of musculoskeletal anatomy lies in its details.

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10

HIGH-RESOLUTION IMAGING

High-resolution imaging of bones, joints, tendons, ligaments and nerves

By **Georgina M. Allen**

MAGNETIC RESONANCE IMAGING

Higher field strength MRI has become more common. Due to the higher signal-to-noise ratio, 3T and 7T systems provide much better resolution than 1.5T, decreasing the need for intra-articular and intravenous contrast agents. This is especially important now that we know contrast-enhanced studies can cause permanent deposition of gadolinium in the brain and other tissues[1]. Although we do not know whether this is harmful, we are now advised to only use gadolinium when absolutely necessary, which does not often apply to musculoskeletal indications.

Better resolution imaging is very important in the musculoskeletal system as we often image small structures in the periphery (Figure 1). Use of 3T MRI in the wrist and hand has been invaluable in reducing the need for arthrography[2]. In some research establishments, 7T MRI is also available; however, higher field strength MRI may cause fluctuations in blood pressure, vertigo and a metallic taste in the mouth. We also need to exclude patients with metallic surgical clips in the gallbladder and brain. Older metallic prostheses are a problem as little is known of their behaviour at 7T where torque and movement are significant risks. Newer titanium clips and prostheses are compatible with 7T MRI, so this problem should diminish.

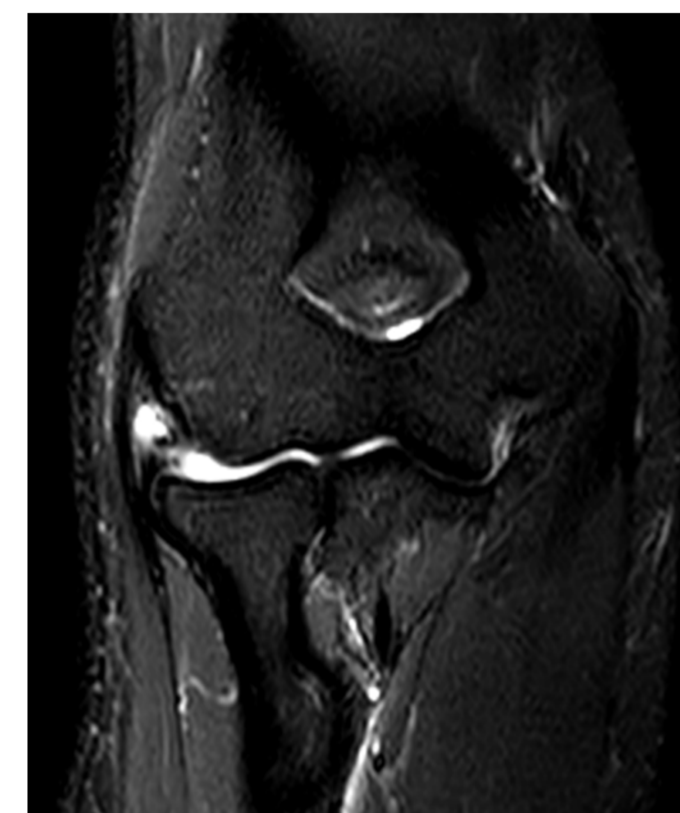
Reductions in contrast resolution at high field strength and difficulties in obtaining a STIR sequence at 7T, such that bone oedema is not well seen, are significant limitations. Using 7T imaging does give improved resolution of cartilage however[3].

All pacemakers inserted before 2011 are labelled as MR-unsafe, but fortunately the newer MR-conditional pacemakers are safe with MRI. A pacemaker is no longer an absolute contraindication to MRI, but the patient should be scanned in an environment where there is liaison with the cardiology department[4] as some devices need to be reset soon after the examination.

There have been advances in surface coil technology to allow us to examine smaller structures. Microscopy coils have been used to improve imaging of small soft-tissue masses in the hand and foot[5].

FIGURE 1

3T MRI showing a tear of the common extensor tendon.



ULTRASOUND

With the advent of higher frequency probes, we may examine smaller structures in more detail. Commercial probes are now available at 22MHz. This is of use in skin disorders, to see the dermis and subcutaneous tissues, and in examining small nerve abnormalities.

High-resolution ultrasound has allowed us to see soft tissue anatomy more precisely due to its better line pair resolution, considerably surpassing the resolution of MRI. Ultrasound allows the operator to target the examination to where it is best needed. In assessing a tendon, dynamic examination may show incongruent movement in full-thickness tendon rupture, allowing distinction of partial ruptures of

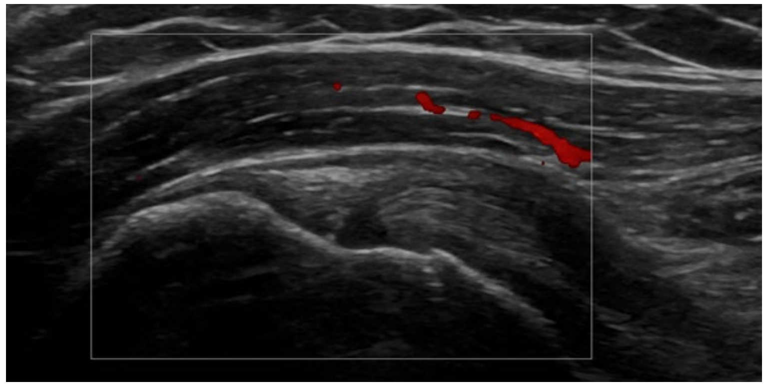


FIGURE 2A

Ultrasound image showing a colour Doppler image of a normal finger pulp.

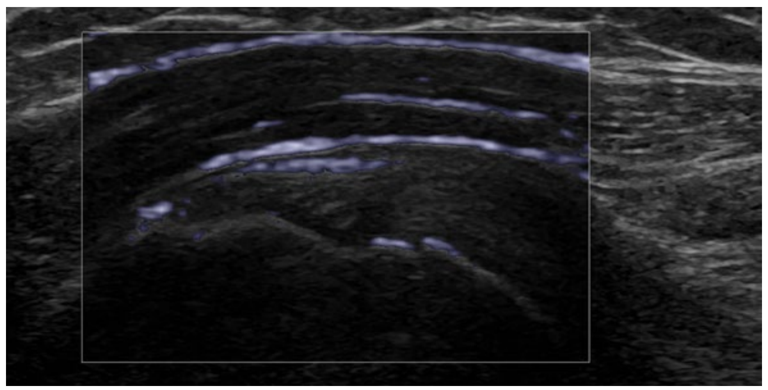


FIGURE 2B

Ultrasound image showing a microvascular image of a normal finger pulp. Note that there is an artefact with 'Colour to bright' interfaces at bone edges and fascial planes.

tendons and ligaments. It also clearly shows the retinaculae such as the pulleys of the fingers. Our increased understanding of the benefits of dynamic and stress manoeuvres has increased the range of diagnosis that we offer. Conventional colour and power Doppler are now challenged by superb microvascular technology (SMI or MVI) which detects capillaries and differentiates between slow blood velocity and movement artefacts. Microvascular imaging is better than the other methods at detecting vascularity in breast masses[6]. SMI has also been shown to be as good as contrast-enhanced ultrasonography (CEUS) in the detection of incomplete laser ablation of benign thyroid nodules[7]. It detects slower flow vascularity and we can expect to see better understanding of the significance of changes in perfusion in very small structures such as the blood supply to a normal nerve (Figures 2A and 2B).

Extended field of view images have allowed us to more precisely locate abnormality within a tendon or ligament.

Strain elastography is an established technique but is still to find a place in routine examination. It originally relied on the operator providing agitation to the tissue, but now the deflection may be induced by soundwaves measuring tissue strain. The advent of shear wave elastography, with its quantitative assessment, may increase the indications for the technique.

COMPUTED TOMOGRAPHY

The introduction of extremity scanners with very low dose and detailed resolution (0.1mm voxels as an isotropic volume) enables us to obtain exquisite detail of the bone structure, which allows mapping

of stress responses within the bone, comparing weight-bearing and non-weight-bearing images. Cone beam CT examination allows dose reduction techniques at a similar dose to an AP and lateral radiograph, plus greater efficiency, with acquisition times of around 20 seconds. This reduces the value of conventional radiographs in a variety of clinical circumstances. With more data, some computers and PACS systems may not have sufficient memory to handle the full DICOM dataset. The minimum specification is a 64-bit processing system with 8 GB of RAM and not all current hospital technology can handle the data!

For example, standing and sitting acquisitions will show the change in size of the joint space in the knee whilst supination and pronation images are useful for assessing elbow prostheses. These machines use a conventional 13 amp plug and do not need as much radiation screening as conventional CT. They are easy to use for the operator and allow the patient to sit in a comfortable position. They have metal artefact reduction and movement reduction algorithms, reducing the number of repeat examinations. These characteristics make cone beam CT especially useful in children and when examining knee replacements and other prostheses[8]. Cone beam CT has also been used in the assessment of adult-acquired flatfoot deformity, examining for osseous malalignment when standing[9]. We have found the technique useful in the assessment of the wrist when the triangular fibrocartilage and the thickness of the cartilage are delineated by ultrasound-guided contrast agent injection[10] (Figure 3).

CT and MRI images can be fused with ultrasound to allow for better understanding of bone and soft tissue landmarks. Fusion imaging may be used to guide nerve root and facet joint injections in the lumbar spine without the need for any radiation. Needle tracking systems with RF transmitters inside the core of the needle make complex intervention both safer and easier.

FIGURE 3

A Cone Beam Computed Tomography arthrogram of the wrist showing cartilage defects in the proximal lunate and the proximal scaphoid and a tear of the triangular fibrocartilage complex with communication with the distal radio-ulnar joint.

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11

BIO-CHEMICAL IMAGING

BIOCHEMICAL IMAGING:
MR imaging and MR spectroscopy

By **Martin Zalaudek** and **Martin Kršsák**

INTRODUCTION

In recent years, magnetic resonance imaging (MRI) has not only developed into a reliable modality for visualising musculoskeletal morphology; non-invasive evaluation of components and metabolites of muscles, tendons, cartilage and bone with quantitative techniques now also provides insights into biochemical changes, before macro-adaptive changes become visible on morphological images. This opens up new strategies for the early detection of degeneration, monitoring of training effects and evaluation of therapy decisions. This chapter provides an overview of hardware and software requirements for biochemical MRI, its current application in clinical studies and its possible future integration into clinical practice.

IMAGING OF TISSUE COMPOSITION

T2 and T2* mapping are the most established quantitative imaging methods with no special hardware required. Using Carr-Purcell-Meiboom-Gill (CPMG) imaging, double or triple-echo steady state, ultrashort echo time (TE) or variable TE sequences, multiple images are acquired with different TEs to subsequently calculate mono or multi-exponential T2/T2* maps. Higher T2/T2* reflects higher water content and impaired collagen architecture of muscle, tendon, cartilage and bone, and quantifies inflammatory changes, early degeneration, functional potential, physical therapy effects and quality of repair tissue[1–3].

Glycosaminoglycan chemical exchange saturation transfer (gagCEST) requires higher field strengths such as 7T or more, though conventional 1H coils can be used for imaging. It is based on the different transfer rates between interchanging protons of water and GAG molecules and can be measured as magnetic transfer ratio. It allows non-invasive direct quantification of GAG and has been used to assess cartilage quality. Besides the requirement of high field strengths, long scan times, a high motion sensitivity and the small CEST effect of GAG are limiting clinical application[3].

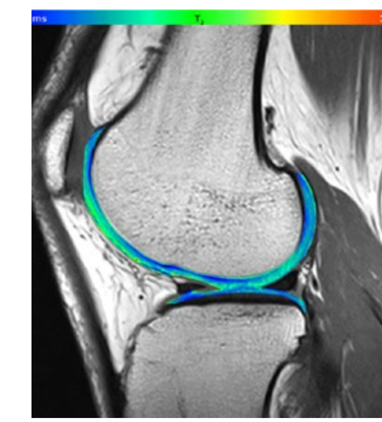
DWI (diffusion-weighted imaging) is a widely established method in neuro and abdominal radiology, additional special hardware components are not required, and the software is widely available. DWI uses the diffusion properties of water molecules in relation to different tissues to generate an image contrast. ADC (apparent diffusion coefficient) maps can quantify altered tissue properties in musculoskeletal tissue because the diffusion of water molecules relative to collagen architecture and proteoglycans reflects their density with high diffusivity, resulting in low ADC values related to disintegration. DWI can be combined with DTI (diffusion tensor imaging) which reflects anisotropy and provides information about the tissue microstructure and mechanical properties of collagen fibres in muscles, tendons and cartilage and may become a useful tool for the detection, prognosis and treatment of sports-related muscle injuries. However, sensitivity to motion, susceptibility effects, misregistration, post-processing and the influence of demographic and physiological parameters necessitate further research before clinical implementation[1, 2].

CSI (chemical shift imaging) or Dixon MRI uses the intrinsic difference of the water and lipid resonance frequencies and the resulting SI (signal intensity) differences to produce in-phase (TE with phase coherence of water and fat protons) and out-of-phase (TE with water and fat protons 180° out of phase) images. The difference in SI of these images is used to quantify fatty replacement[4] of muscular tissue due to injury or denervation, inactivity, myopathy or metabolic derangement or focal fibrosis in articular cartilage. It is a robust method, relatively insensitive to magnetic field inhomogeneities, and has recently been improved in respect to multi-echo signal detection and inclusion of a more realistic spectral model of fat[5]. However, the evidence for application in musculoskeletal tissue is sparse and the described effects must be intensively investigated before clinical implementation[2, 6].

Sodium (^{23}Na) imaging requires dedicated coils, highly specialised sequences and high field

FIGURE 1

Colour-coded T2 map of articular knee cartilage of a healthy volunteer representing the typical zonal stratification with low T2 [ms] in depth and high T2 [ms] in the superficial layer of articular cartilage [image from Juras V et al. A comparison of multi-echo spin-echo and triple-echo steady-state T2 mapping for in vivo evaluation of articular cartilage, published as Open Access under the Creative Commons License in Eur Radiol. 2016 Jun;26(6):1905–12].



scanners with a broadband multinuclear transmit/receive option. This is due to the physical properties of sodium, its very short transverse relaxation times, ~10.8 times lower sensitivity, and the ~3,000 times lower resulting SNR of sodium nuclei compared to ^{1}H MRI. In cartilage, however, a strong positive correlation of sodium with its electrochemical counterpart GAG was found, which allows direct quantification of GAG *in vivo*. Sodium MRI has been successfully used in various studies to assess the quality of cartilage and repair tissue. However, apart from the limitations mentioned above, clinical implementation remains difficult due to long scan times and sophisticated and non-standardised post-processing methods[3].

IMAGING OF TISSUE METABOLITES

MR spectroscopy (MRS) is used for direct non-invasive quantification of various tissue metabolites in order to derive information about muscle homeostasis at rest and in motion. Different nuclei are used as markers for different pathways and effects, all sharing the need for specific hardware and software. In particular, the broader application of MRS on higher field strengths and the resulting gain in SNR have significantly improved quantification precision. Proton (^{1}H) MRS is suitable for the quantification of lipid distribution in the intracellular and extracellular compartments of the skeletal muscle and is used, among other things, for the investigation of training or pathological effects linked to insulin resistance and distribution among different skeletal muscle groups. Further applications of ^{1}H MRS are the monitoring of lactate accumulation during heavy exercise and the determination of creatinine and carnosine for the evaluation of muscle metabolism and monitoring of physiological adaptation and therapy effects.

The evaluation of deoxymyoglobin is a tool for monitoring the dynamic processes of tissue oxygenation, and the direct measurement of acetylcarnitine presents insights into fatty acid metabolism[7]. Carbon (^{13}C) MRS is used to determine glycogen reserves in the skeletal muscle[8]. Phosphorus (^{31}P) MRS uses ATP, PCr and Pi which reflect oxidative metabolism to monitor resting, exercising and recovering muscle, with PCr describing mitochondrial function[2, 9]. Furthermore, the levels of phosphodiesters including glycerophosphoethanolamine (GPE) and glycerophosphocholine (GPC) have been suggested as surrogate markers of skeletal muscle status ranging from muscle dystrophy, through insulin resistance up to aerobically trained muscle[10]. Although the imaging of these metabolites would be useful for some specific clinical questions, these techniques are and will probably remain limited to biomedical or clinical research in the near future, due to the lack of capability of the available scanners for broadband x-nuclei channels.

CONCLUSION

Biochemical MRI techniques are becoming increasingly important due to the development of more robust hardware and software components and thus higher accuracy in the *in vivo* quantification of tissue components and metabolites. In particular, at higher field strengths and with a perspective towards uniform protocols and sophisticated reconstruction algorithms for faster acquisition and automated online post-processing, many of these quantitative MRI methods will find their way into clinical routine and will help to better combine pathological processes with different molecules. Dynamic assessment of metabolic changes in musculoskeletal tissue will support early diagnosis, personalised preventive concepts and therapy monitoring.

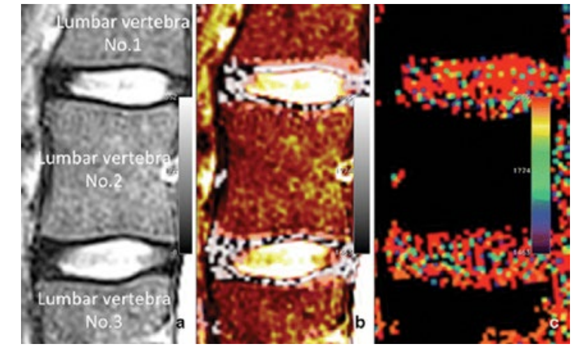


FIGURE 2

Image (B) shows the merged T2w image (A) and the colour-coded gagCEST map of the lumbar vertebra 1–3. T2 image (A) shows no morphological difference, but gagCEST shows different values [MTr=magnetisation transfer rate] of the intervertebral discs L1/L2 and L2/L3, indicating different GAG contents. [images from Haneder S et al. Assessment of glycosaminoglycan content in intervertebral discs using chemical exchange saturation transfer at 3.0 Tesla: preliminary results in patients with low-back pain, published in Eur Radiol. 2013 Mar;23(3):861–8, with kind reprint permission from Springer Nature].

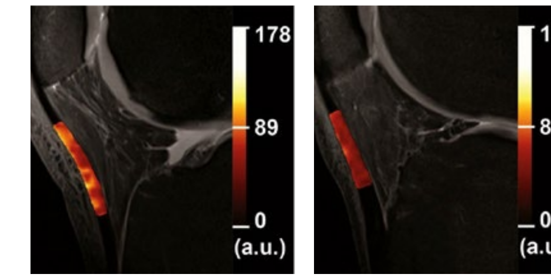


FIGURE 3

Colour-coded sodium image of the patellar tendon of a patient with type 1 diabetes mellitus (B) with higher sodium values (arbitrary units) compared to a healthy control (A) indicating an increased GAG content [images from Marik W et al. Changes in Cartilage and Tendon Composition of Patients With Type I Diabetes Mellitus: Identification by Quantitative Sodium Magnetic Resonance Imaging at 7 T, published in Invest Radiol. 2016 Apr;51(4):266–72 with kind reprint permission from Springer Nature].

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12

DUAL-ENERGY CT

Dual-energy CT and spectral CT

By **Andrea S. Klauser**

Gout is an inflammatory arthritis characterised by the deposition of monosodium urate (MSU) crystals in joint, cartilage and soft tissues and can lead to formation of tophi and joint damage. The metatarsophalangeal 1 (MTP 1) joint is the classic site of involvement, also known as podagra.

It can be challenging to establish a diagnosis if the first onset of gout is in a different location. Novel value-based imaging methods can differentiate gout from septic arthritis and osteomyelitis, or even tumour formation. Microscopic demonstration of MSU crystals in joint fluid or tophus is the gold standard for diagnosis of gout. However, this method is invasive and not always feasible. With respect to imaging methods, both ultrasound and dual-energy computed tomography (DECT) are well recognised in the diagnosis of gout, in addition to measurement of the serum urate level, clinical evidence of tophus and MSU crystals in synovial fluid analysis. The double contour (DC) sign on ultrasound and positive DECT findings have been included in the 2015 American College of Rheumatology (ACR) classification criteria. DECT is a non-invasive method for confirming the presence of MSU crystal deposits, which supports the diagnosis of gout[1, 2]. This has a significant impact on clinical decision making when gout is suspected and in monitoring treatment response[3, 4].

The effectiveness of DECT has been proven in several studies and thus DECT is increasingly used for the diagnosis and follow-up of gout, with a reported sensitivity of 78–100% and specificity of 89–100%5. DECT uses two different energy levels (80 and 140 kV), which can differentiate material rich in calcium from material rich in MSU crystals. Reconstructions can provide colour-coded images in transverse, sagittal and coronal planes, with a slice thickness of 0.75mm at a slice increment of 0.5mm with standardised post-processing thresholds. Ultrasound is also considered superior to standard radiography in the diagnosis of gout, and power Doppler provides additional information about the inflammatory process[6].

FIGURE 1

The MTP 1 joint is the classic site of involvement, known as podagra, showing MSU deposits in green.

FIGURE 2

Extensive MSU deposits at finger flexor tendons and dorsal MCP joints.

Discrepancies between ultrasound and DECT with regard to tophus size, detection rate and location have been reported and are currently under investigation[7].

The clinical relevance of tophus size and number of tophi allows assessment of the 'gouty burden' and this might influence therapy selection. With the utilisation of new medications, these measurements can be used to assess therapeutic outcomes[6].

DECT is a highly reproducible method for measuring urate deposits within tophi and is able to reveal the variable composition of tophi. However, DECT measurements of tophi give smaller volumes compared to the same tophi measured on ultrasound. Furthermore, Pascart et al have shown that ultrasound signs of urate deposition in joints do not correlate with overall DECT volumes of extra-articular deposition[7].

The discrepancy between ultrasound and DECT can be explained by the fact that DECT only measures the crystal content of the tophus and the fibrovascular highly cellular zone, and thus the outer zone might be missed, whereas ultrasound measures the entire volume of the soft tissue[7].

DECT analysis of clinically apparent tophi with a similar physical size has shown that there is a large variation in the amount of urate crystal deposition within these lesions.

Melzer et al[8] reported that DECT can identify 'dense' tophi (with at least 15–20 % urate volume in the tophus), but tophi with lower urate volumes may not be detected on the colour-coded DECT images. This explains the false negative cases in DECT studies (6).

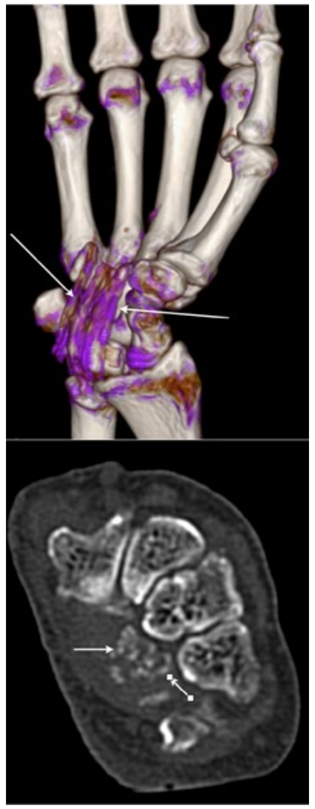

FIGURE 3

Only DECT allows the differentiation in the otherwise similar appearance by conventional CT compared to Figure 2 of finger flexor involvement, but DECT reveals instead a hydroxyapatite crystal deposition disease without any green pixels in the finger flexors at the level of the carpal tunnel.

Tophus formation is the cardinal feature of advanced gout and is strongly associated with joint and bone damage in chronic gout. The presence of tophi and the double contour sign in the 1st MTP joint on ultrasound are very characteristic features. However, at deeper sited locations it may be difficult to differentiate between echogenic MSU deposits from calcium pyrophosphate dihydrate crystal deposition disease (CPPD) or hydroxyapatite crystal deposition disease (HADD)[9].

Furthermore, in larger joints, deep MSU deposits, such as around the cruciate ligaments in the knee and in the radiocarpal joint recess, may be missed on ultrasound[9, 10]. There are similar concerns regarding the detection of intraosseous MSU crystals.

Ultrasound enables evaluation of MSU deposits in soft tissue structures such as tendons and ligaments, and assessment for complications of gout such as tendinosis and enthesopathic change. However, ultrasound is operator dependent and may be constrained by accessible viewing angles; therefore, its role in monitoring tophus resolution has not been fully established.

DECT is more susceptible to artefacts than ultrasound, particularly in well-known locations such as tendons, nail beds and skin, but these are easily recognised with experience. In addition, physiological MSU deposits in costal cartilage and intervertebral discs (in particular in middle-aged and older men) might result in false positive interpretation.

Traditionally, crystal analysis has been considered the gold standard for the diagnosis of gout. With recent developments, ultrasound and DECT have become established imaging modalities for diagnosing gout without the need for crystal analysis. Glazebrook et al[2] have shown that clinicians are happy to rely on positive DECT results, when there has been negative joint aspiration, to initiate medical treatment. In addition, many physicians do not perform synovial fluid analysis and therapy is often initiated with assumed clinical criteria indicating gout[3].

FIGURE 4

DECT allows differentiation of gouty finger joint deposits from finger osteoarthritis by showing MSU deposits at the DIP2 and IP1.

In summary, DECT enables direct visualisation of urate deposits, the main feature of the disease that is needed to establish the diagnosis. Furthermore, DECT gives information about tophus size in terms of gouty burden. DECT can also detect subclinical MSU deposits in patients without clinical evidence of acute gout. Computer-assisted DECT quantification of urate deposition can be useful for serial assessment of patients with gout to assess response to therapy (Figure). These technical advances have changed patient management, with a shift away from radiographs towards ultrasound and DECT.

ACKNOWLEDGEMENTS

Athena Plagou MD, PhD from Athens, Geece, Dr. Iwona Sudoł-Szopińska from Warsaw, Poland, Dr. Lennart Jans from Ghent, Belgium, Dr. Claudia Weidekamm from Vienna, Austria, and James Teh from Oxford, UK, are acknowledged for their contributions to this article.

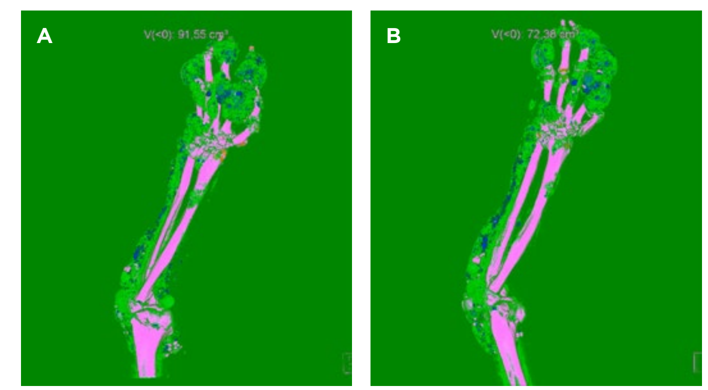

FIGURE 5

58-year-old male with 30-year history of gout: 3D reconstructions of the forearm at beginning of treatment (A) and six months after treatment (B) show a reduction in volume (shown at the top of each exam) of MSU deposits (marked in green). Courtesy: I. Sudoł-Szopińska

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13

MSK ULTRA-SOUND

MUSCULOSKELETAL ULTRASOUND:
What does it offer and what does the future hold?

By **Athena Plagou, Andrew J. Grainger, Andrea S. Klauser, Claudia Weidekamm, Apostolos Karantanas, Maria Tzalonikou** and **Nantia Mertika**

The use of ultrasound as an imaging modality for the musculoskeletal (MSK) system has continued to grow in recent years, in particular as a result of significant advances in technology. In order to assess the importance of ultrasound in MSK imaging one should first recognise the unique characteristics of the modality[1].

Ultrasound provides fast, portable and patient-friendly imaging and allows examination of many MSK structures including tendons, ligaments, muscles, peripheral nerves and soft tissues. It is superior to all other imaging modalities in terms of resolution. It can be the first and, in most cases, the last screening tool in the imaging of superficial structures[2].

Ultrasound is currently performed by radiologists, clinicians and sonographers. The quality of the ultrasound scan and the accuracy of its interpretation are highly dependent on the skills of the operator. Examination requires scrupulous technique for abnormality to be detected. For instance, when scanning for synovitis, both thickened synovium and vascularisation can be hidden if too much pressure is exerted by the transducer[3] (Figure 1). The learning curve for ultrasound is longer for operators unfamiliar with ultrasound scanning in general.

Ultrasound is a real-time method and accuracy of diagnosis depends on the scanning competency of the operator. The diagnosis is reached during scanning and it is difficult, if not impossible, to be revised based on the static images or even video clips acquired by the examiner.

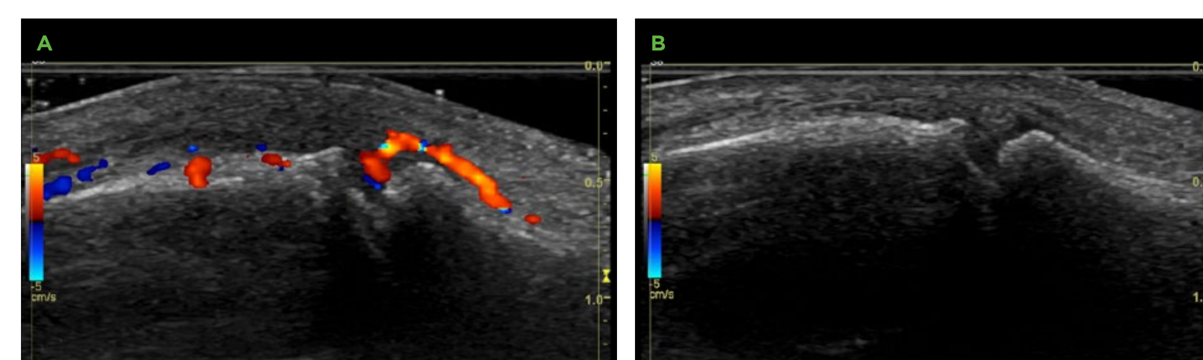
One of the most important advantages of ultrasound imaging is its superiority for superficial imaging[4]. In addition, with the use of colour Doppler, vascularisation is easily and accurately demonstrated. There is no need for application of intravenous contrast media (CM) which should be used with caution as they can cause kidney function impairment (CM for computed tomography) or deposition of gadolinium in the brain (CM for magnetic resonance imaging)[5].

The dynamic nature of ultrasound is maybe its strongest advantage. Assessment of tendon dislocation, muscle herniae, impingement syndromes and ligament tears are only some examples where the dynamic capabilities of ultrasound assist in diagnosis[6].

Ultrasound provides the advantage of easy comparison with the contralateral side, extension of the scanning area and assessment of other structures, such as vessels, during the same examination period[7]. In MSK imaging, quantitative measurements are not always helpful. Appreciating pathology such as tendinopathy or nerve compression is usually based on the qualitative appearances, as well as a contralateral comparison. Ultrasound scanning is the fastest and, in some cases, the only technique that can provide this data. Furthermore, the evaluation of surrounding structures during the same scan can yield clinically important findings. One characteristic example is the possibility to evaluate vein patency, and thus exclude thrombosis, in the context of a patient scanned for muscle injury, usually in the calf. In addition, ultrasound has proven to be very useful in

FIGURE 1

The importance of transducer pressure. (A) Light pressure is exerted with the transducer on the patient's skin which allows the demonstration of neovascularisation in patients with rheumatoid arthritis. (B) Increased probe pressure 'hides' the neovascularisation.



the post-operative assessment of joints, as the artefacts caused by surgical material usually interfere less with ultrasound images compared to CT and MRI[8].

On the other hand, there are properties of ultrasound that can limit diagnostic accuracy. Limited field of view and properties of the sound beam such as reflection and refraction are characteristic examples. Limited field of view in ultrasound scanning is a significant drawback. Other modalities like CT and MRI offer a 'bird's-eye view' which can help the radiologist detect lesions more easily, particularly in deeper tissue layers (Figure 2). Reflection of the ultrasound beam on some surfaces, such as bone, results in the inability to depict pathology beyond the surface, such as bone marrow oedema, an important finding in MSK imaging. Refraction of the ultrasound beam when it passes through layers of different properties, along with attenuation of the beam, weakens the assessment of deeper layers of tissue[9].

Artefacts have an important role in ultrasound imaging and can help promote or decrease confidence in the diagnosis[10]. Anisotropy is probably the most important and frequent artefact in MSK imaging and is seen as decreased echogenicity of an anatomical structure when the ultrasound beam is not directed perpendicular to it. It is frequently encountered in structures with ordered structure of parallel bundles, such as tendons, ligaments and muscles.

Having highlighted the strengths and weaknesses of ultrasound we can get a clearer picture of what the future holds.

Further improving the strengths of ultrasound lies in the improvement of wide bandwidth transducers producing high spatial resolution both in superficial and deep lying structures. Improvement of colour Doppler sensitivity in high and lower frequency ranges will be crucial for diagnosis, especially in rheumatological and oncologic cases. Improvement of elastography will also provide important information about the qualitative characteristics of MSK structures.

Transducers that will produce 3D reconstructed images for the MSK system will facilitate imaging in three planes and provide increases in standardisation and reproducibility. An ultrasound unit equipped with a computer-aided detection system would both reduce screening time and increase diagnostic confidence. Further use and improvement of image fusion technique, which is a combination of images from different diagnostic modalities, will also increase accuracy in diagnosis and interventional procedures in the MSK system.

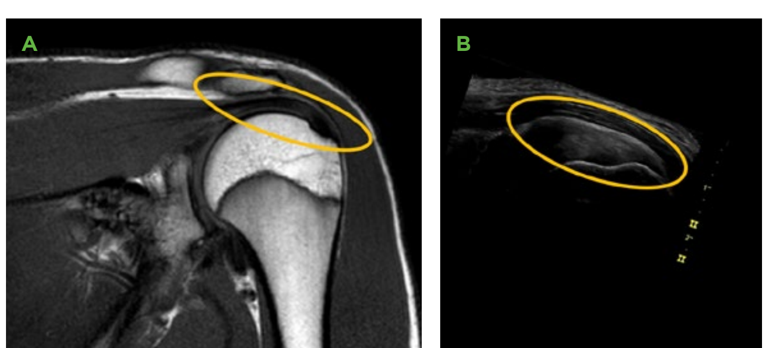


FIGURE 2

Properties of ultrasound imaging. (A) Coronal MRI scan of the supraspinatus (in circle); underlying structures are also demonstrated ('bird's eye view'). (B) Longitudinal ultrasound scan of the supraspinatus (in circle). Limited field of view (no demonstration of underlying structures), high resolution imaging.

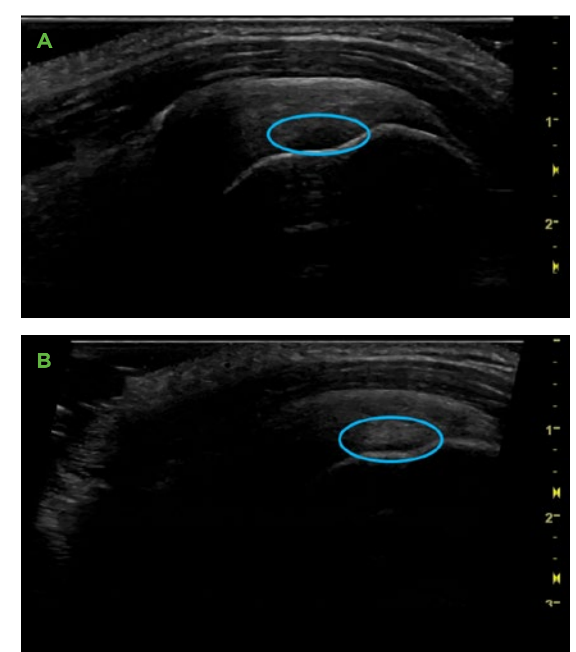
Overcoming the weaknesses of ultrasound represents a challenge for the future. Problems resulting from the physical properties of the sound beam cannot be solved. For example, the inability of ultrasound to 'see' behind bone will always be a disadvantage of the technique.

Nonetheless, there is a possibility of improvement in areas where technology can provide new or better tools. The artefact of anisotropy can be accentuated by techniques such as beam steering (Figure 3). Introduction of tools such as pressure sensors, where the pressure exerted by the transducer is controlled, would increase the diagnostic accuracy when scanning for synovitis and neovascularisation in superficial areas.

Looking into the future, ultrasound is a technique that can further be improved with the aid of technology. Raising clinicians' awareness of the indications of the method can result in increased use of this safe diagnostic tool that can, in many cases, serve as a 'one stop shop' in diagnosis.

FIGURE 3

Anisotropy. (A) Hypoechoic area in the articular surface of the supraspinatus tendon (inside the circle) caused by anisotropy can result in false positive diagnosis of partial thickness tear. (B) Beam steering corrects the effect of anisotropy.



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14

HOLISTIC APPROACH

THE HOLISTIC APPROACH: 3D, whole-body and hybrid imaging

By **Domenico Albano** and **Paola Anna Erba**

Three-dimensional (3D) MRI sequences have well-known strengths and advantages in comparison with two-dimensional (2D) acquisition, due to 3D MRI's increased spatial resolution, high signal-to-noise ratio (SNR) and the possibility to obtain isotropic multi-planar reconstructions, which are crucial for evaluating complex anatomic structures.

To date, fast 3D gradient echo (GRE) sequences have been used in MSK, especially for cartilage imaging and MR arthrograms[1], although GRE images are prone to susceptibility artefacts related to inhomogeneities of the main magnetic field and present changes in image contrast as compared to spin echo (SE) and turbo spin echo (TSE) sequences. Technical advances and the wider availability of 3T MRI scanners have improved the feasibility of 3D TSE imaging, leading to its clinical applicability. The image contrast and SNR of 3D TSE have been optimised while image blurring and scan time have been reduced, with the latter now shorter than the acquisition time of three separate orthogonal 2D sequences. Clinical studies have compared the image quality and diagnostic performance of 3D and 2D TSE in several joints, reporting similar results[2, 3].

Some authors have highlighted some advantages of 3D TSE in detecting subtle cartilage lesions and meniscal tears[2]. Other authors have underlined the potential of 3D TSE in the spine[3]. Indeed, this technique allows the reformatting of images, providing standard orthogonal or specific imaging planes, maintaining high resolution to evaluate spine deformities and transitional vertebrae and better depict nerve roots, besides reducing partial volume and cerebrospinal fluid flow artefacts. A view that is shared by several authors is that 2D and 3D TSE might improve the diagnostic performance of MRI when combined, but in the coming years further technological innovation could improve the accuracy and applicability of 3D TSE, allowing its place in MSK imaging to be defined.

Whole-body MRI is another increasingly used tool that enables the acquisition of images from head to feet in a single examination, without radiation exposure or contrast agent administration. Whole-body MRI has been increasingly used in oncologic settings, especially for myeloma, lymphoma, paediatric neoplasms, prostate cancer and breast cancer[4]. Its superb contrast resolution in bone and soft tissues has led radiologists to apply this imaging modality in several MSK conditions, including inflammatory arthritis and myopathies, muscular

FIGURE 1

A 43-year-old female patient with spondyloarthritis. Coronal T1-weighted (A) and STIR (B) whole body images from head to feet. Coronal (C) and sagittal (D) STIR images of the thoracic spine show syndesmophytes and osteitis (arrows) due to active spondylitis. Coronal oblique STIR image of the sacroiliac joints (E) shows no signs of active sacroiliitis but allows detection of periarticular fat deposits (curved arrows) related to areas of previous inflammation (case courtesy of Dr. Ernesto La Paglia, Torino, Italy).

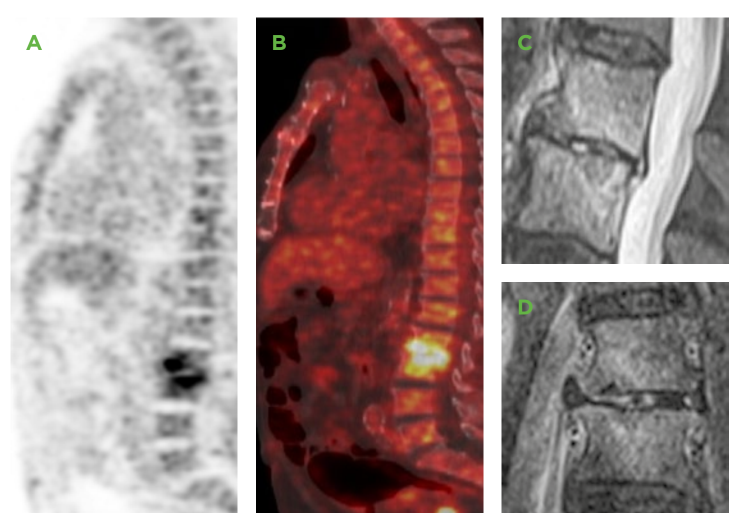
dystrophies, neurological diseases, chronic recurrent multifocal osteomyelitis, and multifocal osteonecrosis[5]. To date, the main MSK indication remains seronegative spondyloarthropathy. Variable imaging protocols are used and adapted to the clinical indication.

Coronal STIR is generally used to detect tissue changes in the joints, entheses, and muscles, while T1-weighted images are essential for evaluating bone marrow, muscle trophism and fatty infiltration. The spine is studied with sagittal STIR and T1-weighted images; transverse images are used for the evaluation of muscles; and oblique planes may be used for specific cases (e.g. sacroiliitis). Recently, whole-body Dixon MRI has been tested with promising results as an alternative option for a comprehensive grading of bone and muscle changes in inflammatory disorders, as well as a reliable tool for body composition[6]. In several conditions, whole-body MRI has already proven to be helpful in diagnosis, assessment of disease activity, and treatment response evaluation. Up to now, the use of this tool has been limited to referral centres, but faster MRI protocols with higher image quality and increased availability of powerful scanners will enable widespread use of whole-body MRI in MSK imaging.

The development of hybrid imaging devices has been an important advance in nuclear medicine. SPECT/CT and PET/CT have increased the diagnostic value of procedures performed with many radiopharmaceuticals, some of which were on the verge of being withdrawn from the market but have now been given a new lease of life by hybrid imaging. This includes the evaluation of infectious diseases when anatomical landmarks are required, e.g. when soft-tissue infection has to be differentiated from osseous involvement, when it is necessary to define all sites of disease and the whole extent of the infection in regions with a complex anatomy, as well as when infection is suspected in regions with underlying alterations following surgery or implantation of medical devices (Figure 2)[7]. Recently, new hybrid systems consisting of PET/MRI have been introduced in clinical practice. In addition to a lack of ionising radiation, which makes PET/MRI very interesting for application in paediatric patients, MRI offers superior soft tissue contrast as compared to CT, particularly in tissues such as cartilage and bone marrow.

FIGURE 2

[^{18}F]FDG PET/CT (A, sagittal emission; B, sagittal superimposed PET/CT) in a patient with fever and back pain, increased CRP and ESR, positive blood culture with isolation of Lactococcus garvieae. Images showed the presence of uptake at the lower aspect of L2 and the upper aspect of L3, extending to the soft tissue, suggesting the presence of spondylodiscitis. MRI (C) confirmed the finding.



Since MRI can offer novel functional contrasts, its combination with PET offers powerful observations of distinct physiological processes occurring in bone and cartilage at the same time. PET/MRI adds a major dimension to research and clinical applications of PET in a variety of MSK disorders, including infection, diabetic foot, painful arthroplasty, metabolic bone disease, back pain, non-malignant bone marrow disorders, and arthritis.

For instance, [^{18}F]FDG-PET/MRI improves diagnostic certainty for the detection of spondylodiscitis (sensitivity=100%, specificity=88%) as compared to standard MRI, especially in patients with inconclusive clinical or MRI findings[8]. Similarly, in patients with diabetic foot, PET/MRI could improve accuracy in detecting soft tissue lesions in osteomyelitis[9].

Nevertheless, due to the limited availability of this scanner, PET/MRI cannot be considered an established modality for clinical practice in diabetic foot. Other examples of possible uses of PET/MRI include osteoarthritis where [^{18}F]NaF and [^{18}F]FDG PET/MRI have been used for the comprehensive imaging of the joint, including soft tissues and bone, as well as the opportunity to simultaneously assess the role of metabolic activity, and to understand the relation between remodelling and inflammation.

In the case of ankylosing spondylitis, the simultaneous acquisition of high-resolution anatomical and functional MRI images and metabolic information by [^{18}F]NaF-PET provides new insights into the link between inflammatory cascades, local metabolic changes, and the development of structural manifest inflammation. In patients with rheumatoid arthritis [^{18}F]FDG-PET/MRI provides metabolic information which can potentially be used to assess different aspects of arthritis, such as bony disintegration and inflammatory activity, which, together with the anatomical and morphological data and excellent soft tissue contrast, maximises the strengths of both imaging approaches in rheumatoid arthritis imaging and treatment monitoring[10]. In addition to [^{18}F]FDG, other radiopharmaceuticals may be used to image rheumatoid arthritis such as the ones allowing the study of synovial hypoxia (^{18}F-fluoromisonidazole and ^{18}F-fluoroazomycinarabinoside).

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15

INTER-VENTIONAL PAIN MANAGE-MENT

Interventional pain management techniques

By **Marina Obradov**

Interventional pain management is defined as the application of interventional techniques in the management of subacute, chronic, persistent, and intractable pain, independently or in conjunction with other modalities or treatments[1].

Traditionally, spine interventional pain procedures have been performed with fluoroscopy, rarely, CT or MRI. Ultrasound enables the imaging of soft tissue structures and bony surfaces, guidance of needle advancement and confirmation of the spread of injectate, without radiation. Fusion of 3D CT or MR data with real-time ultrasound imaging improves ultrasound guidance for interventional procedures in small soft tissue structures and joints[2].

Interventional **spine** procedures must be performed under a rigorous sterile protocol. Contraindications include infection, uncorrected coagulopathy, allergy to any of the medication used, or a patient unwilling to provide informed consent.

Facet joints are responsible for pain in 15–67% of patients with back pain. Infiltrations are performed under fluoroscopy, ultrasound with or without CT, and MRI fusion technique with percutaneous posterolateral access of a needle into the joint or by blocking the nerves that innervate the joint. There is better evidence for the therapeutic effectiveness of medial branch blocks than intra-articular blocks. The frequency would be two to three months between injections, provided that >50% pain relief is obtained for six weeks, for a maximum of four to six times per year.

Epidural space injection is indicated in radicular pain without neurologic deficit, postoperative recurrent pain, equivocal neurologic examinations and spinal nerve root compression. Infiltrations with a mixture of a long-acting corticosteroid and a local anaesthetic can be delivered via interlaminar, transforaminal, or sacro-coccygeal hiatus access.

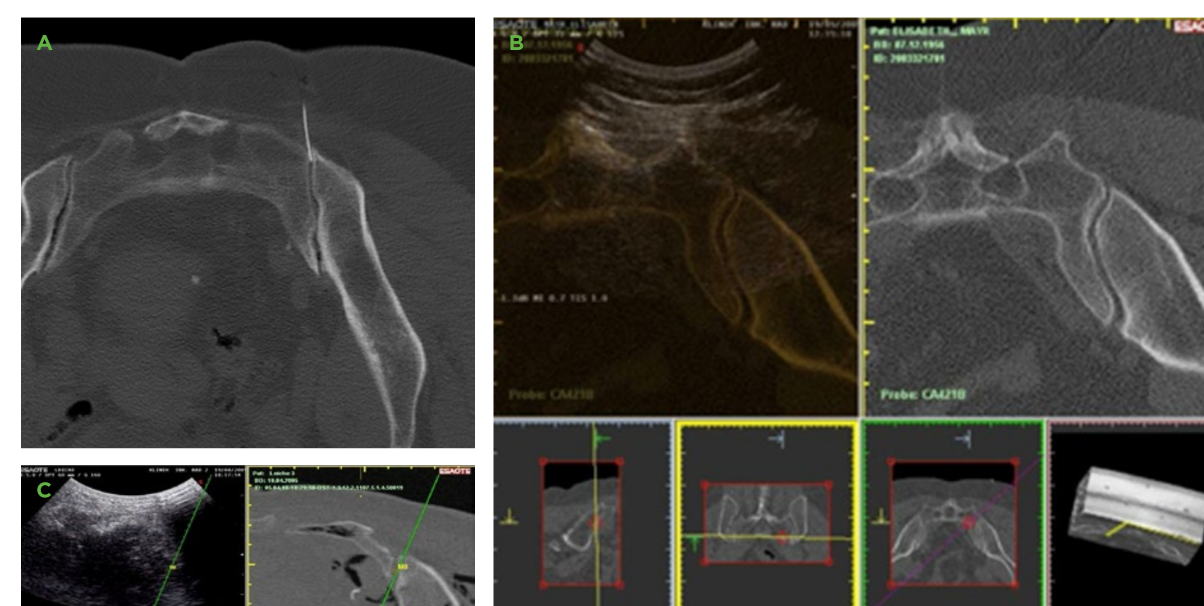
Selective nerve root blocks are used in multilevel pathology to identify the cause of pain. Injection of contrast, local anaesthetic, or other substances around spinal nerves is performed mainly under fluoroscopy. Long-term relief of chronic pain can be achieved by injection of ethanol or phenol or by RF ablation under fluoroscopy or CT guidance.

Sacroiliac joints can produce a pain in the lower back, buttocks, thigh, lower extremities, groin or occasionally abdomen, with a prevalence of 13–30%[1, 3]. Besides CT-guided injections, the use of CT or MRI fusion imaging combined with ultrasound has also been proposed (Figures 1A, 1B)[2]. The evidence for therapeutic injections to the facet joint is fair to good and for the sacroiliac joint it is limited[3].

Intra-articular injection (IA) in **osteoarthritis** is preferred as the last non-operative modality. IA corticosteroid injections provide a short-term reduction in osteoarthritis pain while hyaluronic acid (HA) injections might provide pain reduction in mild osteoarthritis for up to 24 weeks. Platelet-rich-plasma (PRP) injections are promising for relieving pain and improving function and quality of life, especially in mild osteoarthritis

FIGURE 1

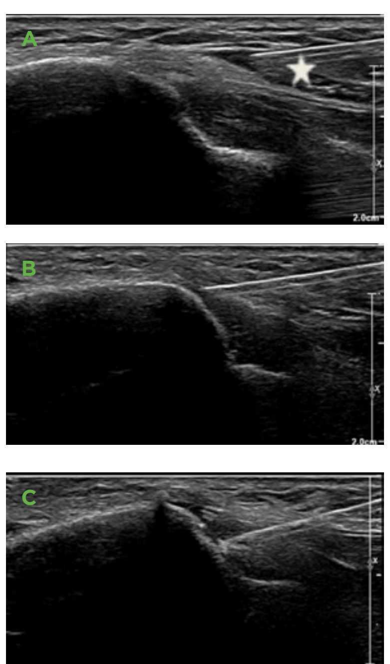
Sacroiliac joint injection. (A) CT-guided injection, (B, C) fusion of CT 3D data with real-time ultrasound imaging to improve ultrasound-guided sacroiliac joint injection (B, C courtesy of Dr. Andrea Klauser).



and younger patients[4]. Different sorts of corticosteroids have similar potency provided with the correct indication, dosage, timing, and application. HA functions through anti-inflammatory, anabolic, analgesic and chondroprotective mechanisms. PRP has a high concentration of growth factors contributing to chondrogenesis, bone remodelling, proliferation, angiogenesis and

FIGURE 2

Percutaneous needle tenotomy (PNT) of the lateral epicondylitis. (A) extensive anaesthesia of the superficial tissue above the surface of the tendon with hydro dissection (*) effect. (B) the needle is advanced along the long axis of the transducer, parallel with the direction of the tendon. (C) the bone tendon interface is specifically targeted.



anti-inflammation. Ultrasound-guided intra-articular injections demonstrate increased accuracy and efficacy regardless of the anatomic location, improving patient-reported clinical outcomes and cost-effectiveness.

Tendinopathy includes tendon thickening, loss of mechanical properties, and pain. The use of ultrasound guidance for direct visualisation of the target and relevant adjacent structures improves accuracy.

Insertion tendinopathy is a common cause of chronic pain in jumping athletes. Percutaneous needle tenotomy (PNT) may be an effective method for the treatment of chronic lateral elbow tendinopathy[5]. After an extensive anaesthetic a needle is advanced along the long axis of the transducer, parallel with the direction of the tendon, targeting calcifications and the bone-tendon interface (Figures 2A, 2B, 2C). The results of a systematic review suggested that autologous blood products may further improve theses outcomes and PRP may be superior to autologous blood in the short-term results[6]. Sclerotherapy together with prolotherapy has limited evidence based on a small number of patients. For definitive conclusions on all these treatments, long-term follow-up and randomised controlled studies with validated clinical, radiological and biomechanical assessment are needed.

Tenosynovitis is the inflammation of the tendon sheath that surrounds a tendon, leading to joint pain, swelling, and stiffness, with de Quervain tendinopathy and trigger finger as common clinical manifestations. Moderate evidence exists for the effect of paratendinous ultrasound-guided corticosteroid injection on the very short term, while HA injection has been associated with short, medium, and long-term improvement in pain in randomised controlled trials[7].

Calcific tendinopathy results from the deposition of calcium hydroxyapatite crystals in or around tendons, in periarticular locations causing

chronic pain and functional impairment. Ultrasound-guided barbotage has a high rate of long-term success and low complication rates with significant improvement in range of motion, pain, and disability during one year of follow-up[8]. Injection and aspiration of calcification is performed with a needle introduced under ultrasound guidance followed by injection of corticosteroid into the subacromial-subdeltoid bursa in the case of rotator cuff calcifications.

Bursitis is usually caused by repetitive irritations, although non-infectious bursitis may be caused by injury, arthritis, gout and calcium deposition along a tendon. Ultrasound-guided intra-bursal corticosteroid injections provide symptomatic relief in the short-term, most marked at six weeks, with decreasing effect at six and twelve months, but still significantly lower than the baseline scores (Figures 3A, 3B)[9].

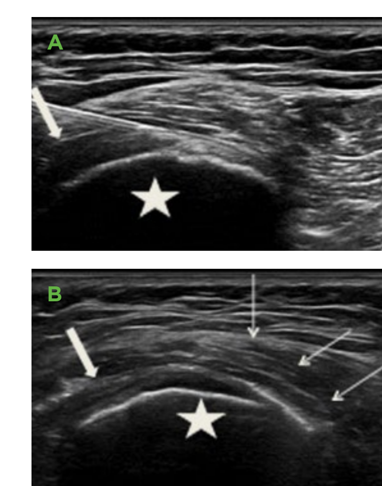
Ultrasound-guided **peripheral nerve blocks** allow visualisation of relevant anatomy and needle positioning under live guidance. The use of ultrasound-guided injections in carpal tunnel syndrome, Morton's and saphenous neuromas, stump neuromas, piriformis syndrome, and meralgia paresthetica allow the radiologist to inject drugs with minimal patient discomfort and often good early response after corticosteroid injections[10], as in the case of Morton's neuroma or carpal tunnel syndrome.

CONCLUSION AND FUTURE PERSPECTIVES

The prospects for the future development of musculoskeletal interventional pain management are bright and promising. Well-established radiological training of residents and fellows, together with technical innovations and evidence-based medicine supported recommendations, have to ensure the balance between benefits, risks and burdens of musculoskeletal interventional pain management.

FIGURE 3

Ultrasound-guided trochanteric bursa injections of corticosteroid for greater trochanteric pain syndrome. (A) needle position, (B) expansion of the corticosteroid in the bursa, greater trochanter (*), gluteus medius tendon (thick arrow), injected solution in the bursa (thin arrows).



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She is project leader of Europe's multicentre randomised controlled trial on ultrasound-guided percutaneous needle tenotomy and physiotherapy in patients with lateral elbow tendinopathy.

At present, she is Chair of the Intervention Subcommittee of the ESSR.

16

QUANTITATIVE MRI

Quantitative MRI and imaging bio-markers of the musculoskeletal system

By **Mario Maas, Edwin H.G. Oei, Robert Hemke** and **Josien C. van den Noort**

INTRODUCTION

MRI is a strong clinical tool for diagnosis, treatment planning and evaluation of musculoskeletal (MSK) disorders. In addition to the usual qualitative MRI analysis, recent developments of advanced MR sequences and high-tech post-processing have enabled quantification of the MR signal. Quantitative MRI provides measures related to disease characteristics: the imaging biomarkers. An imaging biomarker follows three rules: the measurement is closely coupled to the target disease; is accurate, reproducible and feasible; and can measure changes over time, linked to the success or failure of a given therapy. Patients benefit from biomarkers by earlier disease detection and improved treatment planning and monitoring. Early detection leads to optimised treatment, fast recovery, and delayed disease progression, or even prevention. One of the major applications of quantitative MRI is the quantification of articular cartilage. However, more applications have been developed that are finding the way from research to clinic.

BONE MARROW

Patients with Gaucher disease (GD) are some of the first for whom imaging biomarkers have been developed. This rare orphan disease of lysosomal storage is caused by the deficiency of the enzyme beta-glucocerebrosidase. Patients with GD have benefitted from the early development of enzyme replacement therapy. This therapy has proven to be highly successful in treating (at least in part) the clinical symptoms caused by hepatosplenomegaly and cytopenia, and preventing the occurrence of skeletal complications such as bone infarcts, pain and development of avascular necrosis. The storage of accumulated Gaucher cells in bone marrow was the pathophysiological pathway established by quantitative MRI.

An imaging method that has been explored in this context is Dixon quantitative chemical shift imaging (QCSI). This technique enables separation of the specific contribution of fat and water to the acquired MRI signal. Nowadays, Dixon sequences are widely commercially available, yet in the early 1990s they were new. The attention that was given to this technique in a 2010 GD Biomarker Qualification Workshop held at the U.S. Food and Drug Administration shows its importance in the field.

What can be measured? Using Dixon sequences in the lumbar spine, the content of the bone marrow can be analysed non-invasively considering the water and fat fraction (FF). In GD with severe bone marrow involvement, FF is too low. When the FF is lower than 23%, bone complications occur and patients are considered 'bone at risk'. Serial assessment of patients under treatment shows the increase of FF (Figure 1). FF measured by QCSI is a technique that remains stable, also undergoing vendors' machine and software updates, yet support from a clinical physicist is mandatory. Dutch GD patients have been monitored for more than 20 years, and this technique is used in international pharmaceutical initiated trials. Although QCSI has been implemented elsewhere, its major limitation is availability. An alternative semi-quantitative method has therefore been developed: the so called bone marrow burden (BMB) score (Maas-score). By assessing location of involvement, signal intensity and occurrence of complications, description of GD bone burden closely correlates to QCSI. BMB scores are used as secondary endpoint in clinical trials. QCSI FF measurement is able to detect response to treatment in 92%, while the BMB scoring system detects 75%.

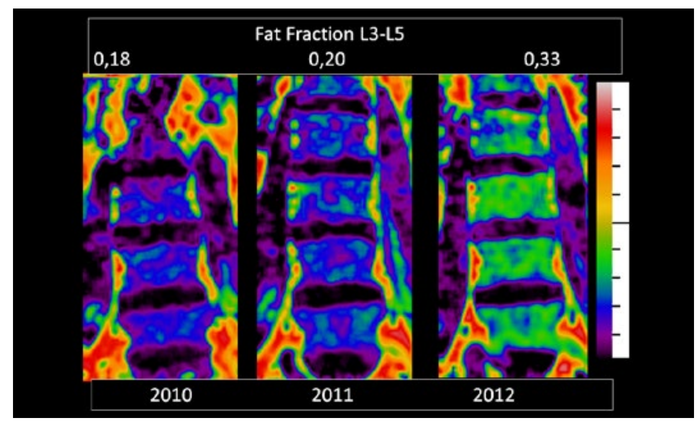
CARTILAGE

Current radiological techniques are characterised by poor sensitivity to early cartilage changes and are limited to visualisation of gross morphological cartilage breakdown. Consequently, cartilage disorders, particularly osteoarthritis, are typically diagnosed at advanced stages when disease-modifying therapies are no longer an option. Hence, there is a growing interest in quantitative imaging biomarkers that allow detection of alterations within cartilage that are indicative of early disease.

Various such MRI techniques have been developed, all aiming to probe the content and network integrity of the main cartilage

FIGURE 1

Serial assessment of a patient being treated for Gaucher disease shows the increase of fat fraction.



constituents – proteoglycans and collagen – that have been shown to diminish in early osteoarthritis. T2 and T1ρ-mapping, dGEMRIC, GagCEST, and sodium MRI are the most established examples of such techniques (Figure 2). While these techniques correlate to a varying degree with collagen and proteoglycans, each has its own advantages and disadvantages (equipment requirements, scan time, contrast agent, image processing).

Application of these methods is not restricted to articular cartilage, but can be extended to similar tissues such as the fibrocartilaginous meniscus and intervertebral disc. Besides research applications in diagnosis and follow-up of osteoarthritis while clinical validation is currently ongoing, there is a reported clinical utility of such techniques in the field of cartilage repair and femoroacetabular impingement.

DCE MRI IN SOFT TISSUE TUMOURS AND INFLAMMATORY JOINT DISEASES

Dynamic contrast-enhanced MRI (DCE-MRI) gives detailed structural and metabolic information about different tissues. In the field of MSK radiology it is used most commonly for the evaluation of (soft-tissue) tumours and inflammatory joint diseases (e.g. rheumatoid arthritis and juvenile idiopathic arthritis). DCE-MRI is the time dependent registration of changes in MRI signal intensity during and after the intravenous injection of a Gadolinium-based contrast agent. DCE-MRI acquisitions are – in the scope of MSK radiology – most often based on T1-weighted images, usually built on a gradient echo sequence with a short repetition time and echo time. DCE-MRI results are rendered as time-intensity curves (TIC) that can be analysed in different ways, e.g. qualitative (visual), pharmacokinetics-based, or descriptive (semi-quantitative), each with its own advantages and disadvantages.

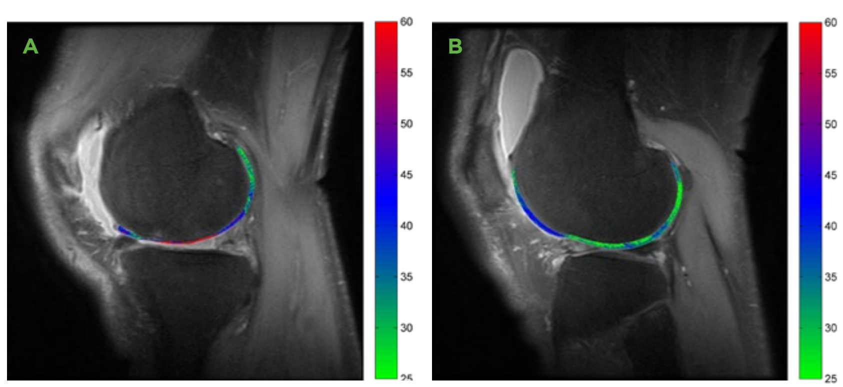
The main applications of DCE-MRI are in soft tissue tumours for the characterisation of the lesions, the identification of viable tumour areas to target biopsy, and monitoring of treatment response. As a reflection of tumour vascularity and perfusion, DCE-MRI enables differentiation between benign and malignant tumours based on the different enhancement patterns (Figure 3). The same concept applies to inflammatory joint diseases since DCE-MRI can provide sensitive quantitative information on perfusion of joint tissues for diagnosis and monitoring of most inflammatory joint diseases.

FUTURE PERSPECTIVE

Other applications for quantitative MRI are, for example, the evaluation of muscle atrophy and

FIGURE 2

(A) T2 mapping of articular cartilage of the knee shows elevated values of T2 relaxation time (red values) in the weight-bearing area of the femoral condyle in a patient with osteoarthritis; (B) normal values.



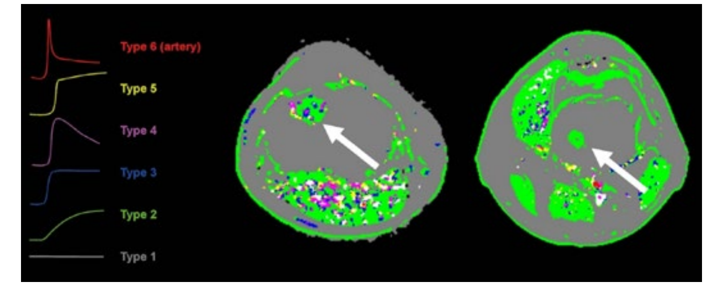


FIGURE 3

Example of DCE-MRI TIC shape maps of the distal femur of a patient with a low-grade chondrosarcoma (atypical cartilaginous tumour [ACT], left) and a patient with an enchondroma (right). The chondroid tumour clearly shows a more heterogeneous TIC shape pattern in the ACT compared to the enchondroma.

fatty infiltration (e.g. sarcopenia) by chemical shift techniques as a measure of body composition, or muscle tissue diffusivity and anisotropy by diffusion tensor imaging for sports injuries in athletes. Furthermore, quantification of metabolites in muscle by MR spectroscopy or ultrashort TE sequences for tendons are of great interest.

The major challenge to quantification and the use of biomarkers in the clinic remains availability. Quantification might require additional scan sequences and manually intensive post-processing. Compressed sensing techniques could lead to clinically feasible scan times, whereas standardised pipelines for automated data analysis do open up the way for fast radiological assessment. Furthermore, advanced techniques such as the use of high field MRI scanners (e.g. 7T) or machine learning will increase the possibilities and reliability of quantification methods.

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During her PhD, she investigated the applications of ambulatory movement analysis systems in clinical motor function assessment in children with cerebral palsy and adults with knee osteoarthritis. Her current work focuses on implementation of advanced musculoskeletal imaging in clinical practice, within MIQC, the Medical Imaging Quantification Center of the Amsterdam UMC. This includes dynamic contrast-enhanced MRI in arthritis and quantitative chemical shift imaging in Gaucher. Her research interest is in biomedical engineering, musculoskeletal imaging, musculoskeletal and neurological disorders, biomechanics and human movement analysis.

17

VALUE-BASED MSK IMAGING

Value-based musculoskeletal imaging

By **Jon A. Jacobson** and **Anna L. Falkowski**

INTRODUCTION

Over the years, imaging in the evaluation of the musculoskeletal system has evolved. Although it began with radiographs, there is now a host of imaging choices, such as computed tomography (CT), magnetic resonance imaging (MRI), ultrasound, and nuclear medicine imaging, each offering unique insight. With such technological advances, more detailed anatomical information has led to a better understanding of form and function, and, importantly, has revealed important pathology. Imaging is now an integral part of diagnosis, offering significant value in clinical decisions related to both diagnosis and treatment. The following discussion summarises several of the applications where imaging plays a key role in evaluation and treatment of the musculoskeletal system.

INTERNAL DERANGEMENT

After an injury, there are many anatomical structures that could be abnormal and cause symptoms. Specific types of imaging are used for evaluation of those structures. Radiographs are typically obtained first, given the accessibility and low cost, with the primary indication to evaluate the osseous structures. Important pathologies can be identified that are often not revealed by physical examination alone, such as fracture and subluxation or dislocation. Subtle fractures are best revealed with CT, where high-resolution images can be reformatted into any imaging plane.

MRI has made an important impact in evaluation of internal derangement regarding the cartilage, ligaments, and tendons and is now routinely considered in such cases[1]. When evaluating the knee, for example, MRI shows abnormalities of the menisci in exquisite detail, especially using high field strength magnets. The cruciate and collateral ligaments are also well visualised. Cartilage abnormalities can be assessed, providing important information to guide decisions regarding cartilage repair procedures.

As an adjunct to routine MRI, the injection of dilute gadolinium contrast into a joint prior to MRI further reveals anatomy and pathology related to internal derangement (Figure 1). Imaging guidance is used with fluoroscopy or ultrasound to ensure the injection is accurately placed within the joint. Termed MR arthrography, the resulting images show subtle cartilage and tendon abnormalities that may not be visible with routine MRI. Examples where MR arthrography is commonly used include the shoulder, elbow, wrist and hip, although other joints may also be included.

Another imaging method used to assess the musculoskeletal system is ultrasound[2]. As a general rule, ultrasound has the highest accuracy and value when assessing a superficial structure. One example is evaluation of the rotator cuff, where accuracy is equal to MRI (Figure 2). Beyond the shoulder, ultrasound can be an effective imaging method for evaluating tendons, ligaments and nerves of the elbow, wrist, hand, ankle and foot. Additionally, ultrasound can help to identify fluid accumulation in and outside of joints. While ultrasound does provide some information when evaluating the hip and the knee, MRI is often required due to the depth of the structures being evaluated, and also to assess bone marrow changes. One significant benefit of ultrasound as a complement to MRI is that it can be used to assess joints during muscle contraction or joint movement[3]. Examples of important pathology revealed with dynamic ultrasound include tendon or peripheral nerve subluxation.

Technological advances in assessment of the musculoskeletal system related to MRI include specific cartilage and tendon sequences[4]. For example, functional MRI has been introduced, as well as MR sequences that can show early cartilage and tendon degeneration, providing information that can potentially affect patient management. Additionally, advances in ultrasound, such as shear wave sonoelastography, can show early tendon degeneration.

FIGURE 1

MR arthrogram of the shoulder shows a displaced labral tear and posterior glenoid rim fracture (arrow).

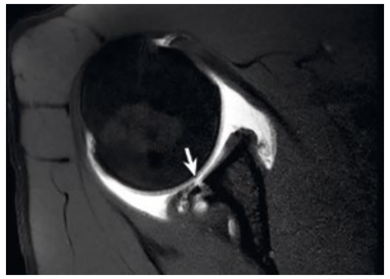
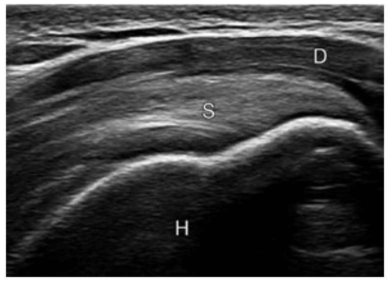


FIGURE 2

Ultrasound of the shoulder shows normal supraspinatus tendon (T), deltoid muscle (D), and humerus (H).



ULTRASOUND VERSUS MRI

Much attention has been focused on the use of musculoskeletal ultrasound relative to MRI. Advantages and disadvantages do exist when using ultrasound. For example, advantages of ultrasound include portability, low cost, no contraindications, dynamic evaluation, direct patient feedback, and the ability to efficiently compare to the contralateral side. Disadvantages include operator dependence, examination time, and limited evaluation of deep structures. Nonetheless, ultrasound can play a significant role, complementing MRI in the evaluation of the musculoskeletal system. It has also been shown in the United States that substituting ultrasound for MRI in specific musculoskeletal applications can significantly reduce medical expenses. In addition, the portability and relatively low cost of ultrasound creates novel situations for its use, bringing ultrasound to rural or less economically advantaged regions of the world.

ULTRASOUND-GUIDED PROCEDURES

While imaging is important in the diagnosis of musculoskeletal pathology, it also plays an important role in percutaneous procedures, which are often the next step in patient care. Such procedures may be diagnostic or therapeutic, identifying the source of the symptom or treating the symptom, respectively. Regardless of the indication, accuracy in needle placement for the procedure is essential[5]. While fluoroscopy can be used for joint injections, ultrasound is commonly used to guide percutaneous procedures of the musculoskeletal system. In addition to guiding joint injections, ultrasound can be used to ensure accurate placement of a needle into or adjacent to soft tissue structures, such as tendons, ligaments, bursae, and peripheral nerves. Using ultrasound, a needle can be guided to its target in real time with continual needle visualisation while avoiding important structures to minimise complications.

One of the most common percutaneous musculoskeletal procedures is a joint, bursal, or tendon sheath injection of an anaesthetic agent or corticosteroid. Ultrasound guidance has been shown to be more accurate and also more efficacious when performing such injections, compared to injections performed without imaging guidance. Ultrasound may also be used to guide injection of contrast into a joint prior to CT or MRI. Other common musculoskeletal procedures using ultrasound guidance include calcific tendinitis lavage and aspiration (Figure 3), joint or bursal aspiration, and peripheral nerve block.

A number of novel procedures have been introduced to treat musculoskeletal pathologies where ultrasound guidance is used to ensure accuracy. For example, treatments for tendinosis or tendon tears may include tenotomy (or fenestration), prolotherapy, whole blood injection, platelet-rich plasma cell injection, and stem cell injection. Other ultrasound-guided musculoskeletal procedures include percutaneous hydrodissection or microwave ablation of peripheral nerves and percutaneous carpal tunnel release. Such novel procedures will require additional assessment to ultimately determine their clinical efficacy compared to other treatments.

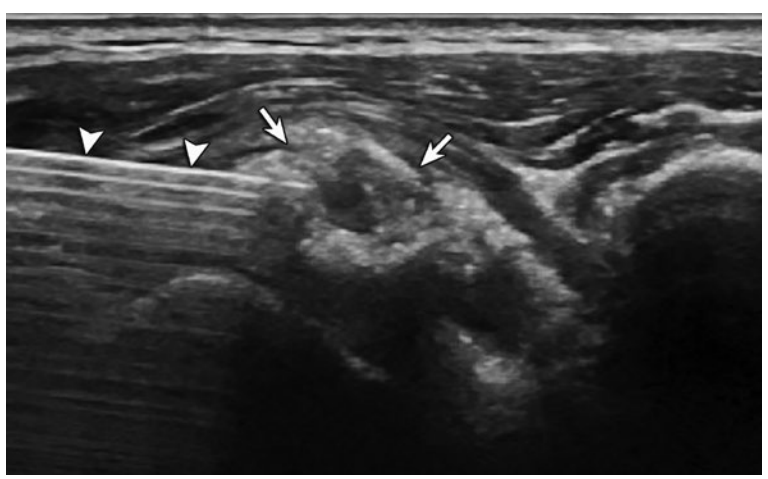


FIGURE 3

Ultrasound of the shoulder shows echogenic needle (arrowheads) entering into calcific tendinitis (arrows) for lavage and aspiration.

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18

RADIATION PROTECTION & SAFETY

MORE CHANCES AND LESS RISK:

Radiation protection and other safety considerations

By **Franz Kainberger** and **Luca Sconfienza,**
in cooperation with **EuroSafe Imaging**

With the European Union Basic Safety Standards (BSS) Directive and other safety regulations (World Health Organization patient safety and empowerment guidelines), summarised in the European Society of Radiology's EuroSafe Imaging Call for Action 2018, *the indications for musculoskeletal imaging in sports, trauma, arthritis, and tumours need an update.*

The rule of thumb that has been used so far to choose the most appropriate imaging modality (first radiography, ultrasound and/or DXA, followed by CT and/or MRI and then, if necessary, nuclear medicine studies and everything else) should be further elaborated.

Panoramic radiographic imaging, such as spine or lower limb teleradiography, can be replaced by more advanced systems administering from one-fifth to one-twentieth the radiation dose of conventional systems. Low dose and even ultra-low dose CT can be performed today. Bearing in mind the technical advances in this field, such as dedicated filters, sensitive detectors and advanced dose management, the indications for CT can be expected to be enhanced. When comparing radiography of the hands with four views to an ultra-low dose CT of the same region, the latter has a comparable or even lower effective dose and with post-processing, 'conventional x-rays' may be reconstructed from the CT data set. Furthermore, new photon-counting CT systems support additional reduction of radiation dose, while improving spatial resolution.

According to the BSS, non-medical exposures have to be included as part of the justification process and should be carried out in accordance with appropriateness criteria and many of these cases are part of musculoskeletal imaging: sports and occupational medicine, age-determination of adolescents, and immigration health checks are all likely to be encountered in MSK radiology.

So-called alternative modalities should be used instead of those with ionising radiation whenever possible, according to the rules of radiation protection. By following this principle, with high-resolution ultrasound with transducer frequencies of 24 MHz and beyond, radiography may be replaced for diagnosing superficial abnormalities of joints and surface abnormalities of the bones. According to the current recommendations for the first line diagnosis of rheumatoid arthritis, ultrasound has become a definite part of the process, together with radiography. However, despite the increasing value of ultrasound for imaging of the joints and the superficial soft tissue, radiography still has a place in the diagnostic work-up because of its high sensitivity in the detection of calcifications in cases of calcifying tendinitis or pyrophosphate arthropathy. For imaging the spine and the sacroiliac joints to diagnose spondylarthritis, MRI has a diagnostic impact similar to HLA-B27 and should be performed prior to radiography. MRI, with the upcoming technique of zero echo-time imaging, has the potential to generate CT-like images at a quality which may allow the diagnosis of fractures and other osseous abnormalities in the future.

Preventive musculoskeletal imaging is gaining increasing importance. The great majority of overuse and injury of the joints, soft tissues and bones may be avoided or reduced in severity if prognosed on the basis of anatomic variations or other morphology with a higher risk, or if detected at an early stage. An upcoming issue is that with CT, quantification of bone mineral density and architecture, vessel calcification and fat, or other parameters of body composition, to some degree have a prognostic impact on the patient's quality of life and life expectancy. This aspect should be considered when defining the appropriateness criteria with regard to radiation protection.

With the increasing number of CT investigations, the number of follow-up CT studies may become an issue, especially in trauma surgery and in paediatric imaging, for which dedicated scenarios of appropriateness should be designed. In order to avoid too much exposure from repeat CT examinations, the International Atomic Energy Agency (IAEA) has recently recommended that the cumulative entry dose should not exceed 100 mSv.

Another aspect is that in many guidelines the number of recommended radiographic views is being reduced further and further. For the spine, oblique views for diagnosing the 'scotty dog' as an indicator of spondylolysis and for quantifying the degree of foraminal stenosis, should no longer be performed. The same is true for the routine use of the transoral view of the dens axis and for the adjusted view of the lumbosacral junction. Flexion and extension views of the lumbar spine are not needed by spine surgeons and should only be exposed if there is a special reason for therapy planning. In fact, the lateral and oblique views of the lumbar spine are currently those with the highest dose area product of all non-fluoroscopic exposures in radiography.

The standardisation of both the appropriateness criteria and the investigation technique is important in terms of the indication-driven investigation, which is a significant topic of the *EuroSafe Imaging Call for Action 2018*.

An important issue is that new research results should be implemented with a special focus on radiation protection and the circumstances under which such exposures should be performed must be defined. For musculoskeletal imaging, such new developments are artefact reduction, new dual-energy applications, digital volume tomography, and 3D printing, with most of these techniques having high potential to increase radiation exposure to the patient.

Another safety issue which must be faced is the potential retention of Gadolinium-based contrast agents in patients' tissues after repetitive intravenous administration. Gadolinium has been routinely used as an MRI contrast agent for several years, with safety issues limited to patients with impaired renal function. At present, the potential accumulation of this material in the brain – with unknown clinical implications so far – postulates the need for a new approach. Patients who were previously administered multiple Gadolinium doses (e.g., diagnosis and follow-up of rheumatologic conditions or musculoskeletal tumours) should now be examined differently: new MRI techniques that do not need contrast administration, or spectral CT, may play crucial roles in these fields.

In summary, the next few years will see the need for a refinement of musculoskeletal imaging indications to achieve increased safety for patients and the general population.

ABOUT EUROSAFE IMAGING

EuroSafe Imaging is the European Society of Radiology's flagship campaign to promote quality and safety in medical imaging. The mission of EuroSafe Imaging is to support and strengthen medical radiation protection across Europe following a holistic, inclusive approach. Radiation protection focuses on three cornerstones, namely justification of any medical exposure, optimisation of the imaging task to keep the exposure as low as reasonably achievable, as well as dose limits. EuroSafe Imaging has launched its Call for Action 2018 to guide all activities, which build upon these principles. The ESR's EuroSafe Imaging campaign is pleased to present this article focusing on radiation protection in musculoskeletal imaging.

ESR EUROSAFE IMAGING

19

INFORMATICS AND AI

IMAGING INFORMATICS:

Artificial intelligence, structured reporting and beyond

By **Patrick Omoumi** and **Mansoor Fatehi**

In the near future, the perception of artificial intelligence (AI) by the community of radiologists will probably have moved from the current fear and rejection to slow acceptance and adoption.

This transition will happen naturally, as AI tools become more readily available and integrated into the radiologist's workflow, thereby alleviating some of the most cumbersome aspects of our job, while increasing our efficiency and impact. AI will most likely change many aspects of our jobs, far beyond the mere act of image interpretation or reporting.

STRUCTURED REPORTING

One of the areas where this change is most likely to happen first is that of structured reporting, which consists of predefined segments and elements that might be enriched by tagged or annotated images relating to the report content.

Why structured reporting?

The advantages of structured reporting have been emphasised for a long time, but their spread in clinical routine has been slow. The wide availability of picture archiving and communications systems (PACS) and radiological information systems (RIS), as well as voice recognition systems, has allowed easier implementation of structured reports in clinical routine. As a consequence, national and international societies such as the ESR and the RSNA have been actively endorsing and promoting their use[1, 2]. Structured reporting presents numerous advantages. The use of standardised reporting structures and vocabulary ensures more complete and reliable communication of results to the referrers, as well as increased homogeneity and comparability of reports across radiologists. Furthermore, the use of structured reports can promote adherence to patient management guidelines by the integration of decision support systems[3]. One of the main advantages of the use of structured reports further resides in the ability to perform data mining and analytics, whether for educational, quality management, or research purposes. The use of common data elements (CDEs), or standardised units of information, would be greatly beneficial in this regard[4]. CDEs will help radiologists describe abnormalities in a standardised way that goes beyond the mere use of templates.

Nevertheless, despite research data supporting its advantages, and the availability of template libraries, structured reporting has yet to be widely adopted by practicing radiologists. Some of the obstacles hindering its spread are reported in Table 1.

AI and structured reporting

The implementation of structured reports will certainly benefit from the data mining capabilities of AI, allowing automatisation of image quantitative analysis and integration of these measures into the report. Based on this information, classification models can then automatically suggest the most likely diagnoses.

On the other hand, AI can enhance structured reporting practice, by tailoring the template according to patients' problems and by inserting information extracted from the images into the report[5] (Figure 1). Finally, implementation of structured reporting in routine practice paves the road for bringing imaging-related research to a whole new level, by providing layered 'labelling' of cases and findings on the go.

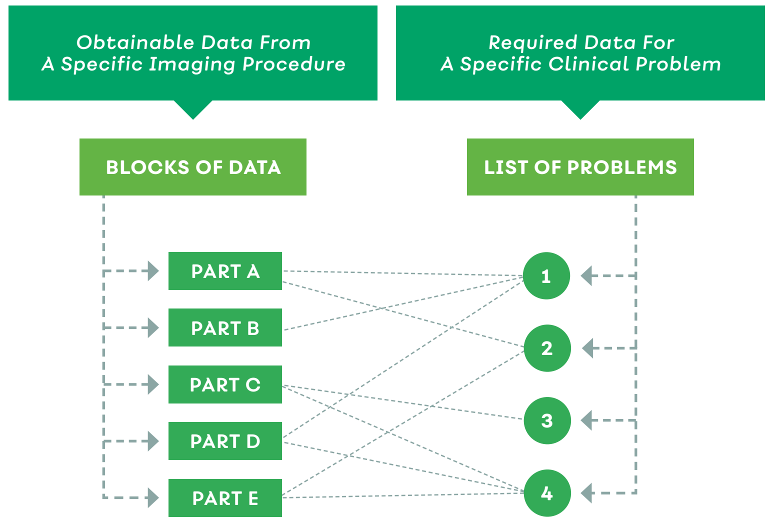
TABLE 1

Structured reporting: advantages & disadvantages

ADVANTAGES	DISADVANTAGES
COMPREHENSIVENESS	TIME CONSUMING DATA ENTRY
DECISION SUPPORT INTEGRATION	LESS FLEXIBILITY
RESEARCH POTENTIAL	LACK OF CONSENSUS ON STANDARD LANGUAGE/LEXICON
LANGUAGE INDEPENDENCE	RESISTANCE TO CHANGE IN RADIOLOGISTS
DICOM SR	UNFAMILIAR TO REFERRING PHYSICIANS
	MUST BE INTEGRATED INTO THE PACS/RIS

FIGURE 1

Problem specific structure reporting dynamic template composition[7]
In order to avoid unnecessary lengthy structured reporting templates and reports, components of the template can be mapped to the clinical conditions and the templates can be composed dynamically, keeping only required and demanded sub-segments of the original comprehensive template. This is an area where AI can improve structured reporting.



AI INTEGRATED INTO THE RADIOLOGIST'S WORKFLOW

AI applications will certainly not be limited to the reporting of imaging examinations. In fact, every step of the radiologist's workflow will be affected, from the management of the radiological request, analysis of the clinical situation from the medical record data, the protocoling and production of images, and their interpretation, to the communication of results to the referring clinician. For each of these steps, different AI techniques can be used. Natural language processing algorithms will help automatise the analysis of the radiological request or the patient's digital medical records, including previous imaging reports, thereby providing prioritisation of the exams based on appropriateness criteria, automatisation of the protocoling, and optimisation of the interpretation of images, based on relevant clinical information.

Generative models will lead to improved image quality, with reduced radiation dose or acquisition time. Segmentation algorithms will automatically provide quantitative data, and regression models will provide automatic grading and classification of images, all of which will be integrated into the structured report.

Finally, the use of neural networks applied to imaging will open new doors for diagnosing and predicting the prognoses of our patients. Data mining and radiomics, by scrutinising large amounts of imaging data, have the potential to extract information that is currently inaccessible to the human eye. Many applications in this field already exist, especially in the field of oncology.

CHALLENGES AHEAD

While the potential applications of AI in radiology are ever-increasing, their implementation in clinical routine does not go without challenges and limitations.

The first challenge relates to the data required to develop, validate and test AI algorithms. Large volumes of good quality curated data are required, which are both difficult and costly to obtain. Major ethical issues related to the interinstitutional exchange of patient data, which is necessary to develop and validate AI algorithms, will have to be considered.

The second challenge relates to medicolegal responsibility, which in the foreseeable future should remain with the radiologist. Our community should be at the forefront of the development of the regulations that are necessary for the proper use of this technology. Regulatory issues related to reimbursements for AI applications will also have to be addressed.

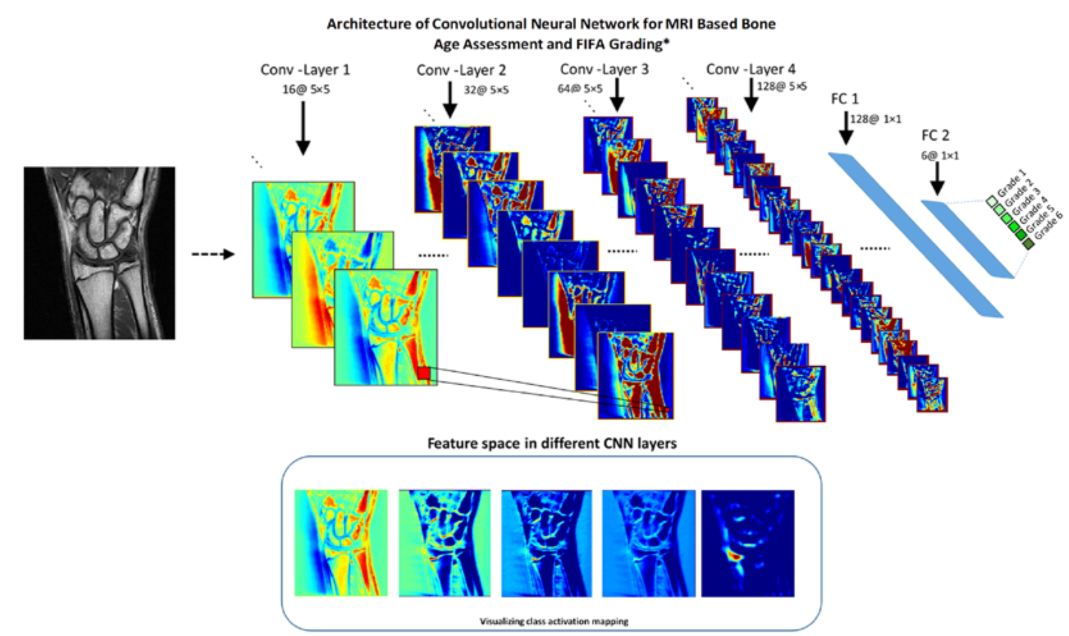
AI applications, which are currently designed to perform only one specific task, need to be integrated seamlessly into the clinical workflow. This requires proper interfacing of all the AI tools with the PACS or RIS. Finally, radiologists, both practicing and in training, will have to be educated on the proper use of these tools, their limitations, and failure modes[6].

CONCLUSION

Despite difficulties, limitations and challenges ahead, there is room for optimism in thinking that AI will eventually help radiologists not only tackle their routine tasks more efficiently

FIGURE 2

AI algorithm for bone age determination in athletes using MRI images[8]. Diagram illustrates a typical CNN architecture reflecting deep learning layers, with the goal of classifying wrist MRI images in six grades based on changes in epiphyseal growth plate.



• From: Automatic Bone Age Determination Using Wrist MRI Based on FIFA Grading System for Athletes: Deep Learning Approach, M. Fatehi, R. Nateghi, F Pourakpour, ESSR2-19 Annual Meeting, (Unpublished Research) and keep up with their ever-increasing workload, but also that AI will augment the performance of radiologists at many levels, including workflow organisation, image production, image interpretation, and communication with the referrers. Just as has been the case for the long list of technologies adopted by radiologists over the past decades, embracing AI will ensure we remain in the driving seat of imaging diagnostics.

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His research activities include the development and validation of novel techniques for the imaging of joints, and the clinical use of those techniques for the understanding of the pathophysiology of osteoarthritis.

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His research interests include clinical themes, mainly in sports imaging and osteoporosis. His primary focus is on imaging informatics research and exploring the potential design and implementation of structured reporting, particularly in the field of MSK radiology. He has published 37 books, and has given more than 180 invited lectures at international and national events. He is a board member of the European Society of Medical Imaging Informatics (EuSoMII) and a member of the global out-reach committee of the Society of Imaging Informatics in Medicine (SIIM).

20

CLINICAL DECISION SUPPORT

Indications for musculoskeletal imaging: clinical decision support

By **Christoph Schäffeler** and **Franz Kainberger**

Referrals for imaging, a crucial step at the beginning of diagnostics, have been increasingly standardised during the last decade.

The recommendations from the American College of Radiology (ACR) have recently been adopted by the European Society of Radiology (ESR) and contain empirically collected, frequently used clinical scenarios with expert definitions of which modality is most appropriate in each case. As the appropriateness depends not only on the pre-test probability of a test, but also on issues of health economy and the traditions in the medical service of each country, the recommendations must be adopted at both a European level and also a national level.

For musculoskeletal imaging, the peculiar challenge is that the number of entries in the database of appropriateness criteria – currently more than 7,000 – is by far the highest compared to other radiological subspecialties. This is due to the fact that many similar scenarios are repeated for all major joints, that additional techniques like dual-energy x-ray absorptiometry (DXA) are available, that for some disease entities the terminology is under continuous discussion, and that the degree of detailing has been increasing due to the dynamic in research. It can be expected that the number of entries for musculoskeletal referrals will steadily increase in the future.

The European Society of Musculoskeletal Radiology (ESSR), the body responsible for adjusting the appropriateness criteria for imaging in this field at the European level, has begun its input into this project in two ways: beside the experts' knowledge that is being brought into this project, a new concept is being developed for a more homogenous standardisation of the clinical scenarios for referrals. Additional to the referral diagnosis, the modality to be chosen and the clinical background information (underlying diseases, demographic information), the crucial point of this concept is to standardise the attributes of the referral diagnosis, the aspects of patient safety and radiation protection, and patient empowerment. With this more advanced concept of homogenisation of referrals, some important aspects can be covered:

- Radiation protection, as prescribed by the European basic safety standards directive, is included in this concept, including non-medical exposures.
- Communication can be improved by using pre-defined fields with dropdown lists of standardised and precisely predefined terms. For IT-solutions, information can be transferred from the RIS and PACS to the predefined fields of the database for reporting.
- Role definitions for referring physicians, radiologists, radiological technicians, other healthcare providers and, last but not least, patients can be defined for all entry fields of the database.

It is of crucial importance to implement functional processes, which ensure that the databases and clinical decision support systems are up to date, new developments in musculoskeletal research and imaging techniques are reliably adapted and obsolete procedures are identified and deleted.

Regarding the increasing financial pressure on healthcare systems, guidelines for the referral of musculoskeletal radiological examinations may improve the justification of radiological procedures and to lead the way to a fast and appropriate diagnosis for the patient.

Finally, this standardised and harmonised concept of filling out computerised order entries in a practical way will form the basis for the further use of artificial intelligence (AI) schemes.

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21

BIO-MECHANICAL RESEARCH

Biomechanical and biochemical imaging research

By **Alberto Stefano Tagliafico**

The aim of biomechanical imaging research is to improve the understanding of the human body in normal and pathological states (pre-clinical or clinical) in order to develop tools or methods of measurement to predict the risk of injury.

This concept is valid throughout all age groups, from the paediatric ages to the elderly. In addition, risk factors predisposing individuals to injuries are also linked to different medical conditions such as genetic alterations or endocrine disorders.

Medical imaging will be used to better describe biomechanical and biochemical characteristics of the variety of human structures, components and subsystems that can be injured, to foresee the risk of injury before a real injury occurs. Indeed, human tissues are highly dynamic and are able to be remodelled in response to training, underuse or overuse, and finally aging. The possibility to study the biomechanical and biochemical characteristics of human tissues with medical imaging to foresee injuries will be a niche for imaging professionals in the era of personalised medicine. Indeed different needs will have to be taken into account concerning the variability of human beings in terms of age, sex, race, metabolisms and genetic patterns.

In the coming years it will be evident that several options offered by medical imaging that can provide information which would not be directly visible to the human radiologist's eye will employ the use of '-omics', such as radiomics and genomics, and artificial intelligence. An example is represented by the study of the bone where remodelling is the final common pathway expressing all genetic and environmental factors affecting the attainment, maintenance and decay of the bone's material and structural strength[1]. With advanced, non-routine techniques such as high-resolution peripheral CT and scanning electron microscopy, it has been possible to study the human bone in-depth to understand that most of the bone loss in the elderly is cortical, not trabecular, at peripheral sites, and about 50% of cortical bone loss at peripheral sites was the result of remodelling within the cortex adjacent to the marrow1. The intra-cortical remodelling thinned the cortex from within by cavitation, increasing porosity and leaving cortical bone similar to trabeculae, leading to overestimation of trabecular density in old age.

This data has potential clinical relevance because it could underestimate age-related trabecular bone loss and porosity was not captured with bone densitometry or quantitative CT[1]. It has been estimated that, if porosity of the bone is included in risk calculation, the ability of bone to deform without cracking decreases three-fold as porosity increases from 4% to 20%[1]. This is an example of how a static complex study with high-resolution images provides information useful from a biomechanical and biochemical point of view.

However, it is not sufficient to acquire even very complex and advanced medical images to fully understand how the biochemical properties of a tissue combined with the calculated biomechanical properties of a tissue will result in a pathological condition or not. Indeed, to fully appreciate the real influence on the patient of the calculated biomechanical and biochemical characteristic of a human tissue, it is necessary to have an experimental approach using models to measure the forces to which the body is exposed and simulations to assess the human responses to the specific nature and locations of injury[2].

As radiologists, we are entering the era of radiomics, where a lot of information not visible to the human eye will be extracted from the tissue under examination. The amount of extra information acquired with radiomics, called radiomic features, could reveal new prognostic factors providing valuable information for personalised diagnosis, therapy or injury prevention. Today, radiomics is considered one of the most advanced applications within radiology. However, even if the technique will be applied

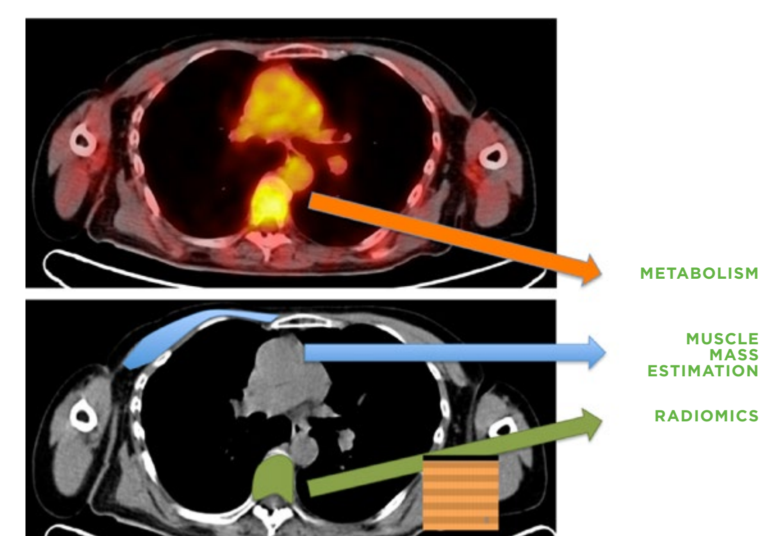

FIGURE 1

Metabolic, anatomical, functional and radiomics data will be integrated into the global patients assessment starting from imaging. Example of the potential to estimate the muscle mass from the muscle area (blue area) is taken from: Rossi F, Valdora F, Barabino E, Calabrese M, Tagliafico AS. Muscle mass estimation on breast magnetic resonance imaging in breast cancer patients: comparison between psoas muscle area on computer tomography and pectoralis muscle area on MRI. Eur Radiol. 2019 Feb;29(2):494-500. doi: 10.1007/s00330-018-5663-0. Epub 2018 Aug 7.

to any medical study where a disease or a condition can be imaged, the 'features' reflecting complex biomechanical and biochemical characteristics of the tissue will require simulation and tests on real patients.

In the near future, it will be necessary to test these hypotheses not in long, expensive and partially biased clinical prospective studies, but on models relying on artificial intelligence technology. In addition, some algorithms, such as deep learning (also known as deep structured learning or hierarchical learning), will be employed to test different hypotheses, considering the static biomechanical and biochemical characteristic of a tissue evaluated with medical imaging and the dynamic actions of the subject studied, considering different variables such as age, level of activity, and medical conditions.

AI algorithms will also be included in models to predict the chances of recovery after an injury and the possibility to resist a strain or a force applied to a certain tissue. Finally, I do not have the crystal ball to foresee the future application of computer sciences on medical imaging, but I suppose that a thorough integration of metabolic, anatomical, functional and radiomics data will find several clinical applications (Figure 1).

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22

ORTHOPAEDIC HARDWARE

IMAGING OF ORTHOPAEDIC HARDWARE: The future is here

By **Reto Sutter**

THE SUCCESS OF ORTHOPAEDIC IMPLANTS

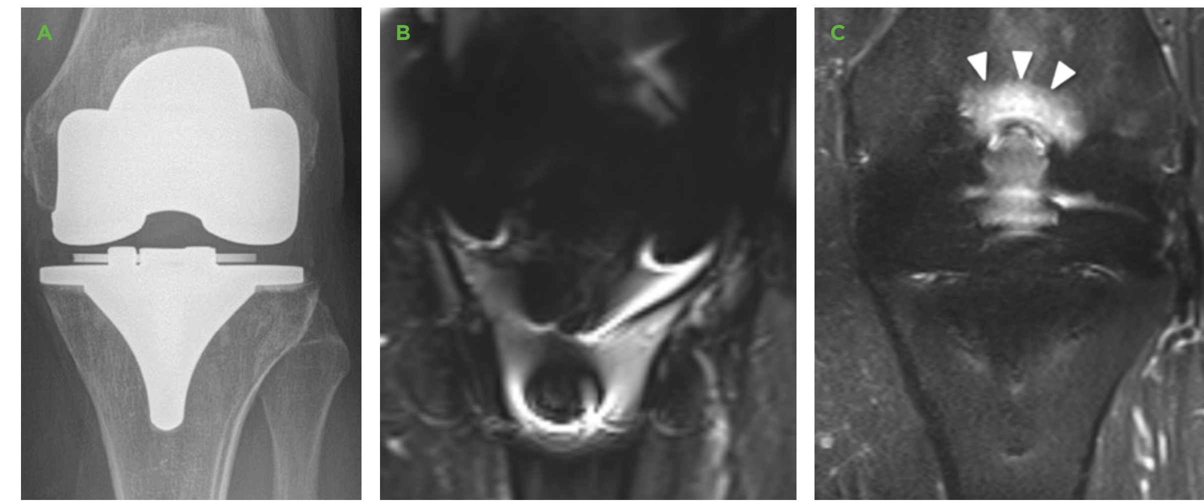
Orthopaedic hardware is an important pillar in the standard treatment for many patients with acute trauma or long-standing degenerative conditions of the musculoskeletal system. Many procedures to implant hardware into the body are a big success: indeed, total hip replacement (THA) has been termed the 'operation of the last century', because of its excellent long-term results and the restoration of the joint function, as well as the patient's quality of life, even in athletic patients with a high mechanical load on the joint[1]. Nevertheless, with the increasing overall number of patients with orthopaedic implants and elderly populations leading much more active lifestyles, the number of patients presenting with suspected complications of orthopaedic hardware is on the rise.

HOW TO IMAGE ORTHOPAEDIC HARDWARE

The last ten years have seen a substantial shift in the imaging of orthopaedic hardware. A decade ago, patients with orthopaedic implants or joint replacements were imaged mostly with conventional radiographs and computed tomography (CT): these modalities were used to assess the position and integrity of the implants, check fracture healing, and look for complications in the surrounding osseous structures. In cases of suspected infection or stress reaction of the bone next to the implant, scintigraphy or single photon emission computed tomography (SPECT) may be used to reach a diagnosis. Ultrasound has been employed to assess the soft tissues around orthopaedic hardware, and in some cases a joint aspiration and subsequent microbiological analysis is necessary to confirm or rule out infection.

FIGURE 1

74-year-old patient with total knee replacement of the left knee and new onset of pain. (A) Conventional anteroposterior radiograph shows no loosening or dislocation of components. (B) Standard coronal STIR sequence is non-diagnostic due to severe metal artefacts. (C) Coronal STIR-SEMAC sequence with eight slice-encoding steps in the same patient shows marked reduction of artefacts, and depicts focal bone marrow oedema (arrowheads) at the intercondylar notch due to mechanical irritation.



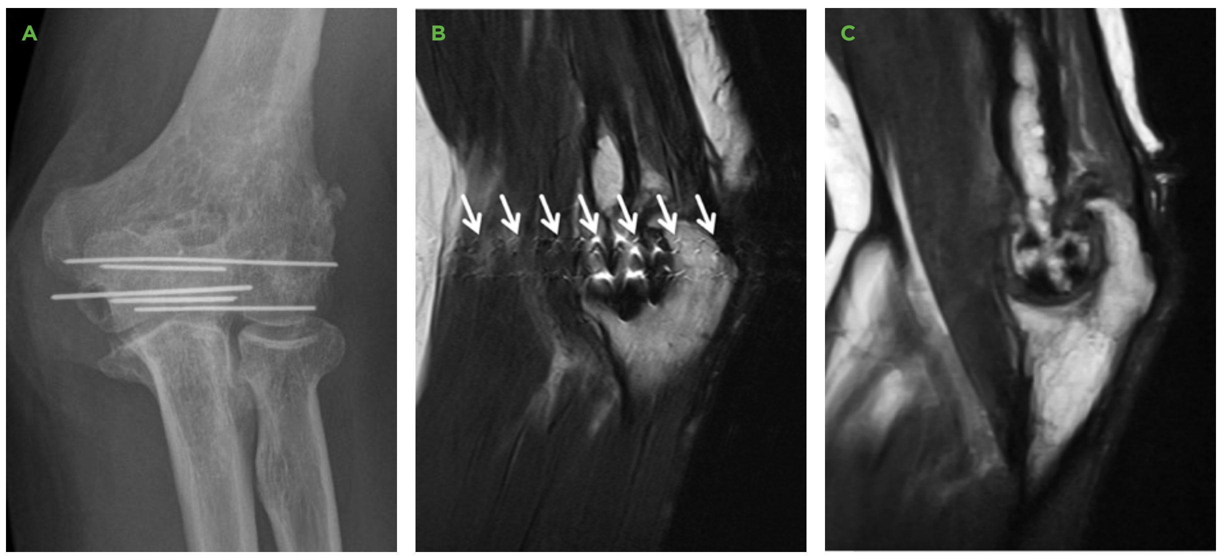
Traditionally, magnetic resonance imaging (MRI) has rarely been used in patients with orthopaedic implants due to the large areas around the implant that are affected by metal artefacts such as severe image distortion, or failure of fat suppression (Figure 1). Significant advances in MRI technology over the past decade have altered this situation: with advanced metal artefact reduction sequences, MRI has become an excellent tool for assessing patients with orthopaedic hardware, with no or only few residual artefacts hampering image quality.

A FEW SIMPLE STEPS

When imaging metal hardware with MRI, a few simple steps go a long way. The first concerns the field strength of the magnet: as the number of artefacts is roughly proportional to the field strength, 1.5T magnets perform much better at metal imaging than 3T magnets. A small field of view, thin image sections, and a small voxel size are also beneficial for reducing artefacts. Turbo-spin-echo (TSE) sequences are much more stable when it comes to metal artefacts than gradient echo or three-dimensional sequences[2]. Further steps for reducing metal artefacts include increasing the receiver bandwidth: this technique may actually be the most potent simple step for everyday use of standard TSE sequences in the presence of metal[3], but it has a limited effect when it comes to achieving a suitable fat suppression. Employing optimised

FIGURE 2

72-year-old male with k-wire fixation of an elbow fracture almost 30 years ago, depicted on an anteroposterior radiographic view of the left elbow (A). K-wires are made of stainless steel, which causes extensive metal artefacts (arrows) and image distortion in a sagittal intermediate-weighted sequence (B) of the elbow, with a resulting image quality that is non-diagnostic for evaluation of the elbow joint. (C) Sagittal intermediate-weighted sequence with compressed-sensing SEMAC in the same patient shows successful correction of metal artefacts and depicts the k-wires in the trochlea of the distal humerus, as well as osteoarthritis of the humeroulnar joint.



inversion pulses for short tau inversion recovery (STIR) sequences or the use of Dixon sequences have helped in both reducing metal artefacts and achieving stable fat suppression of the image in the presence of metal implants[4, 5].

ADVANCED MRI OF METAL IMPLANTS

The largest technological leap in MRI of metal implants was achieved with through-plane distortion correction, as implemented in techniques such as slice encoding for metal artefact correction (SEMAC), or multiacquisition variable-resonance image combination (MAVRIC). These sequences allow correction not only of distortions within a given image section, but also distortions from adjacent image sections, and enable diagnostic image quality in the majority of patients with joint replacements (Figure 2)[6,7]. When these techniques were introduced, the main drawback was a long acquisition time of 7–11 minutes, which may result in substantial motion artefacts depending on the physical condition and compliance of the patient. Nevertheless, techniques with through-plane distortion correction have been implemented into clinical sequences by several manufacturers.

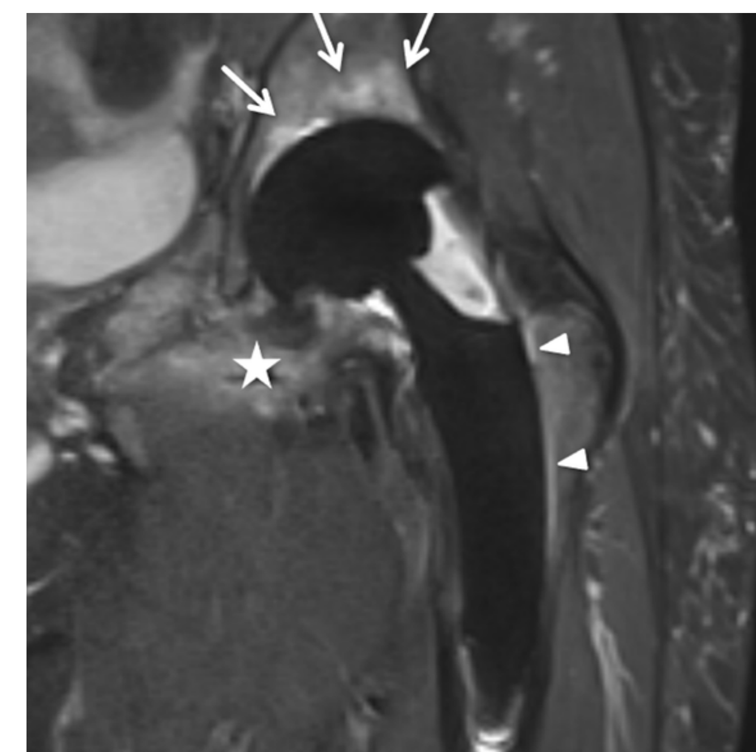
In order to solve the problem with long acquisition times, compressed sensing (CS) can be employed with great success: for SEMAC this allows both a decrease of acquisition times to 5–6 minutes, as well as an increase of slice-encoding steps, making the metal artefact reduction even stronger than before[8, 9]. With sequences that are both fast and deliver stable metal artefact reduction even for fat-suppressed sequences, the use of advanced MRI will become much more widespread in the next five to ten years (Figure 3).

HIGH CLINICAL IMPACT

Advanced MRI of metal implants has a high clinical impact: it allows assessment of the bone and the implant itself, as well as the surrounding soft tissues. Indeed, the most common complications in patients with residual pain after joint replacement are related to the soft tissues next to the replaced joint. While conventional radiographs are still the basis for follow-up of patients with joint replacements, the unique ability of MRI with metal artefact reduction to depict all affected tissues in a single examination is making it the preferred candidate for second-line examinations in patients with suspected complications of joint replacements. This is especially true for fat-suppressed sequences with through-plane distortion correction, as these sequences allow common complications of joint replacement procedures to be readily identified. With a good soft tissue contrast, advanced MRI is also beneficial

FIGURE 3

Total left hip replacement in a 52-year-old female patient after dislocation of the hip replacement and closed reduction. Coronal STIR SEMAC sequence with 19 slice-encoding steps shows extensive bone marrow oedema (arrows) adjacent to the acetabular cup, as well as a thin zone of loosening of the femoral shaft (arrowheads). Muscle contusion of the adductor muscles was seen, (asterisk), but there was no damage to the abductor tendon insertion. Note that the image is almost free of metal artefacts in this advanced MRI sequence.



for the planning of revision surgeries, for example in patients with metallosis due to metal-on-metal hip replacements, and for assessing the extent of soft tissue infection in patients with septic arthritis[10].

CONCLUSION

Does every patient with a painful implant need MRI with advanced metal artefact reduction? Surely not. Conventional radiographs are still the first step in imaging of orthopaedic hardware. But if a diagnosis cannot be made based on radiographs, advanced imaging modalities such as CT or MRI come into play. MRI has a lot to offer in these patients: if done correctly, MRI allows assessment of both the bone and the adjacent soft tissues, which are the two main locations where complications occur in patients with orthopaedic hardware.

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23

BONE BEYOND LOCO-MOTION

BONE BEYOND ITS SIGNIFICANCE IN LOCOMOTION:

Ageing and general health

By **Alberto Bazzocchi** and **Maria Pilar Aparisi Gómez**

We have only recently started to understand the extent of the role of bone in metabolism, ageing and health in general.

The gathering of new evidence proves that besides being a very metabolically active tissue, bone is also an active communicator with other organ systems, functioning in a comparable way to the endocrine system.

A close functional bond exists between bone and muscle. Mechanically, the skeleton provides support for the body and anchorage for muscles. The concept of the bone-muscle unit defines their robust relationship, which serves a common function: movement.

But beyond this, their development and maintenance are mutually modulated and influenced by age.

The peak in bone and muscle mass is reached in the early adult years, with a progressive decline starting with the fifth decade. In the sixth decade, the decline of muscle mass occurs at a yearly rate of 1%, with associated modification of muscle and cell populations[1].

New concepts are arising related to the bone-muscle interaction. Muscle is now known to act as a secretory organ, with a regulatory function on metabolism. Bone (osteocytes) can act as an endocrine organ, establishing feedback with organs like the kidney, but also with muscle. The communication between bone and muscle happens through muscle-secreted (myostatin, irisin, ß-aminoisobutiric acid) and bone-secreted factors (osteocalcin, transforming growth factor ß and Prostaglandin E2)[2]. The secretion of many of these factors is regulated by load, which means that exercise could be contributory to healthy ageing in roles that we have not yet explored[3].

Sarcopenia and osteoporosis are often simultaneous and part of the changes in body composition (BC) occurring with ageing. It is unclear whether they are linked and if there is a sequential order. From a mechanical explanatory approach, the loss of muscle could trigger the development of osteoporosis, but osteoporosis exists without sarcopenia, and sarcopenia does not necessarily result in osteoporosis.

Bone mineral density (BMD) and lean mass (LM) decrease with ageing, and there is a progressive increase and redistribution (central and visceral) in fat mass (FM) (Figure 1).

FIGURE 1

DXA whole-body scan for body composition assessment in an athlete.

The commonly used definition of frailty includes three of the following: muscle strength loss, slowness, fatigue, low physical activity and loss of body weight. Frailty results in increased risk of falls, proximal femur fracture, disability and mortality. Evidence suggesting that body weight is positively associated with bone health in older adults is increasing and there is also evidence that lean and fat masses might have different interactions with bone mass[4].

BONE MARROW: THE NEXT STEP IS IN WHAT LIES WITHIN

The ageing process in bone involves the accumulation of adipose cells within the bone marrow. The marrow adipose tissue (MAT) has been investigated in recent years, as the main component of the stroma of the bone marrow organ. There is evidence this stroma is indirectly involved in haematopoiesis, providing a microenvironment that facilitates haematopoiesis; for instance, in the production of growth stimulating factors.

An increasing amount of evidence suggests that there is an inverse association between bone marrow fat fraction, BMD and bone integrity[5].

Through the decrease in BMD, the increase in bone marrow fat results in osteoporosis and fragility[6]. Recent studies have also demonstrated that vertebral bone marrow fat positively correlates with parameters such as visceral adipose tissue (VAT), organ fat (liver fat, intramyocellular fat), insulin-like growth factor 1 (IGF-1) and serum triglyceride levels, all of which are known cardiovascular risk factors[7].

The quantification of MAT provides information on the ageing status of bone, but also on conditions like obesity and diabetes.

MR spectroscopy is currently the gold standard for bone marrow fat quantification (fat fractions and fatty acid composition parameters), however there is no standardisation of equations and measurement sites (the amount of fat is location-dependent), making comparison between studies difficult. Other MR imaging tools allow quantitative evaluation but without the precision of spectroscopy, such as the calculation of fat fraction based on the chemical shift on water-fat imaging, for example. T1-weighted imaging can also be used semiquantitatively[8] (Figure 2).

Bone marrow fat has not been demonstrated to be significantly higher in type 1 diabetes.

In type 2 diabetes, a slight increase in bone marrow fat has been proven, with the particularity that the level of unsaturated fat is significantly reduced. Low unsaturation has been seen to be associated with low BMD and fragility fractures, which suggests that a diet intervention, with higher unsaturated fatty acid intake, could reduce fracture risk[6].

Vertebral bone marrow fat has been demonstrated to positively correlate with HbA1c levels, so it could serve as a potential biomarker for glycaemic control, and a predictor of late diabetic complications[9].

NEW HORIZONS FOR THE RADIOLOGICAL ASSESSMENT OF BONE

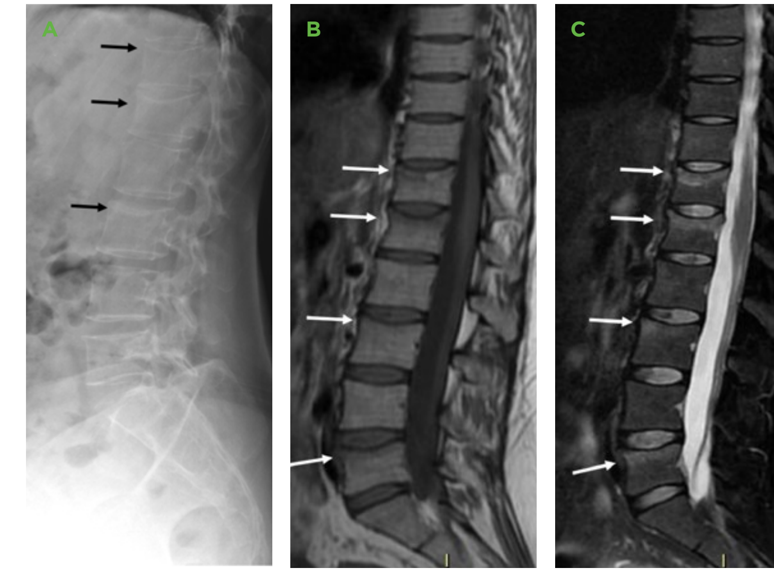
Imaging has become pivotal in the assessment of body composition, with multiple studies proving the excellent correlation of some imaging parameters with laboratory biomarkers.

The most widely used technique to assess BMD in clinical practice, and the method of choice for therapeutic decisions, is dual energy x-ray absorptiometry (DXA).

FIGURE 2

Sagittal T1-weighted spin echo in a (A) 32-year-old female and (B) 84-year-old female. Note the difference in signal intensity of the bone marrow in the vertebral bodies. In the younger patient, the bone marrow signal (solid arrow) is almost the signal of skeletal muscle (arrow silhouette). In the older patient, the bone marrow signal (solid arrowhead) is similar to that of the subcutaneous tissue fat (arrowhead silhouette). T1-weighted sequences allow for a semiquantitative assessment of fat marrow contents.

FIGURE 3



Severe back pain in a 32-year-old female, who had given birth three weeks before. (A) Lateral radiograph demonstrates fracture of the T12, L1 and L3 superior vertebral endplates (black arrows). (B) Sagittal T1-weighted spin echo and (C) sagittal T2-weighted fat sat reveal there is also a fracture of the superior endplate at L5 (white arrows indicate fractures). Pregnancy related osteoporosis is a rare condition, which has been hypothesised to be due to scavenging of maternal calcium in the third trimester (foetal growth, and then lactation) and hypoestrogenism from amenorrhoea, but also related to musculoskeletal laxity and biomechanical alterations in the locomotive system in the context of hormonal changes. The condition is treated with calcium, vitamin D, weaning and eventually teriparatide. Biphosphonates should be avoided as they accumulate and may pass to the foetus through the placenta in the case of a subsequent pregnancy.

Quantitative ultrasound parameters of trabecular transmission in the heel (speed of sound, broadband ultrasound attenuation) correlate well with DXA, and its use to predict fragility fractures has been validated.

Quantitative computed tomography allows the assessment of cortical and trabecular bone separately, with superb sensitivity for detecting osteoporosis. Using conversion factors, reliable measurements can be obtained from the spine and hip from routine abdominopelvic post-contrast multidetector CT scans[10]. This provides opportunistic data on the state of bone; something that can change the future of the radiological assessment of bone. Extra information can be supplied to clinicians to help with risk stratification. Besides, with the application of artificial intelligence (AI), it is possible that, in the future, adiposity and sarcopenia scores will be automatically included in our reports.

High resolution CT and MR are excellent tools for research, from which mechanical and architectural parameters can be obtained to study bone involvement in ageing and other processes. CT and MRI remain pivotal for opportunistic and specific diagnosis of fragility fractures (Figure 3).

The implementation of radiological techniques and the advances in AI will open up new horizons in the assessment of bone and facilitate the understanding of normal and pathological processes related to bone metabolism.

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24

BONE TUMOURS

Bone tumours

By **Iris-Melanie Nöbauer-Huhmann, Gerhard M. Hobusch** and **Reinhard Windhager**

During the past five decades, tremendous progress has been achieved in the diagnosis and treatment of primary malignant bone tumours and metastases.

This chapter aims to present an outline of recent advances in bone tumour imaging and to mention some possible future developments, with a few references that provide a more comprehensive overview of each field.

RECOMMENDATIONS AND STANDARDISED ALGORITHMS FOR BONE TUMOUR IMAGING

Primary bone tumours are rare, and appropriate imaging at the time of the primary diagnosis is essential for an early correct diagnosis, which in turn influences the prognostic outcome. Standardised imaging algorithm recommendations have been developed. Among them, the European Society of Musculoskeletal Radiology (ESSR) approved consensus guidelines also include local image assessment criteria and aspects of distant staging. Moreover, they detail which patients should be referred early to MSK tumour competence centres[1].

Radiological or interdisciplinary national societies, such as the AMSOS in Austria, offer advice for radiologists and clinicians in difficult cases[2].

TECHNICAL ADVANCES IN MR, CT AND PET FOR BONE TUMOUR IMAGING

To date, high-field MR scanners of 1.5 Tesla or higher, with dedicated multi-channel coils and rapid sequences, provide excellent image quality, even for extensive bone tumours. For approximately a decade, MR imaging sequences, such as dynamic contrast enhancement assessment (DCE) or diffusion-weighted imaging (DWI), have been increasingly implemented. These sequences add information about the tumour biology, and can be used to target biopsies or to monitor therapy response (Figures 1A–1H)[3, 4]. For the latter issue, calculation of quantitative parameters such as the percent slope analysis for DCE, or ADC ratio for DWI have proved useful. In the future, coverage of very large tumours, with even better spatial and temporal resolution, can be expected.

High-resolution isotropic 3D sequences have been developed, which allow for reconstructions in arbitrary planes and which are especially useful for the assessment of oblique interfaces and structures such as nerves.

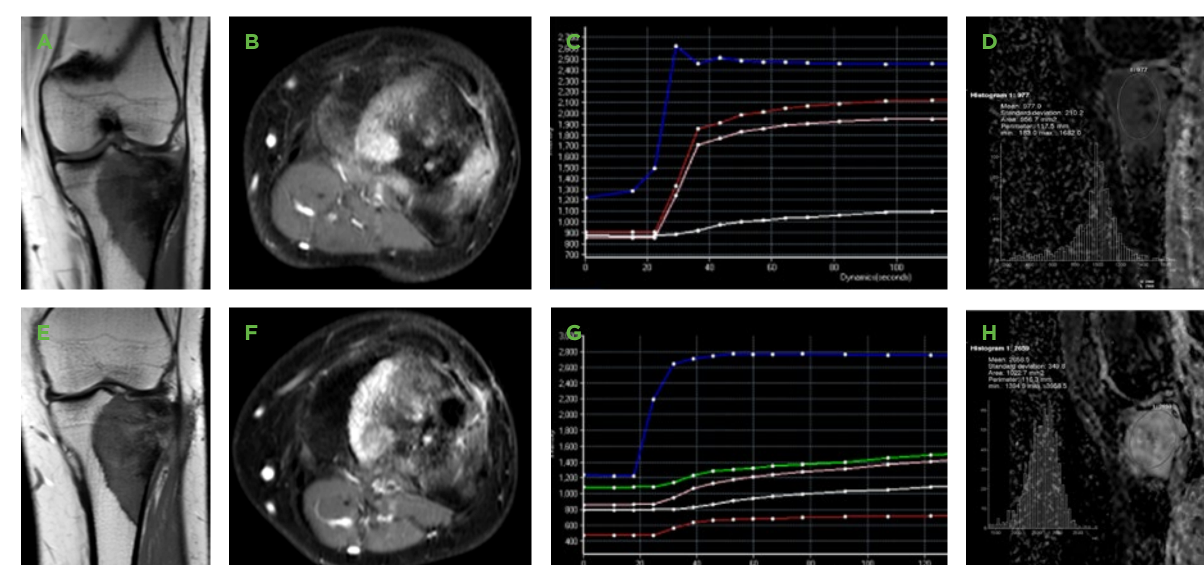
Modern Dixon-type sequences offer four contrasts in a single acquisition, with robust fat saturation. In bone tumour imaging, Dixon sequences have the advantage of being sensitive enough to show marrow replacement by osseous lesions[5].

A major issue in post-operative follow-up has been imaging around metals, such as endoprostheses.

In MRI, dedicated sequences have been developed to reduce metal artefacts[6]. The metal artefact reduction sequence (MARS) uses high bandwidth, thin section selection, an increased echo train length, decreased echo spacing, and an increased matrix (Figures 2A, 2B). WARP further decreases in-plane distortion by adding multidirectional view angle tilting (Figure 2C). For through-plane distortion reduction, sequences like MAVRIC (multi-acquisition with variable resonance image combination) or SEMAC (slice encoding for metal artefact correction) have been introduced (Figure 2D). Current drawbacks are the

FIGURE 1

A 15-year-old female patient with osteosarcoma. MR images before (A–D) and after (E–H) neoadjuvant chemotherapy. T1w (A, E), T1w FS axial post Gadolinium (B, F). DCE signal intensity time curves of the tumour (with arterial and muscular reference curves) (C, G) and ADC with ROI analysis (D, H), demonstrating response to treatment.



high SAR and increased imaging time. The latter is addressed by the use of compressed sensing. It is very likely that next-generation sequences will further deal with these issues.

Two important CT techniques to overcome metal-related artefacts are projection-based metal artefact reduction (MAR) algorithms, which mainly address photon starvation, and dual-energy techniques, where virtual monochromatic images at high energy levels can reduce beam-hardening artefacts[7] (Figure 2E). Nevertheless, several newly created artefacts will have to be overcome in the future.

FIGURE 2

Imaging around metals. Postoperative MRI of the spine with metal artefacts post fusion on T2w TSE sequences at 1.5T (A–D); without metal artefact reduction (A) and with MARS (B), WARP (C) and SEMAC (D). Metal artefact reduction with dual source CT and reconstruction in the coronal (E) and axial (F) plane, in a patient post amputation and in preparation with osseointegrative device for exoprosthesis. PET/CT with recurrent osteosarcoma adjacent to a megaprosthesis (G).

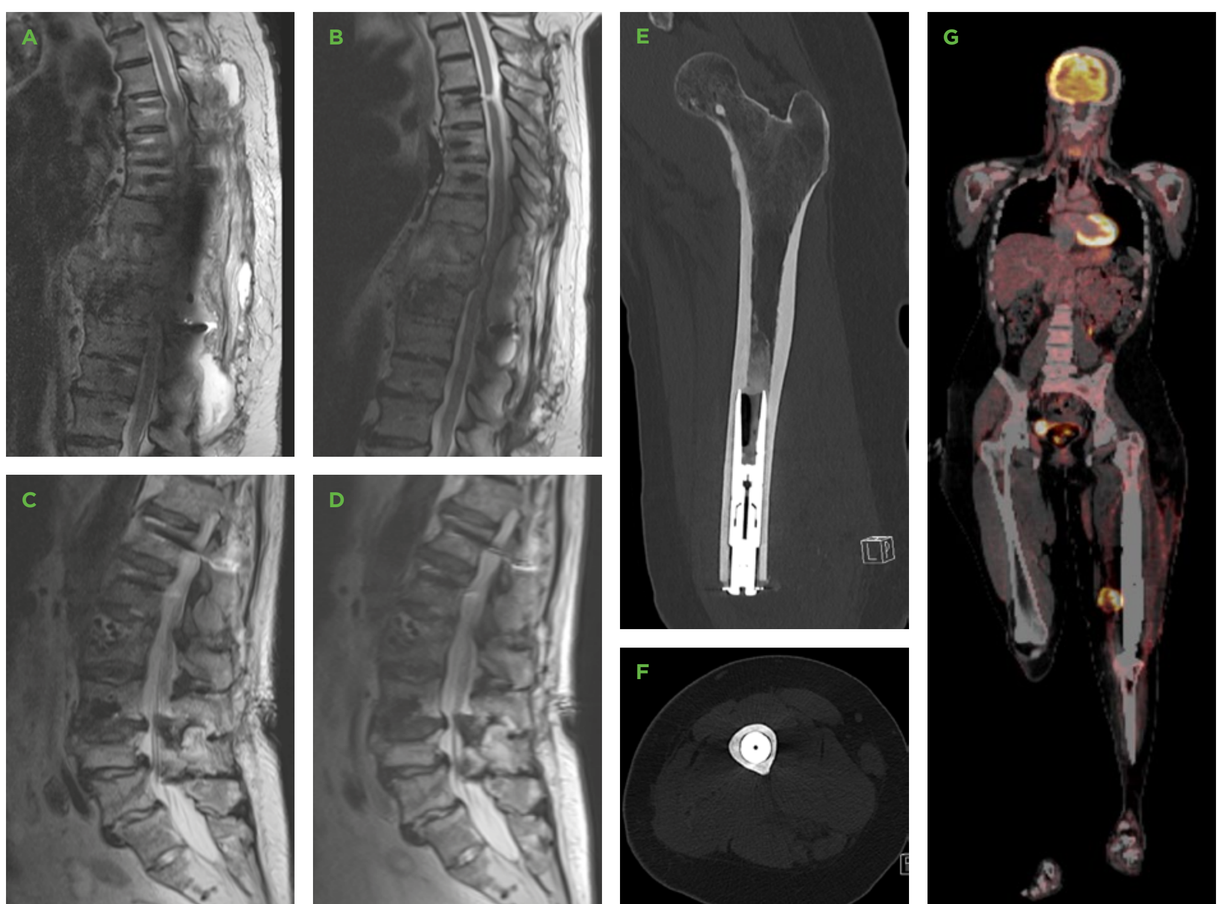
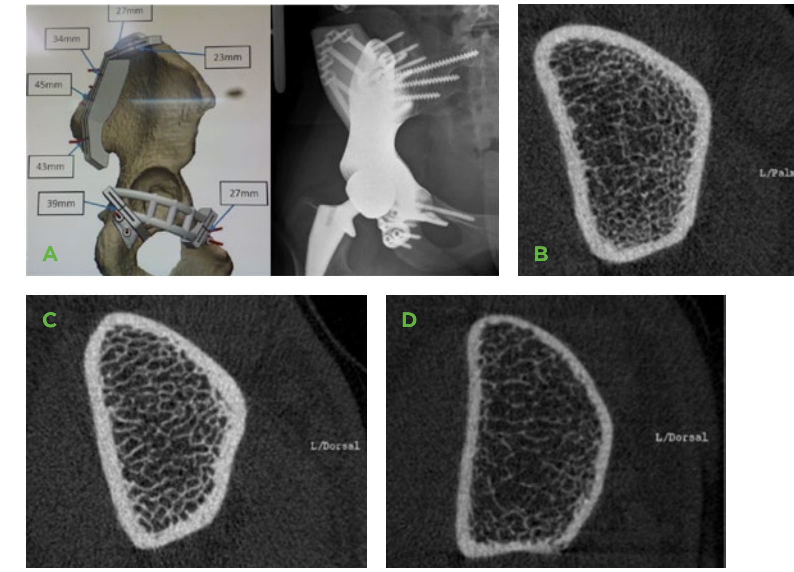


FIGURE 3

Personalised pelvic reconstruction in a patient with bone sarcoma: virtual planning by the use of the CT dataset and implanted 3D-printed pelvic model (Materialise ®) (A). HR-pQCT CT of a healthy control (B), and survivors of Ewing's sarcoma, without (C) and with fracture (D).



In PET/CT, ^{18}F-FDG (reflecting glucose metabolism) is the most commonly used tracer. ^{18}F-fluoride serves as an osteotropic surrogate for 99mTc-MDP, with better pharmacokinetic characteristics in lesions with osteoblastic activity. Emerging entity-specific PET tracers will contribute to precision staging examinations, potential personalised therapy, and improved assessment of response and recurrence. Recurrence detection by PET/CT profits from its capability to assess increased uptake, even next to metallic tumour prostheses (Figure 2F).

STANDARDISED IMAGE INTERPRETATION

Advances have been achieved in the standardisation of imaging response assessment, with the establishment of the RECIST 1.1 criteria (and PERCIST for PET/CT). Standardised computer-aided tumour response assessment has been proven superior to unstructured free-text reporting, and implementation into clinical routine can be expected. It should be stressed, however, that quantitative imaging parameters cannot replace pathologic evaluation of the surgical specimen to definitively assess the response to therapy.

BIG DATA SETS AND ARTIFICIAL INTELLIGENCE IN BONE TUMOUR IMAGING

Recently, radiomics, a computational approach to extracting image characteristics and using them for prediction, has shown promising results. Feature extraction, together with machine learning, enables the exploitation of fine-grained detail in imaging data[8]. Deep learning approaches by the use of big data set analyses and data-characterisation algorithms have great potential to provide standardised image analysis with a consistently accurate diagnosis of bone tumours, and may provide valuable information for precision therapy and estimation of patient prognosis. Extensive, rapid literature research (including bone tumour cases, as rare entities, in heterogeneous study populations) and meta-analysis with artificial neural networks will be possible far beyond existing human capacities. Initial radiomics studies on bone tumours have been published, e.g. on the prediction of recurrence, based on preoperative image characteristics[9].

Imaging data sets can be used for better intra-operative resection control, either by preoperative co-registration of different modalities, such as MRI and CT, or by the intra-operative use of CT. Personalised bone reconstruction is possible with 3D printing based on CT data (Figure 3A). Close and increasing interdisciplinary cooperation with professional providers is both promising and mandatory, especially in complex settings such as hemipelvectomy.

SURVEILLANCE OF BONE HEALTH AND COMPLICATIONS

Patients with osteosarcoma and Ewing's sarcoma now undergo multimodal treatment and can look forward to considerably improved prognoses. As a consequence, more attention can be directed toward quality of life and long-term complications. With the help of cancer rehabilitation, cancer survivors are able to gain self-competence and to recover more easily after cancer treatment[10]. At the same time, the increasing standardisation of follow-up examinations and new imaging techniques allow for better patient surveillance.

Traditionally, amputation was the surgery of choice. Rotationplasty is usually stable but is cosmetically unappealing. With the possibility of biological reconstruction and the implantation of megaprostheses, limb salvage has become feasible in many patients, with adequate local and systemic tumour control rates. The complication rate (categorised by the ISOLS classification) is higher than in amputation. In the growing skeleton, the number of revisions can be reduced by the implantation of self-extending prosthesis.

Long-term survivors of Ewing's sarcoma and osteosarcoma are prone to develop both a low bone mineral density (BMD) and a high fracture rate post chemotherapy. Clinical studies, however, have not revealed a clear association between low areal BMD and fractures[11]. High-resolution, peripheral, quantitative CT (HR-pQCT) is able to differentiate between cortical and trabecular bone density in vivo, provides a suitable technique for the microstructural analysis of human bone, and may provide new answers to the problem (Figures 3B–3D).

ACKNOWLEDGEMENTS

Marc-André Weber from Rostock, Germany; Georg Langs from Vienna, Austria; and Richard Crevenna from Vienna, Austria, are acknowledged for their contributions to this article.

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25

SOFT TISSUE **TUMOURS**

Soft tissue tumours

By **Marc-André Weber** and **Iris-Melanie Nöbauer-Huhmann**

Soft tissue tumours are a rare and diverse group of heterogeneous entities. Sarcomas account for only approximately 1% of soft tissue tumours in adults. However, in these patients, an early, accurate diagnosis with subsequent appropriate treatment is crucial for the best possible clinical outcome. Thus, in 2015, the European Society of Musculoskeletal Radiology (ESSR) established its own guidelines for diagnostic imaging[1].

RECOMMENDATIONS AND STANDARDISED ALGORITHMS FOR SOFT TISSUE TUMOURS

Standardised imaging algorithm recommendations have been developed, which include both local image assessment criteria and aspects of distant staging. Moreover, they advise which patients should be referred early to MSK tumour competence centres[1]. The imaging algorithm for local diagnosis, as summarised in the ESSR consensus document, is as follows:

1. Imaging should be performed in all patients with suspected soft tissue tumours.

2. Ultrasound is considered the most appropriate initial triage modality for accessible tumours, to clearly determine benign lesions.

3. Any tumour with a reasonable chance of being malignant, or at a previous excision site, requires an MRI (or, in specific cases, CT).

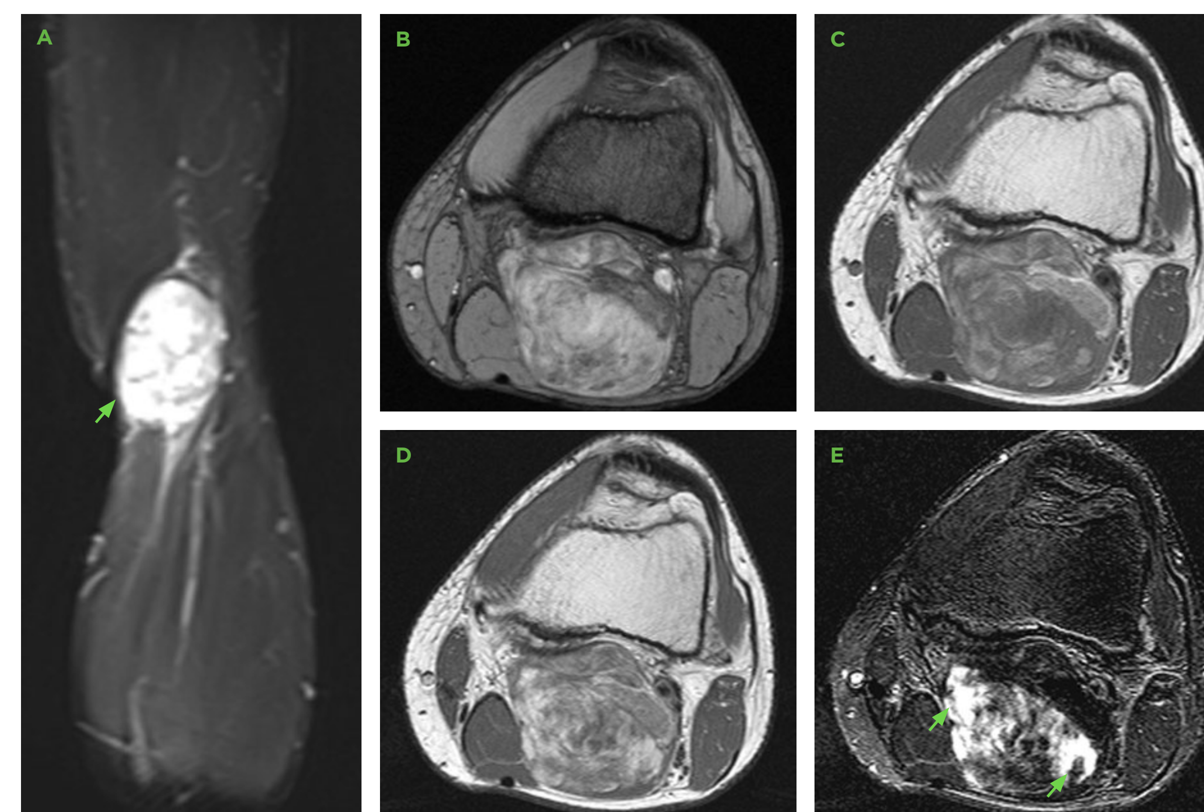
4. MRI, as the imaging modality with best soft tissue contrast, serves for further characterisation of the tumour, local staging and therapy planning, and biopsy targeting (Figure 1).

5. Projection radiography (or, in complex regions, CT) should be performed as an additive primary modality in deep palpable lesions, para-articular lesions, and large masses to characterise soft tissue calcification or ossification and bone involvement.

Contrast-enhancement patterns in ultrasound and MRI offer additional information about the differentiation of an unknown soft-tissue mass with homogeneous or absent contrast enhancement as specific signs for benign lesions[2]. Also, the most predictive features for malignancy have been reported to be heterogeneous contrast-enhancement in ultrasound and MRI, lesion roundness, diffusion restriction, cystic/ necrotic intralesional areas, higher patient

FIGURE 1

Myxoid liposarcoma at the popliteal fossa in a 37-year-old man. (A) coronal STIR, (B) axial T2*-weighting, (C) axial T1-weighting, (D) contrast-enhanced axial T1-weighting, (E) subtraction images (contrast-enhanced T1-weighted MRI minus unenhanced T1-weighted MRI). The tumour is highly hyperintense on T2-weighted images (arrow), contains fat on T1-weighted images, and shows heterogeneous enhancement. The subtraction image clearly shows the avidly enhancing parts of the soft tissue sarcoma (arrows).



age, surrounding oedema and intralesional Doppler hyper-vascularity[3].

OPEN TASKS AND DUTIES FOR US RADIOLOGISTS WITHIN THE NEXT FIVE TO TEN YEARS

As soft-tissue sarcomas require aggressive treatment, often with a combination of radiation therapy, chemotherapy, and surgical resection, and as local recurrences are common even after multimodality treatment, regular follow-up imaging is required. However, to date, no evidence-based recommendations exist for routine follow-up in surgically treated sarcomas. In Europe, follow-up is regularly performed for ten years after initial diagnosis[1]. Since it has been reported that more frequent follow-up is associated with improved survival in high-risk relapsing patients with extremity soft tissue sarcomas by providing greater opportunities for adequate reoperation, evidence-based guidelines should be established by using modern biomarkers. In addition, we definitely need clear protocols for soft tissue sarcoma patients[1]. Furthermore, interpretation of post-treatment MR images may be complicated by changes in the surgical bed or treatment field.

The challenge of distinguishing post-treatment change from recurrent tumour may be minimised by using an organised, systematic approach to imaging, with an emphasis on the patient's clinical and surgical history with knowledge of operative success and a review of pre-treatment images. According to Noebauer-Huhmann et al[1], local MRI (including contrast-enhanced sequences) is the method of choice for local surveillance, but ultrasound has also been reported to be promising for exclusion of local recurrence, with a sensitivity/specificity of 88%/94%[4].

Regarding therapy monitoring, although advances have been achieved by standardising imaging response assessment by applying the widely used Response Evaluation Criteria in Solid Tumours (RECIST), the current RECIST 1.1 criteria have the limitation that the size measurement is not sensitive to modern targeted therapy and cellular changes, e.g. apoptosis, mitosis, as well as changes in a tumour's vascularity are expected to precede macroscopic volumetric response of the soft tissue sarcoma.

Thus, for response assessment after radiotherapy of soft tissue sarcomas, the criterion size in MRI should not be used to reflect response alone. Histopathological changes such as necrosis and haemorrhage influence dimension-based assessments, a significant shrinkage of tumour volume following radiotherapy is rare (except in myxoid liposarcomas), and there has been no correlation of RECIST with outcome reported, i.e. shrinking tumours are still viable and stable/growing tumours present with dramatic histological response[5]. Furthermore, the histopathologic response to chemotherapy and radiation therapy is an important prognostic indicator of disease-free survival after the treatment of musculoskeletal sarcomas. Since the criterion size based on standard morphological imaging is not sufficient, we crucially need robust and validated biomarkers to move precision medicine forward to predict the right treatment for the right patient at the right time. Also, we need to present these functional and morphologic parameters in a timely, structured and condensed manner to our clinical partners to enable a real decision-making business.

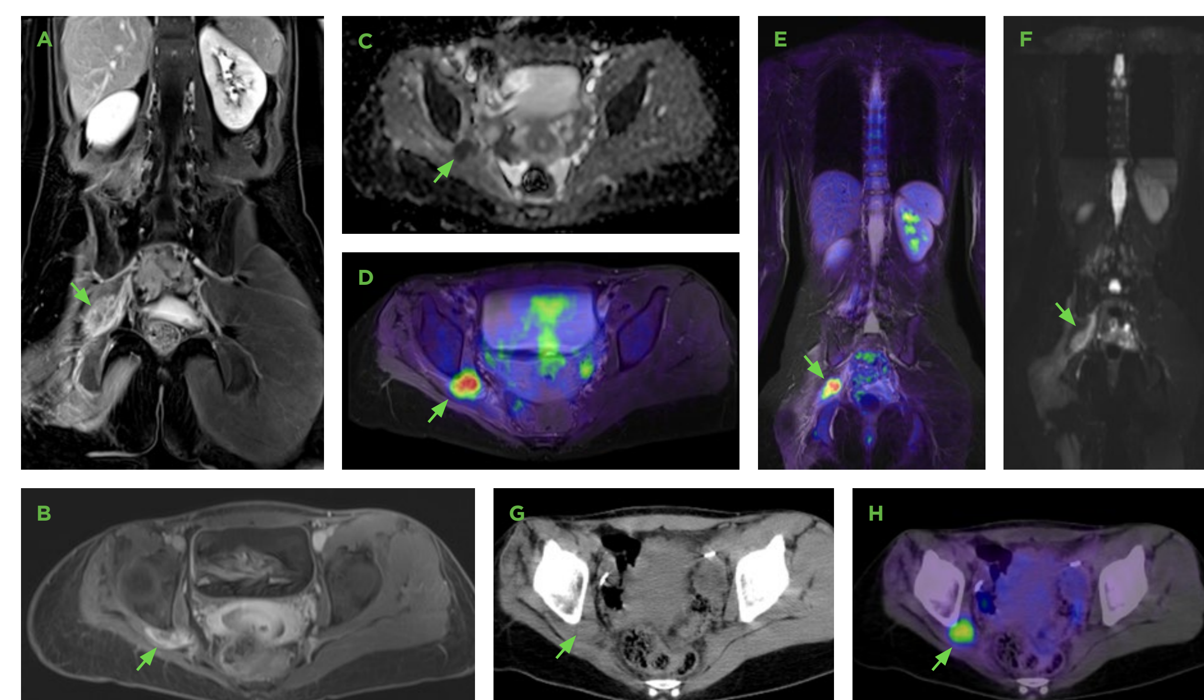
TECHNICAL ADVANCES AND AVAILABLE BIOMARKERS FOR USE IN SOFT TISSUE TUMOURS

We now have plenty of advanced morphologic and functional MR techniques available[6,7], such as whole-body MR imaging for staging, chemical shift imaging (in-phase, opposed phase), Dixon-type imaging (in phase, out of phase, water only, fat only), diffusion-weighted imaging (DWI) to assess cellular density of soft tissue tumours, dynamic contrast-enhanced (DCE) MRI to visualise and quantify a tumour's vascularity and MR spectroscopic imaging (MRSI) to obtain information about the cellular metabolism (energy state and proliferation index).

In soft tissue sarcomas, DCE or DWI have been increasingly implemented and can be used to target biopsies, or to monitor therapy response. For the latter issue, calculation of quantitative parameters such as the percent slope analysis for DCE, or ADC ratio for DWI, have proved useful. DWI and DCE, when used in addition to conventional imaging, increase the accuracy for response assessment in soft-tissue sarcomas treated neoadjuvantly before surgery, when compared to conventional MRI alone[8]. This is true particularly for tumours that form granulation tissue and fibrosis rather than necrosis as a histologic response to treatment.

FIGURE 2

PET/MRI in neurofibromatosis type 1 depicting a malignant peripheral nerve sheath tumour in a 32-year-old woman. (A) coronal contrast-enhanced fat-saturated T1-weighted VIBE, (B) axial contrast-enhanced T1-weighted VIBE with fat saturation, (C) axial ADC map from DWI, (D) axial 18F-FDG PET/MRI fusion (contrast-enhanced fat-saturated T1-weighting), (E) coronal FDG PET/MRI fusion (STIR), (F) coronal DWI from PET/MRI, (G) axial CT from PET/CT, (H) axial FDG PET/CT fusion. A space-occupying lesion in the right greater sciatic foramen (arrows) with intensive tracer uptake and restricted diffusion representing vital tumour tissue is illustrated. The SUV_{max} was 5.0. No other suspicious lesions are present on whole-body imaging.

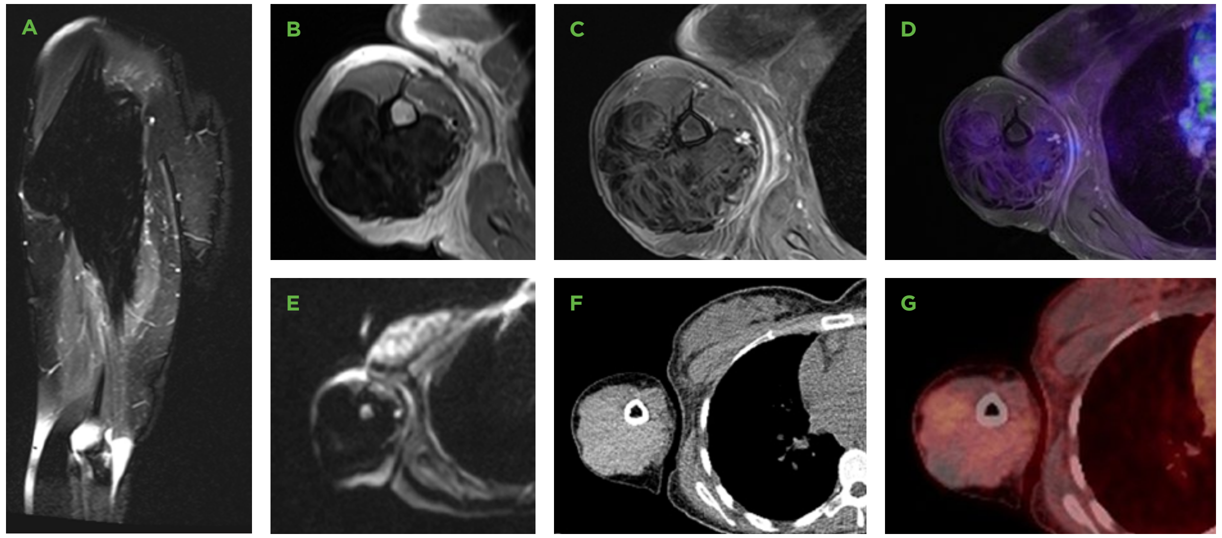


In addition, DCE and DWI are highly sensitive for assessment of the degree of non-viable tumour. In the coming years, we as radiologists have to work on a higher degree of standardisation both regarding sequence details and post-processing models. From what we said before, it becomes obvious that we should use both morphologic and (some) functional MR sequences to assess response after radiotherapy or chemotherapy. In favour of a response are reductions in size, decreased contrast enhancement and reduced restricted elements visualised by DWI.

Meanwhile, hybrid imaging techniques are becoming more and more widely available throughout Europe, which have the major advantage of combining metabolic and anatomical information in a single examination. ^{18}F-fluorodeoxyglucose positron emission tomography (PET)/CT (^{18}F-FDG-PET/CT) has a high diagnostic value in the follow-up of adult patients with soft tissue sarcomas. Compared with PET/CT, PET/MRI has a superior soft tissue contrast that is advantageous for detecting local infiltration of the bone and invasion into adjacent muscles or other compartments (Figures 2–4). Also, the radiation dose is lower in PET/MRI and there are a variety of biomarkers, e.g. for perfusion and cellularity, available by using the MRI component. In soft tissue sarcomas, the combination of PET with DWI data in PET/MRI is very promising[9].

FIGURE 3

PET/MRI for follow-up of a desmoid tumour of the right upper arm in a 26-year-old woman under imatinib (protein kinase inhibitor) therapy. (A) coronal fat-saturated T2-weighting, (B) axial T1-weighting, (C) axial contrast-enhanced fat-saturated T1-weighted VIBE, (D) FDG PET/MRI fusion (T1w VIBE fs), (E) axial DWI (b=800 s/mm^2), (F) axial CT and (G) axial FDG PET/CT fusion five months before the PET/MRI. The soft tissue tumour is strongly hypointense on T1 and T2-weighted sequences and is presenting with poor FDG uptake both in PET/MRI and PET/CT carried out five months before. There is no restricted diffusion and no difference in size during follow-up. Thus, because of the young age of the patient subsequent controls would be carried out solely by using MRI without PET until there is a significant difference in size.

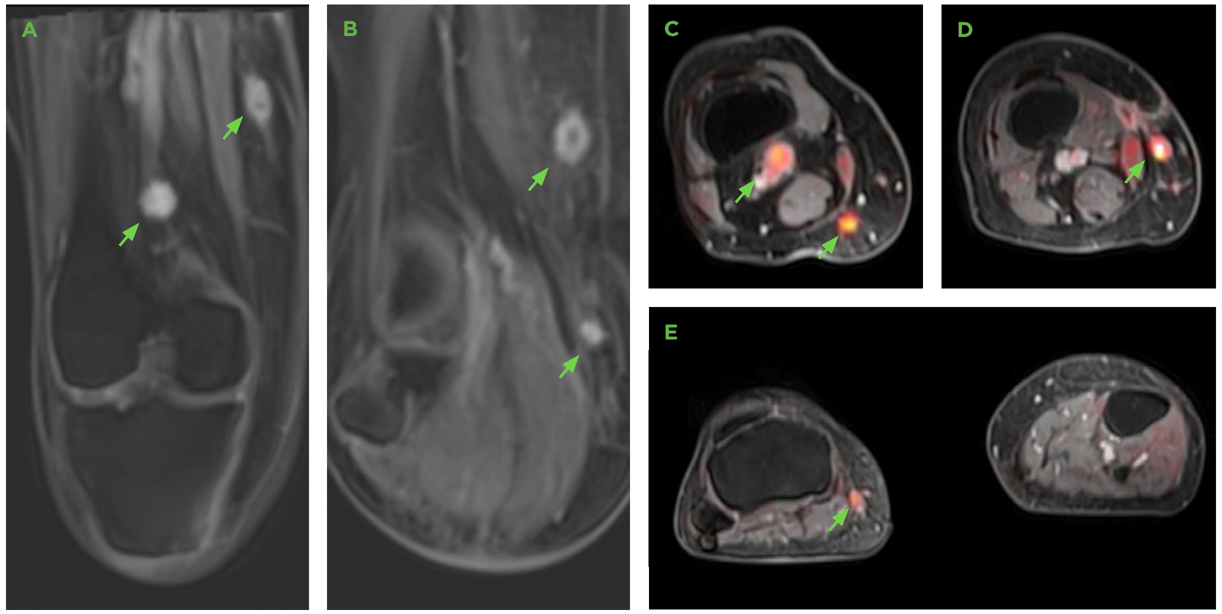


In summary, after treatment of musculoskeletal sarcomas, the histopathologic response to (neoadjuvant) chemotherapy and radiation therapy is an important prognostic indicator of disease-free survival that may be assessed by functional MRI and hybrid imaging techniques. After neoadjuvant therapy and before surgery, contrast-enhanced static MRI is of limited value for response assessment, because both viable tumour and post-treatment scar tissue present with contrast enhancement. PET/CT or PET/MRI may help to solve problems in suspected local recurrence. ^{18}F-FDG PET/MRI has been reported to be an excellent imaging method in the evaluation of recurrent soft tissue sarcomas after surgical excision, yielding superior tumour detection when compared to MRI alone[10].

Last but not least, in addition to the implementation of novel imaging techniques, the field of big data analysis by machine-learning-driven data mining, as well as artificial intelligence approaches (radiomics) in soft tissue tumour imaging, may play a major role in the ten years to come. Radiomics approaches have the potential to provide image analysis or better data analysis that enables risk stratification in soft tissue tumours and may provide valuable information for precision or personalised medicine.

FIGURE 4

PET/MRI in case of local recurrence with subcutaneous ^{18}F-FDG-positive metastases within the amputation stump after resection of an angiosarcoma at the right lower leg of a 75-year-old woman. Several clearly measurable subcutaneous metastases with SUV_{max} of 2.9–6.3 are depicted by PET/MRI. No distant metastases are present in the whole-body imaging. (A–B) coronal contrast-enhanced fat-saturated T1-weighted VIBE, (C–E) axial FDG PET/MRI fusion (T1w VIBE fs).



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26

IMAGE-GUIDED BIOPSY

What can we expect from image-guided biopsy of mass lesions?

By **Jan L. Gielen**

INTRODUCTION

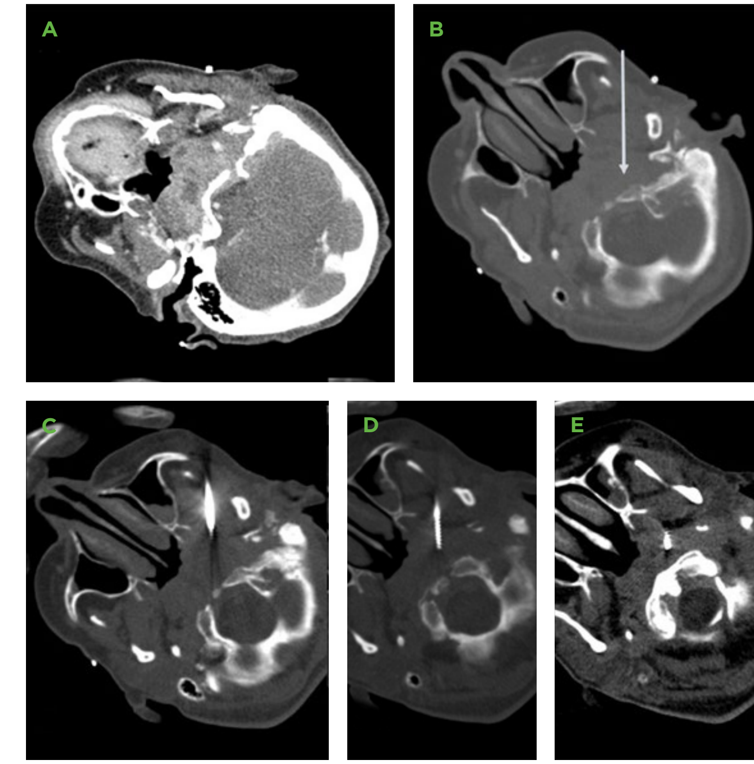
In most lumps, imaging work-up is an essential primary step in the triage of benign versus indeterminate or likely malignant lesions. The detailed imaging work-up for soft tissue lesions is discussed in the ESSR Approved Guidelines for diagnostic imaging[1]. In a suspect lesion of bone or soft tissue, adequate biopsy is an essential secondary step in diagnostic work-up, to inform treatment planning and promote optimal outcome. It is recommended that the biopsy of indeterminate or likely malignant tumours is performed at a specialised sarcoma centre in close collaboration with the multidisciplinary sarcoma team[3].

BIOPSY PROCEDURE

As an alternative to open biopsy, core needle biopsy (CNB) guided by computed tomography (CT), ultrasound (US), or even MRI, has gained popularity as a safe, technically accurate and less invasive procedure, especially in smaller and deeply located lesions[2–9]. Image-guided procedures are generally performed under local anaesthesia whereas open biopsies often require a short period of hospitalisation with regional or general anaesthesia. A biopsy trajectory that minimises the risk of damage to neurovascular structures or the seeding of neoplastic lesions is chosen in collaboration with the treating surgeon. Multiple tissue samples are preferably taken from viable (i.e. contrast enhancing, colour Doppler vascularised, or most hypermetabolic on PET) areas of the lesion, avoiding cystic and necrotic parts. All available imaging examinations are reviewed to define the specific intralesional locations of the biopsy.

FIGURE 1

Sixty-year-old female with retropharyngeal mass. Three transmucosal biopsies prior to the CT-guided procedure were not successful. Iodine-enhanced CT reveals an enhancing mass with cystic-necrotic areas (A). A biopsy procedure was performed with a 14G Spirotome® needle (B–D) and revealed Leishmaniosis.



During the procedure, the quality of the specimens is examined, preferably by a cytopathologist, and it is decided whether a satisfactory amount of viable tissue has been obtained or if the procedure must continue[3]. If after a percutaneous needle biopsy the diagnosis is still uncertain or if the results vary from what was clinically expected, a repeat biopsy (needle or open) is indicated and performed in about one case out of six[9, 10]. In cases of primary malignant lesions, the methylene blue coloured biopsy trajectory is resected together with the primary lesion to prevent seeding.

GUIDANCE TECHNIQUES

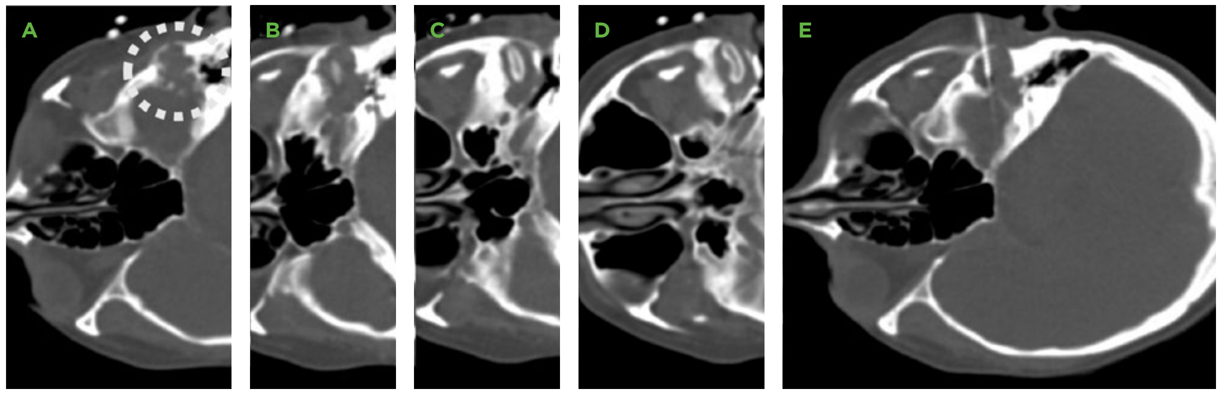
CT and ultrasound are the main modalities for imaging-guided needle biopsy in soft tissue lesions (STL) as well as in superficially located osteolytic bone lesions (OBL), while CT-guided needle biopsy is preferred in most osseous lesions. MRI-guided biopsy is available for soft tissue and bone lesions but needs compatible needles at a higher cost and is less frequently used in clinical practice. MRI-ultrasound or CT-ultrasound fusion-guided biopsy, for bone and soft tissue lesions that are not in reach of ultrasound alone, needs dedicated, advanced ultrasound equipment.

BIOPSY TECHNIQUES

The accuracy rate of fine needle aspiration is lower (61%) than that of core

FIGURE 2

Forty-year-old female with sclerotic lined osteolysis of 14mm at the temporal bone pyramid (A). A biopsy was performed with a 10G Spirotome® needle (B–E) obtaining a cylinder with a length of 1cm. Diagnosis: chondrosarcoma grade III.



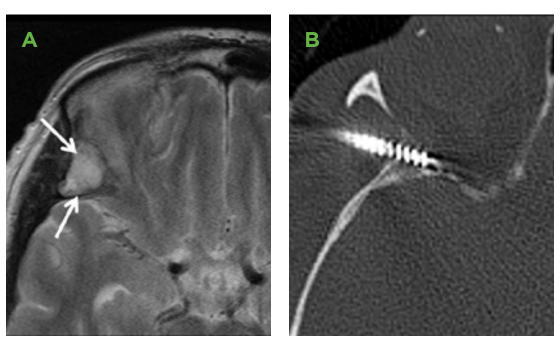


FIGURE 3

Sixty-year-old female patient. MRI without and with IV gadolinium administration demonstrates a non-enhancing small expansile osteolytic lesion at the right ala major of the sphenoid bone with intraorbital expansion (A: axial flair sequence, arrows). CT-guided biopsy with 10G Spirotome® (B) provided a 10mm soft tissue cylinder. The pathological result was a dermoid cyst.

biopsy (>74%) and is not recommended for likely sarcoma lesions[9].

Thick (preferably 8 or 10 G) core biopsy side load (Trucut) or end load (Bard Mission®, Spirotome®) needles are used to obtain large soft tissue cores in a minimally invasive way in soft tissue lesions (STL) or osteolytic bone lesions not covered by calcified tissue (OBL). End load systems are preferred in specific situations to prevent seeding, in critical locations or in small lesions in front of neurovascular structures, pleura or joints.

In sclerotic bone lesions (SBL), bone cutting core biopsy needles (for instance Bauer Medical Temno® Bone Needles; Angiomed Ostycut®; AprloMed AB Bonopty®; Care Fusion Jamshidi) may be used. With those devices, the cortex is penetrated through tapping,

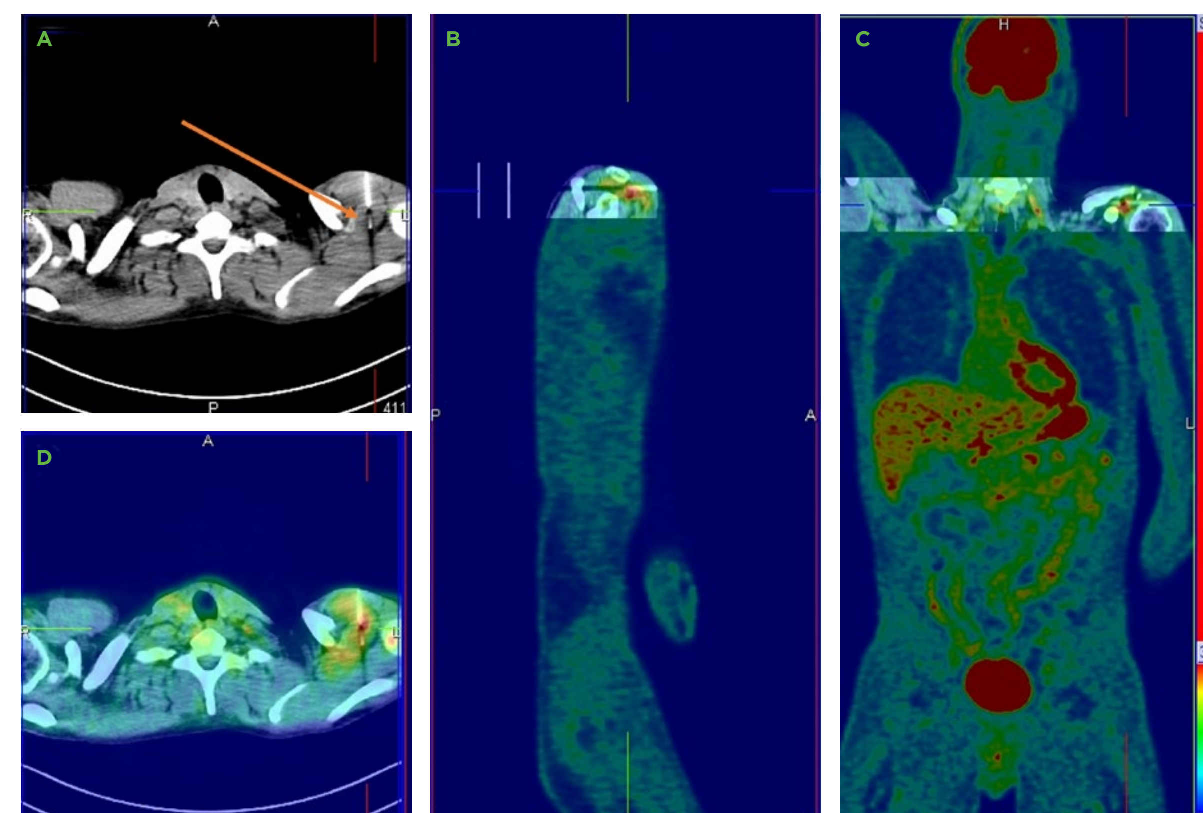
manual pressure or, in case of Bonopty®, screwing in an auger.

To obtain adequate specimens in non-sclerotic solid bone lesions, 18-gauge core biopsy needles or a biopsy gun through a 12 or 16-gauge bone cutting needle can be used[3, 9, 11].

In cystic or partly fluid-filled bone lesions, solid core biopsies are hard to obtain. In such cases, the same procedure as for non-sclerotic bone lesions may apply, using a biopsy gun, or the internal wall of the lytic lesion can be scraped after bone penetration using a dedicated (Temno®, Ostycut® or Bonopty®) needle[3].

FIGURE 4

Forty-one-year-old male with complaints of anterior impingement at the right shoulder. Ultrasound examination revealed a non-specific 1cm nodular mass at the rotator interval. The patient refused further interventional work-up. One year later, the patient returned with a soft tissue mass at the anterior cranial aspect of the shoulder. MRI examination revealed an 8cm non-homogeneous enhancing mass, solitary location and non-homogeneous hypermetabolic on PET. PET/CT-guided biopsy was performed with a 10G Spirotome® needle at the most hypermetabolic area. Diagnosis was monophasic spindle cell synoviosarcoma. The sarcoma was resected; follow-up until today, eight years later, revealed no metastatic disease. (A) Axial CT with demonstration of the needle tip in the mass in the left subacromial area. (B), (C) and (D) sagittal, coronal and axial PET/CT fused images with demonstration of the needle position.



Based on location and lesion characteristics, the radiologist decides which guidance technique (ultrasound, CT or MRI) and needle is preferred, taking into account the success rate and safety.

ACCURACY OF BIOPSY TECHNIQUES

The accuracy rate of CNB ranges between 75–96%[2]. In a study with controlled intralesional biopsy location the accuracy rate was 86%[9]. In a randomly distributed prospective controlled study at our institution, we assessed the efficacy of PET/CT-guided biopsy of areas of most intense radiolabelling (AMIR) of musculoskeletal tumours and pseudotumours, STL and bone lesions (BL) obtained with commonly used biopsy devices, compared with CT-guided biopsy and surgical biopsy. In this study, all 149 cases, except spine lesions (n26), were randomly distributed between biopsy systems (CT (n68), PET/CT (n40) or Surgical (n41)).

Spine lesions (n26) were randomly included in CT (n22) or PET/CT (n4) procedures only. The efficacy of characterisation (Fisher exact: P 0.2756) was 80.5% for surgical procedures, 88.2% for CT-guided procedures and 92.5% for PET/CT-guided procedures. The grading efficacy (Fisher exact: P 0.5642) was 90.2% for surgical procedures, 95.6% for CT-guided procedures and 95% for PET/CT-guided procedures. The diagnostic efficacy of PET/CT and CT-guided biopsy of musculoskeletal lesions in our study was better than surgical biopsy.

DISCUSSION

Biopsy is a mandatory secondary step in bone and soft tissue lesions that are clinically suspect or appear suspect on imaging. Imaging-guided biopsy is safe and more accurate compared to surgical biopsy procedures. These procedures are best performed in a specialised sarcoma centre.

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27

RHEUMATOID ARTHRITIS

INFLAMMATORY MSK DISEASES:
Rheumatoid arthritis

By **Lennart Jans**

The presence of active inflammation is a key feature for the diagnosis of inflammatory rheumatic diseases and rheumatoid arthritis (RA) in particular. Treatment guidelines for RA[1], including 'treat-to-target' strategies[2], stress the importance of abrogation of inflammation.

RA is the most common inflammatory arthritis, affecting approximately 1% of the world's population. The disease involves synovial joints and subchondral bone marrow, as well as intra-articular and extra-articular fat tissue, and leads to progressive joint destruction and disability. New strategies for disease management, the emergence of new biological therapies, and better utilisation of conventional disease-modifying antirheumatic drugs have significantly improved long-term outcomes. Prompt diagnosis and treatment are recognised as essential for improving clinical outcomes in patients with early rheumatoid arthritis. Imaging of patients with RA may be carried out for diagnosis, treatment guidance and follow-up.

Radiography currently remains the cornerstone of imaging in RA[3]. It is fast, cheap and readily available. Typical features of RA are pocket erosions of the MCP and MTP joints, and carpal and tarsal bones. The ulnar styloid process and PIP joint are often affected; there is sparing of the DIP joints. Radiography is well-suited to follow-up, as changes in the number and depth of erosions can be easily detected.

It has been shown that CT performs significantly better in detecting erosions compared to radiography[4]. However, in clinical practice, CT of the hand and wrist, or feet, is rarely obtained. The reason for this may be that classic CT fails to show acute inflammation and that if cross-sectional imaging is warranted, MRI remains the imaging modality of choice. CT still plays a role in evaluation of the extent of erosions of the cervical spine, in particular of C2, when instability is suspected.

Recently, it has been shown that dual-energy CT allows the visualisation of bone marrow oedema in patients with RA of the hands[5]. This technique would allow for a one-stop-shop, with evaluation of both hands and feet in one examination, allowing detection of active inflammatory bone marrow oedema and superb detection and quantification of erosion compared to radiography.

Ultrasound is often used in daily practice as it is fast and readily available when the patient visits the clinician. Ultrasound is well-suited to showing joint space inflammation of the small joints of the carpus, tarsus, foot and hand, whether it is joint effusion or synovitis[6, 7]. Furthermore, Doppler and power ultrasound show the perfusion of the thickened synovium. Ultrasound can guide biopsy of the synovium, as well as therapeutic interventions. The major drawback of ultrasound is that the findings are dependent on both the operator and the machine, which makes ultrasound less suited to long-term follow-up.

MRI has long been the only imaging modality that enables detection of active inflammation in RA[8]. Different forms of inflammation can be depicted: bone marrow oedema, joint space inflammation and soft tissue inflammation are seen on fluid-sensitive sequences. Synovitis and pannus formation enhance with intravenous gadolinium administration. Since the goal of treatment of RA is to abrogate active inflammation and thus prevent structural lesions, MRI is well suited to treatment guidance and follow-up. Unsurprisingly, this has led to development of scoring systems like RAMRIS with MRI as the single imaging modality[8]. However, MRI has some major disadvantages. MRI is not readily available, it is

FIGURE 1

Radiography of the hand in a 50-year-old female with RA. Generalised periarticular demineralisation is present. Typical erosions can be seen of the carpal bones, MCP joints and PIP joints.

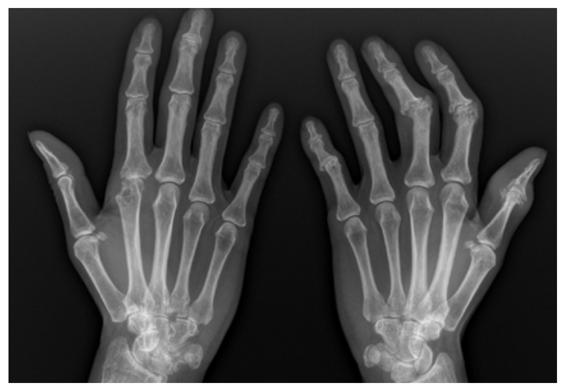
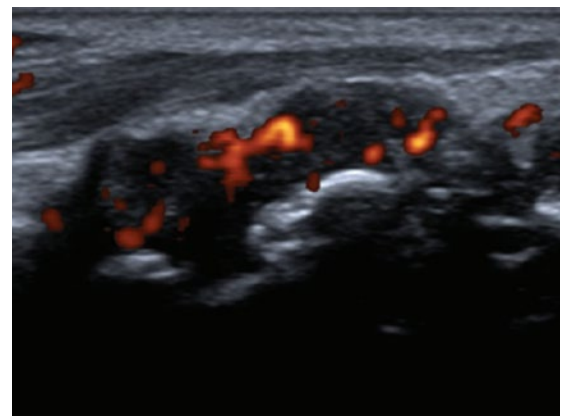


FIGURE 2

Ultrasound Power Doppler image shows active grade 3 synovitis as prominent vascularity in the thickened synovium of the radiocarpal and midcarpal joints.



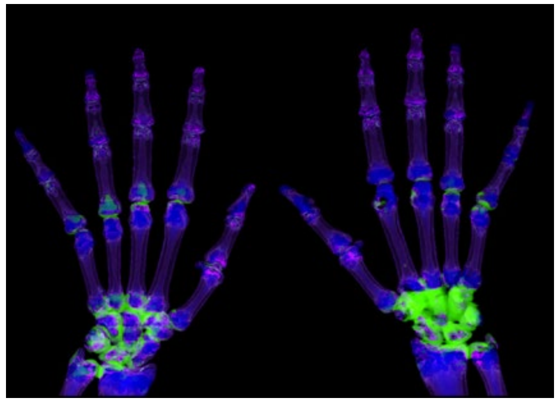


FIGURE 3

Dual-energy CT image in a 47-year-old female with RA. Post-processed image shows extensive bone marrow oedema of the right carpal bones in green.

FIGURE 4

Contrast-enhanced T1-weighted MR image of the spine in a 64-year-old male RA patient. Enhancing pannus formation with erosion of the dens is seen, with altered alignment.

expensive and it requires the patient to lay still in the 'Superman' position, which may be challenging for elderly RA patients. A full MRI examination requires contrast examination and only one hand or foot can be scanned at a time.

SPECT/CT in the early soft tissue phase will show an increased tracer uptake in inflamed joints in RA[9], which is suggestive of hypervascularity and inflammatory synovitis. The tracer distribution on delayed images in the osseous phase displays different uptake patterns as it is in keeping with osteoblastic activity. The CT is not diagnostic but rather meant for anatomic correlation of the findings on SPECT. SPECT/CT is therefore not the imaging modality of choice, but early RA may be detected, so radiologists should be aware of this typical serendipity.

In conclusion, radiography and ultrasound remain the cornerstones of imaging in RA. Dual-energy CT allows detection of bone marrow oedema and will play a prominent role in the future. MRI remains a solid technique for evaluation of all types of RA-related inflammation and is thus best for determining abrogation of inflammation, which is the goal of treatment.

FIGURE 5

SPECT/CT image in a 64-year-old male RA patient shows tracer uptake in the carpus and MCP joints.

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28

SPONDYLO-ARTHRITIS

Recent advances in MRI analysis for the diagnosis of axial spondyloarthritis

By **Antoine Feydy**

MRI and conventional radiography are both used in the screening and diagnosis of axial spondyloarthritis (axial SpA). MRI is a relatively new imaging technique in the field of axial SpA. Its advantage is the early detection of bone marrow oedema on short tau inversion recovery (STIR), or similar sequences, consistent with inflammation.

MRI of the sacroiliac joints was introduced to the imaging arm of the Assessment of SpondyloArthritis international Society (ASAS) definition of axial SpA in 2009. Although ASAS recently developed criteria for spinal MRI, these criteria are not routinely used for patient classification and their additional value has yet to be determined. We will now focus on the value of spinal MRI in the evaluation of patients with suspected axial SpA.

DIFFERENTIAL DIAGNOSIS BETWEEN AXIAL SPA AND DEGENERATIVE DISC DISEASE

Lesions in the spine associated with axial SpA have been well documented and various scoring systems have been developed. However, in addition to lesions associated with axial SpA, concomitant degenerative changes in the spine are prevalent both in patients with axial SpA and in the general population. Degenerative changes in the spine can become relevant when they mimic axial SpA. In a recent study, de Bruin et al[1] showed that the prevalence of degenerative changes on MRI and conventional radiographs of the spine is high (70%) in an early inflammatory back pain cohort (≥3 months, ≤3 years, onset <50 years). Modic changes were found more often in patients with no axial SpA (29/239, 12.1%) versus patients with axial SpA (19/409, 4.6%, p=0.01). Other degenerative lesions were evenly distributed. With trained readers, discrimination between degenerative changes and axial SpA lesions is very possible, with little overlap between degenerative and axial SpA readings (Figure 1).

DIFFERENTIAL DIAGNOSIS BETWEEN AXIAL SPA AND DISH

Diffuse idiopathic skeletal hyperostosis (DISH) is, like axial SpA, a disease characterised by the ossification of ligaments and enthesis of the axial skeleton, with prevalence that increases with age. The typical radiographic feature of DISH is the presence of flowing ossification along vertebral bodies, mostly found in, but not limited to, the thoracic spine. Although their clinical and radiological results are often pragmatically described as radically opposed, differential diagnosis between DISH and axial SpA might be a challenging issue in clinical practice in certain settings. In a recent study, Latourte et al[2] showed that inflammatory lesions of the spine are common on the MRI of symptomatic DISH patients, and more than half fulfilled the ASAS criteria for a spine MRI suggestive of axial SpA. By contrast, bone marrow oedema lesions were scarce on sacroiliac joint MRI of symptomatic DISH patients. Consequently, only a few patients met the ASAS definition of active sacroiliitis, suggesting that MRI of the SI joint, but not of the spine, might allow the differential diagnosis of DISH versus axial SpA in the elderly. Moreover, erosion both at the spine and the sacroiliac joint level was infrequent in DISH and could help discriminate DISH from axial spondyloarthritis in the elderly. Overall, the take-home message is that MRI lesions must be interpreted carefully, and in the light of a thorough clinical and biological workup, to discriminate between DISH and axial SpA (Figure 2).

FIGURE 1

Differential diagnosis between axial SpA and degenerative disc disease.

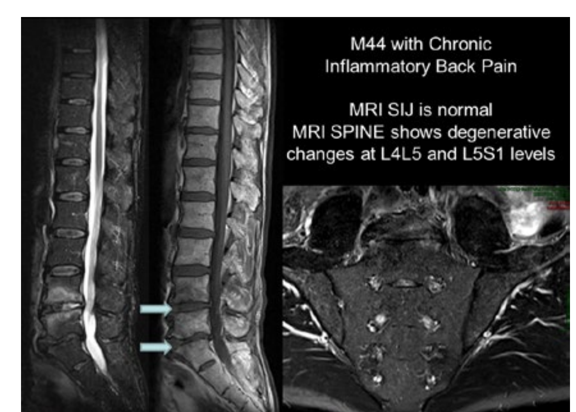
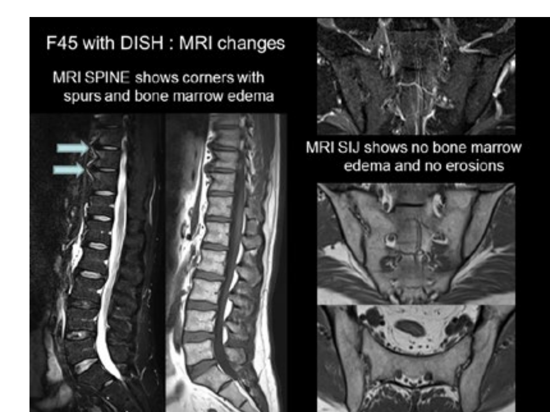


FIGURE 2

Differential diagnosis between axial SpA and DISH.

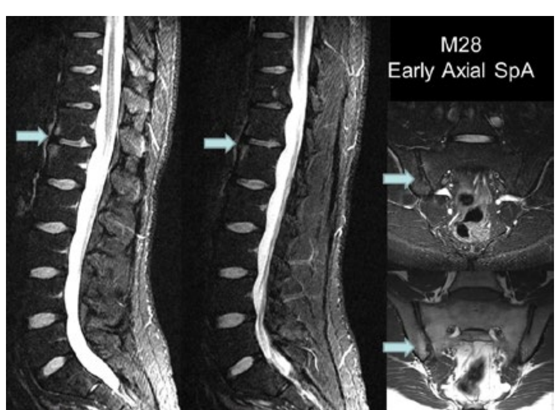


YIELD OF A POSITIVE MRI OF THE SPINE AS IMAGING CRITERION IN THE ASAS CLASSIFICATION CRITERIA FOR AXIAL SPONDYLOARTHRITIS

Several studies have shown that besides inflammation of the sacroiliac joints on MRI (MRI SIJ), inflammatory lesions may also be found in the spine on MRI (MRI-spine). A consensus definition for a positive MRI-spine was developed by the ASAS/Outcome Measures in Rheumatology (OMERACT) MRI working group[3]. In this consensus definition a positive MRI-spine is described as the presence of ≥3 inflammatory lesions in the vertebrae, whereas each lesion needs to be present on ≥2 consecutive slices. De Hooge et al[4] recently proposed a cut-off value of ≥5 inflammatory lesions that defines a positive MRI-spine with higher specificity of ≥95% (i.e., <5% patients without axial SpA with a positive MRI-spine). In a recent study[5], Ez-Zaitouni et al aimed to evaluate the presence of spinal inflammatory lesions on MRI in patients with a maximum chronic back pain duration of three years in two different cohorts, the SPondyloArthritis Caught Early (SPACE) cohort and the DEvenir des Spondylarthropathies Indifférenciées Récentes (DESIR) cohort. Overall, the prevalence of spinal inflammation was low. In addition, spinal inflammation in the absence of sacroiliitis on MRI-SIJ and XRay-SIJ occurred in a very small proportion of patients. Consequently, adding a positive MRI-spine (represented in various definitions) as an imaging criterion to the ASAS criteria resulted in a very low percentage of newly classified patients. Considering the number of MRI-spines needed to additionally classify a few patients, the longer scanning time for the patient and higher costs, this study concluded that the yield of adding MRI-spine to the ASAS criteria is unacceptably low in relation to the number of MRI-spines needed to be performed in patients with early disease (Figure 3).

FIGURE 3

Positive MRI of the spine as imaging criterion in the ASAS classification criteria for axial spondyloarthritis.



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29

RARE RHEUMATIC DISEASES

Rare rheumatic diseases and their MSK manifestations

By Iwona Sudoł-Szopińska, Chiara Giraudo, Paolo Simoni and Anne Cotten

The most common rheumatic diseases are rheumatoid arthritis (RA), spondyloarthritis and juvenile idiopathic arthritis (JIA). No less important are the remaining systemic connective tissue disorders, many of which fulfil the European Commission definition of rare diseases[1]. They are multisystemic and associated with significant morbidity and mortality. The leading examples are systemic sclerosis (SSc), systemic lupus erythematosus (SLE) and systemic vasculitis. These diseases can affect virtually every system and greatly impair the quality of life of both adults and children[2, 3].

Early diagnostic work-up as well as modern treatment have significantly reduced morbidity and mortality associated with these diseases and have had a positive impact on patients' quality of life. It is expected that increasing understanding of the immunologic, genetic and epigenetic factors involved in their pathogenesis will improve diagnostic accuracy and patient outcomes. The emergence of personalised, outcome-oriented imaging measures to monitor treatment efficacy will also contribute to this.

Early inflammatory changes within the MSK system occurring in the course of these diseases may be non-specific, resulting in diagnostic delays. A precise diagnosis at this stage often relies on specific serum markers. However, the same biomarker may be positive in several entities, e.g. rheumatoid factor in RA, SLE and secondary Sjögren's syndrome (SS), anticitrullinated antibodies in RA, scleroderma and psoriatic arthritis (PsA), or it may be negative. The situation is further complicated by the fact that these entities may overlap, a condition referred to as overlap syndrome. An example of an overlap syndrome is mixed connective tissue disease (MCTD), which develops in adults and children, and is characterised by the presence of at least two rheumatic diseases, typically SSc, scleroderma, polymyositis (PM) or dermatomyositis (DM), RA or PsA[4].

As damage progresses, producing more specific clinical and radiographic signs, the diagnosis becomes more obvious.

SYSTEMIC SCLERODERMA

In the case of systemic scleroderma, the hallmark of the disease is symmetrical involvement of the hands. Radiographs can demonstrate soft tissue resorption at the fingertips, acro-osteolysis with conical deformity of the phalanges, soft tissue calcifications within the fingertips and flexion contractures, as well as osteolysis involving numerous bones. Ultrasound may help differentiate the cause of malalignment in joints of the hands and reveal calcifications in soft tissues. CT is valuable in demonstrating paraspinal calcifications, while MRI may help determine their relation to neurological structures. The advantage of MRI is that it shows muscle atrophy or inflammatory myositis and is a useful tool for selecting a muscle biopsy site.

Juvenile scleroderma may present as a more limited form of systemic sclerosis than in adults. Inflammatory changes may lead to severe disproportions in skeletal development (linear scleroderma within the limbs, often described as *'en coup de sabre'*, i.e. sword wound scleroderma) (Figure 1). Early diagnosis and the introduction of more efficient treatment has significantly reduced the number of debilitating and disfiguring complications such as hemifacial atrophy.

SYSTEMIC LUPUS ERYTHEMATOSUS

The typical imaging appearance of systemic lupus erythematosus is symmetrical,

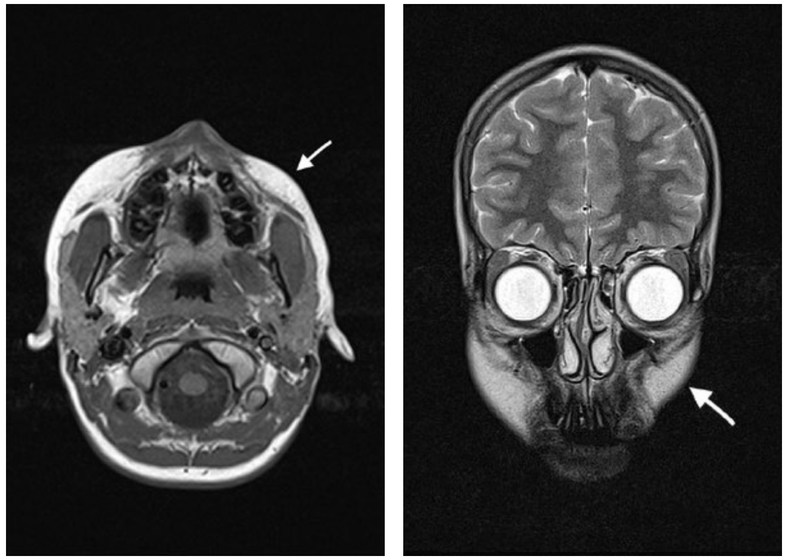


FIGURE 1

Axial T1-weighted (A) and coronal T2-weighted (B) TSE images in a 12-year-old girl with scleroderma *'en coup de sabre'* with significant atrophy of the subdermis (arrows).

FIGURE 2

Coronal T2-weighted STIR in a 13-year-old boy with dermatomyositis with involvement of numerous muscles of the upper and lower girdle, limbs, neck, pelvis and back (arrows).

deforming arthritis similar to RA but without erosions, with a predilection for hands, wrists, feet and knees (lupus arthritis, Jaccoud's arthropathy)[4]. Radiographs may show acro-osteolysis, with deformities of the hands and feet, periarticular calcifications, erosions (in the rhupus form), acral sclerosis and osteonecrosis. Ultrasound and MRI may demonstrate tenosynovitis and tendinosis, tendon tears, synovitis and erosions. MRI additionally shows BME and avascular necrosis.

Juvenile SLE often begins with transient arthritis, usually involving the knees, ankles, hands and wrists. Jaccoud's arthropathy is uncommon, and erosions only develop rarely.

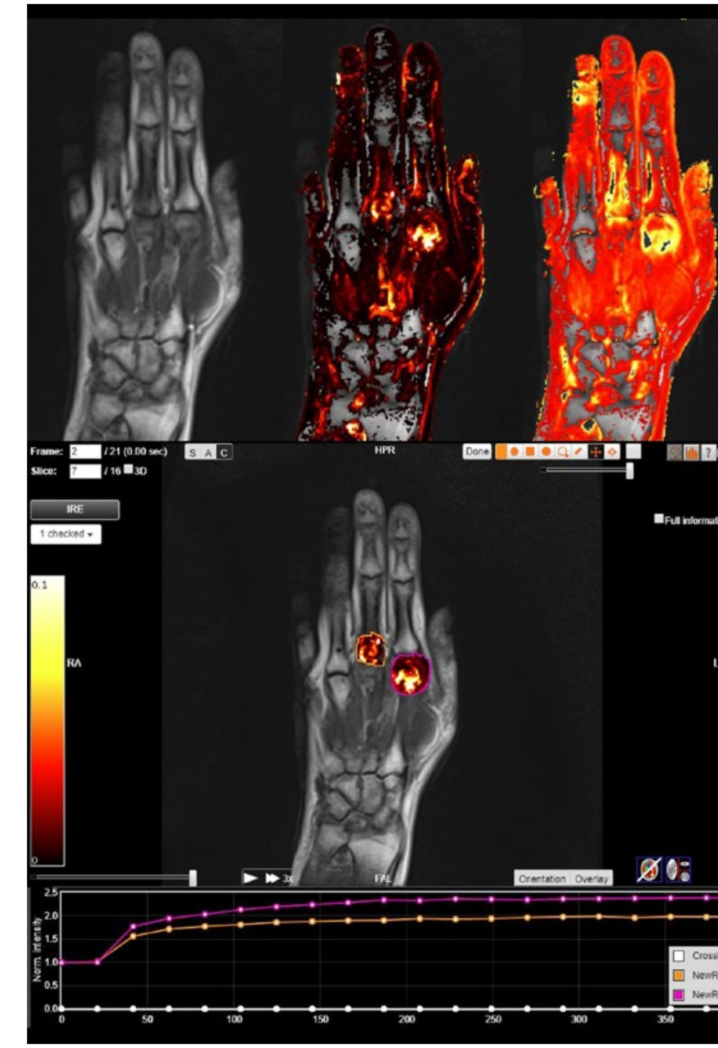
POLYMYOSITIS AND DERMATOMYOSITIS

Polymyositis and dermatomyositis are diseases where whole body MRI (WB-MRI) has revolutionised early diagnosis. Short tau inversion recovery (STIR) or T2 fat-suppressed WB-MRI has become the modality of choice for the assessment of muscle inflammation (Figure 2). This modality may be useful for identifying a site for muscle biopsy, which is the fundamental diagnostic tool. As an imaging biomarker, STIR/T2FS MRI may help determine treatment efficacy or the degree of chronic damage, presenting on T1-weighted images as fatty involution of muscles[5].

WB-MRI is also useful for diffuse fasciitis with eosinophilia (eosinophilic fasciitis, Schulman disease) which presents with symmetrical fasciitis and cellulitis of the muscles within the extremities, body and neck. MRI can be used to determine the site for a biopsy and for treatment monitoring.

FIGURE 3

Dynamic MRI study of the left hand with motion artefact correction (Dynamika, IAG, Image Analysis Group) in a 34-year-old man with undifferentiated arthritis showing an enhancing synovitis of the 2nd and 3rd MCP joints. Upper row: T1 TSE (no map); IRE map (initial rate of enhancement) and ME map (maximum enhancement); middle row: IRE map restricted to ROIs on 2nd and 3rd MCP joints; bottom image: the corresponding signal intensity curves, purple (2nd MCP) and orange (3rd MCP).



POLYMYALGIA RHEUMATICA

Ultrasound and whole body PET/CT have improved our understanding of polymyalgia rheumatica (PMR), a disease that affects the shoulders, hip girdle or neck. The addition of ultrasonography to the EULAR/ACR scoring algorithm has improved the specificity in distinguishing PMR from non-PMR patients to 81% and in discriminating PMR from other shoulder disorders to 89%[6].

In systemic vasculitides of large, medium and small vessels, as well as variable vessel vasculitis, imaging enables the evaluation of morphological changes and metabolic activity (using PET/CT); however, there are still challenges regarding imaging of the microvasculature.

CONCLUSION

In conclusion, modern imaging has greatly contributed to the reduction of disability and functional impairment in the daily lives of patients with rheumatological diseases. MRI has become a fundamental tool in the early diagnosis and treatment monitoring of rheumatic diseases, gaining the status of an imaging biomarker, particularly for myopathies, fasciitis and post-inflammatory muscle atrophy. It has also become a new standard for work-up of early avascular necrosis (AVN) and a promising tool in the diagnosis of undifferentiated arthropathies (Figure 3).

In the next few years, through the engagement of radiologists, rheumatologists, immunologists, molecular biologists and IT teams, it is expected that radiomics and radiogenomics will further improve our knowledge. The improved recognition of the key mediators and factors involved in these diseases, together with the ability to detect alterations in gene expression and DNA methylation, as well as the availability of micro RNA profiling, will enable us to find the best imaging and epigenetic biomarkers to allow the early detection and monitoring of rheumatic diseases.

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Prof. Cotten has authored more than 225 papers and 145 book chapters, and edited six books.

30

PERIPHERAL NEURO-PATHIES

Imaging in peripheral neuropathies

By **Gustav Andreisek** and **Hannes Platzgummer**

INTRODUCTION

Imaging plays an increasing role in the management of peripheral neuropathies and it has gained much attention in recent years, not only from radiologists, but also from clinicians[1, 2]. Imaging centres that already offer peripheral nerve imaging have reported a steep increase in patient referrals for either ultrasound or magnetic resonance imaging (MR neurography)[3].

Since the early days of radiology, imaging of the central nervous system has been a major focus, both clinically and in research. However, the peripheral nervous system has not received the same attention, even though peripheral nerves connect the brain and spinal cord to the periphery of the body. Malfunction of peripheral nerves includes sensory disorders and motor dysfunction and may cause severe disability, reduction in quality of life and sometimes even reduced lifespan. Peripheral neuropathies include a variety of different aetiologies, including congenital and hereditary disorders, endocrine and autoimmune disorders, metabolic and inflammatory disorders, infectious diseases, trauma and post-operative disorders, tumour and mass lesions, and static or dynamic compression syndromes[4].

CLINICAL EVALUATION

The evaluation of peripheral neuropathies has traditionally relied on the patient's history, clinical examination and electrodiagnostic testing. However, the final diagnosis often remains unclear since clinical examinations may be difficult to perform or because electrodiagnostic tests show ambiguous results. Therefore, imaging is not only used as a problem-solving tool in selected patients but more and more as a standard exam for many patients with neuropathic disorders. Imaging can provide clinicians with additional, new information that aids verification of pathological abnormalities, excludes differential diagnoses, allows reliable documentation of the location or extent of a disease, and supports therapeutic decision making. Nerve imaging may also be used for staging and follow-up in benign and malignant diseases, as well as to guide therapeutic injections or even minimally invasive surgical interventions.

ULTRASOUND AND MR NEUROGRAPHY

The main modalities for imaging of peripheral nerves are ultrasound and MR neurography[5]. For the former, high resolution ultrasound probes, as well as the latest techniques such as elastography and contrast-enhanced ultrasound, might be employed. Increasingly, ultrasound is used by referring clinicians. For them, ultrasound is the perfect extension of their traditional diagnostic portfolio and they frequently use ultrasound during initial clinical examinations as a part of the routine work-up. Imaging of the peripheral nervous system is underrepresented in the radiology training curriculum. The clinician's advantage is familiarity with the anatomy of the peripheral nervous system, as well as knowledge about innervation patterns of nerves and muscles and the characteristics of the various neuropathies. Thus, any radiologist starting with nerve imaging has to invest a significant amount of time and dedication to keep up with the level of neurologists[6]. Once well trained, specialised radiologists can perform nerve ultrasound with great accuracy and with the additional benefit of access to multimodal imaging.

MR neurography is a new term which nerve imaging specialists recommend to use whenever nerve-specific MR protocols are employed (e.g. nerve-dedicated 2D sequences, high-resolution 3D imaging with good fat or vessel suppression and with multi-planar reconstructions)[7, 8]. MR neurography may also include functional MR sequences such as diffusion-weighted imaging and diffusion tensor imaging, which can be used for both qualitative and quantitative evaluation of peripheral nerves. MR neurography is typically performed by radiologists who are specialised in the evaluation of peripheral nerves. Detailed knowledge about nerve anatomy, innervation patterns and nerve pathologies is mandatory for reliable image evaluation and interpretation of abnormal findings.

CURRENT STATUS

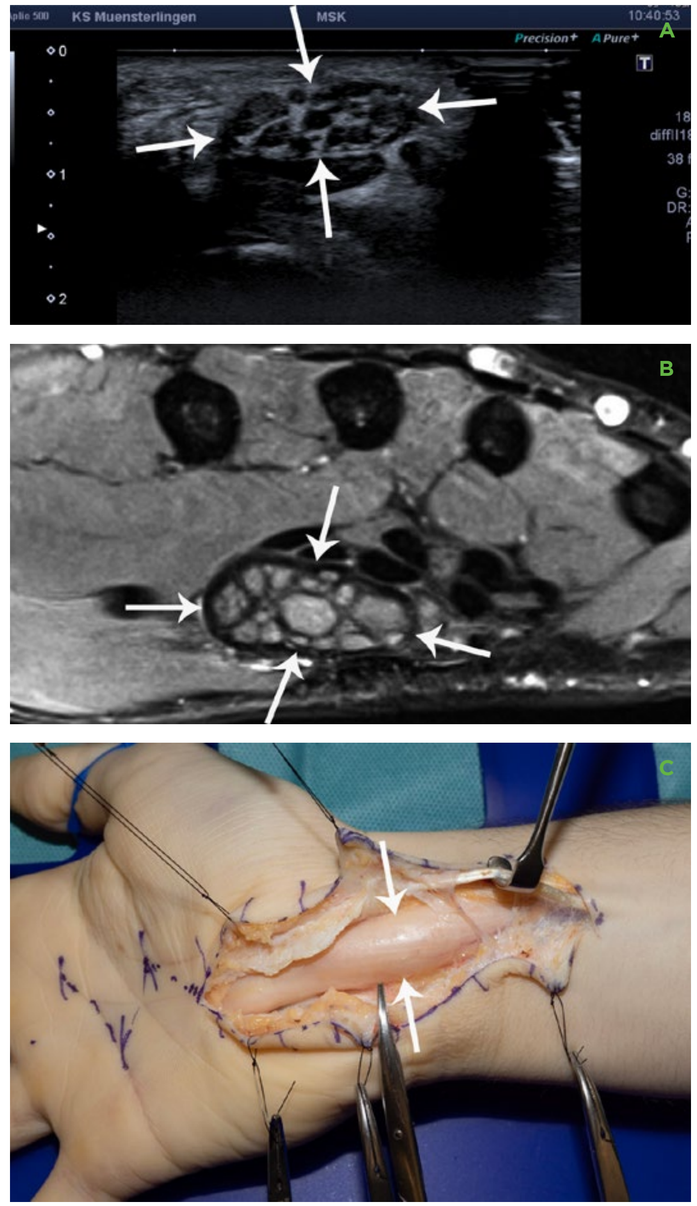
Over the past few years, there has been a steep increase in the number of publications about peripheral nerve imaging in the radiological literature. At the same time, almost all congresses have started to introduce nerve imaging teaching sessions, courses and workshops. In some countries dedicated societies for peripheral neuropathies have been founded, which typically include not only radiologists but also neurologists, plastic surgeons and orthopaedic surgeons, as well as rehabilitation specialists. This interdisciplinary approach reflects the daily clinical situation in many centres, as peripheral neuropathy cases are best discussed in interdisciplinary rounds[7]. This helps to avoid radiological misinterpretation and improve the learning curve. Case-by-case discussion is not a sign of weakness but strengthens the role of MSK radiologists in interdisciplinary teams.

The current literature about peripheral nerve imaging has weaknesses. Most publications deal with technical advances in nerve imaging. Unfortunately, relatively few studies deal with the outcome or the implication of imaging on therapeutic decision-making[9, 10]. However, those few studies show a remarkable impact. We believe that the observed increase in referrals in daily routine is a direct consequence, suggesting that the sparse literature might not be wrong about the importance of imaging in the field of peripheral neuropathies.

The impact of peripheral nerve imaging can best be exploited when preselected patients undergo these exams. Therefore, radiologists should step up and actively approach clinical partners to discuss patient selection and imaging pathways. Not all patients are suitable for nerve imaging studies and well-defined indications will help to

FIGURE 1

A 20-year-old male patient with clinical symptoms of carpal tunnel syndrome. (A) Ultrasound revealed a massively enlarged median nerve (arrows) at the level of the carpal tunnel with thickened fascicles and a disproportionately high amount of echogenic internal epineurium. (B) MR imaging shows a pattern of nerve abnormalities pathognonomic for fibrolipomatous hamartoma with serpinguous nerve fascicles surrounded by epineurial fat as well as perineural fibrosis[13]. (C) Corresponding intraoperative image taken during carpal tunnel surgery shows massive nerve enlargement causing carpal tunnel syndrome.



increase the radiological impact and avoid wasting scan time and other resources.

LITERATURE AND FUTURE PERSPECTIVES

Detailed descriptions of ultrasound and MR neurography techniques are beyond the scope of this article. There are numerous good and very recent publications already in the literature. Those articles summarise the current status as well as the future perspectives. High-resolution ultrasound and high-resolution MR imaging of peripheral nerves are currently performed in most imaging centres, using standard ultrasound techniques and standard MRI techniques (T1, T2, fat sat, post contrast). Despite the great advantages of diffusion-weighted imaging and diffusion tensor imaging in MR neurography, these techniques are still not routinely used and they remain technically demanding. They also lack standardisation and current literature does not provide enough normative values[4, 11].

It is a task for the radiology community to work on developing the knowledge about these functional imaging techniques in the coming years, as it has been shown that functional imaging parameters such as fractional anisotropy (FA) and apparent diffusion coefficient (ADC) may act as biomarkers. Thus, they could potentially be used like laboratory values in the future. Great potential also lies in the application of nuclear medicine techniques, in particular in the use of nerve specific tracers[12]. Initial reports in the literature show that specific tracers may have the potential to display not only sites of abnormal glucose activation but also the source of pain. These are still reports based on preclinical studies, and routine application is far from near, but researchers are trying to overcome current boundaries.

CONCLUSION

Imaging in neuropathies has found its way into clinical routine. Nerve imaging techniques are offered by more and more institutions and practices. We advise all beginners to get familiar with peripheral nerve anatomy and the different neuropathies, as well as possible treatment options, to get the best out of the exams and to keep the value of imaging as high as possible. Interdisciplinary approaches are recommended. Advanced imaging techniques with great potential for the future are currently being investigated in preclinical and clinical studies and we expect to see them in clinical routine in the coming years – at least in selected cases.

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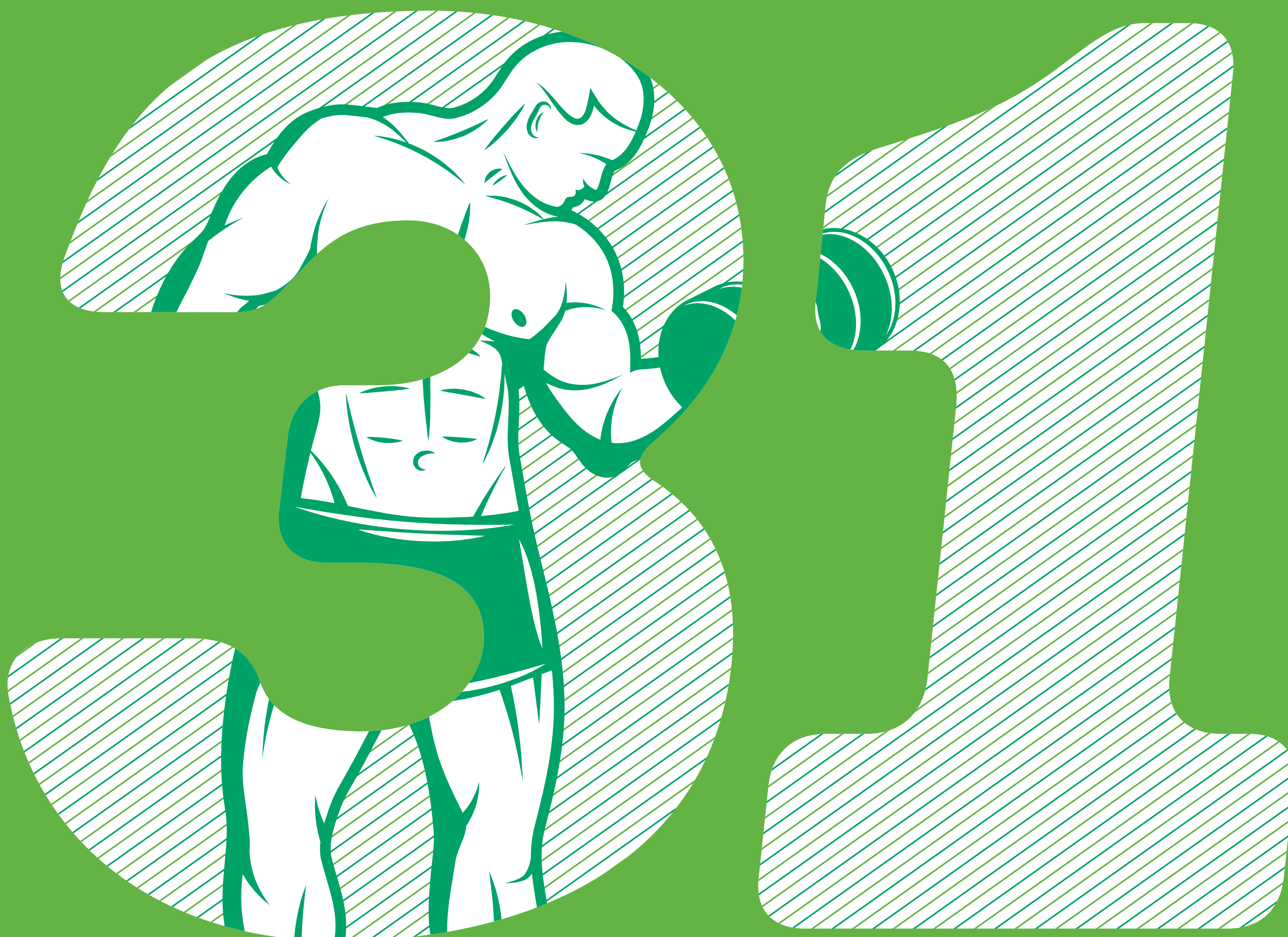


31

CASE-BASED SIMULATIONS **EDUCATION**

CASE-BASED SIMULATIONS

How do we educate our successors?

By **Richha Arora**

How we educate our successors is vital to how we meet the triple aims of the highest possible standard of health for our patients, medical care experience and value of care.

Medical education research is an important, continually evolving area, which focuses on the pros and cons of various teaching methodologies in an effort to bolster the preparation of future clinicians for a new century. There is a growing trend of moving from the traditional idea of educational outcomes being determined by curricula towards educational objectives being determined by the healthcare needs of the population[1].

Due to the existing practice of evidence-based medicine, radiology has become an integral part of most patients' management. Overwhelmingly, clinical environments have become more complex and diverse, and healthcare problems more complicated over the years. On top of that, musculoskeletal radiology has enjoyed a progressive and productive status over the last few decades. This is especially true for sports imaging, due to a steady increase in athletic activity and the resulting number of sports injuries in all age groups, which 70% of people experience in their lives, with a more than 50% increase in incidence of sports related injuries compared to the previous decade.

Accordingly, musculoskeletal radiologists have emerged as team leaders, playing a pivotal role in the management of athletes of all ages, elite or weekend warriors, professional or amateur. Additionally, historical teaching with standard textbooks and lectures lacks clinical scenario simulation, in addition to being monotonous and boring. As a consequence, medical educators are urged to take on the arduous task of backing up standard radiology curricula with new innovative methods of teaching, along with gaining further proficiency in one or two subspecialties for vitally required 'integrative problem solving of patients' and to be more useful to clinical colleagues[2, 3].

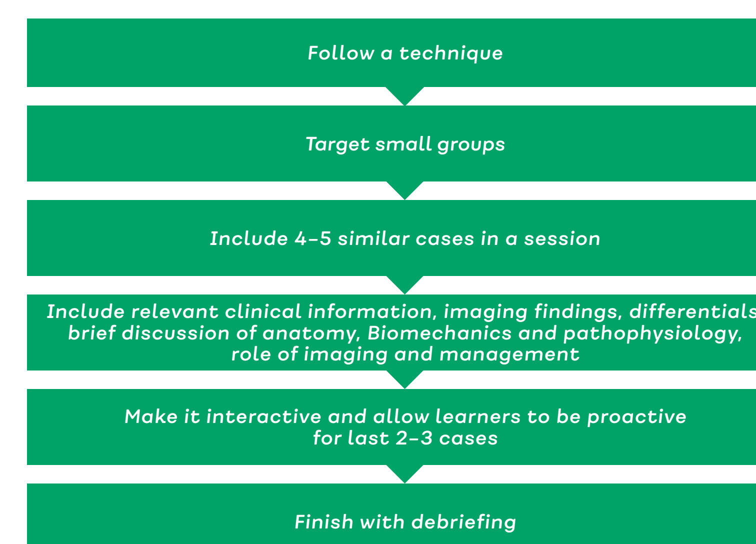
It is important for musculoskeletal radiologists to not only be aware of imaging findings and prognoses of various musculoskeletal pathologies, including rheumatological disorders, trauma, and degenerative and neoplastic conditions, but also to understand anatomy, biomechanics, pathophysiology and medical and surgical treatment of these patients.

Case-based simulations use trigger cases in clinical practice to impart knowledge pertaining to a particular topic and are considered to be a high-fidelity simulation (HFS) education method. Case-based teaching is not only interesting, but also enables interactive learning and is a fruitful approach to improving clinical reasoning competency, in addition to invigorating critical thinking and enhancing communication skills. It is also a productive technique for indoctrinating a systematic approach to various practically encountered clinical conditions.

The trick for the tutors to achieve good educational outcomes is to show a small group of pupils a few similar cases pertaining to mimicking diseases and follow a ritual of discussing all the relevant aspects pertaining to a case. Discussion may start with the patient's demographics, proper clinical history and examination findings, imaging findings, differential diagnosis, and final diagnosis; then proceed to a brief introduction and discussion of anatomy, biomechanics and pathophysiology, and management of all the related entities. It is a good idea for the teacher to be more vocal for the first one or two cases and allow learners to be more proactive for next two or three cases to make the session more interactive and rewarding, which is a way of heading towards 'competency based

FIGURE 1

Conceptualised case-based simulations in musculoskeletal radiology (high-fidelity simulation education method)



medical education'. Furthermore, wrapping up sessions with a debriefing, where instructors and pupils review and reflect on what they have learnt and how to apply the knowledge to their future practice, makes the process more meaningful (Figure 1).

To summarise, a multifaceted case-based teaching approach (in teaching of not only radiology registrars and fellows, but also for continuing medical educational programmes for practicing consultants), integrating traditional textbook learning and basic sciences lectures with simulation of clinical cases, is indispensable for improving clinical reasoning competency, which is crucial in ever-evolving musculoskeletal radiology practice. It is also indispensable in helping the development of more personalised approaches to various routinely encountered clinical scenarios, also known as precision medicine, which is the need of the hour. It is also a step forward in our mission to use education to strengthen inter-dependent healthcare systems[1]. Moreover, concluding the session with debriefing, thereby confirming and reinforcing the contents learnt in the lecture, also helps to make the educational experience more interactive, interesting and effective.

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is a fellowship-trained musculoskeletal radiologist working as a Consultant MSK Radiologist at the Department of Radiology of the Countess of Chester Hospital, UK. She did her MSK fellowship at Leeds Teaching Hospitals, UK and is also an alumna of the National University of Singapore and fellow of the Royal College of Radiologists, UK. Her research interests include rheumatology imaging and sports imaging. She has authored a book on preparation for FRCR 2B examinations. She has more than 30 publications and two book chapters to her credit and is also a member of the editorial board of many indexed journals. She has given invited guest lectures at many national and international conferences.

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32

CASE-BASED SIMULATIONS **EXPERIENCE**

CASE-BASED SIMULATIONS: A real-life experience

By **Omar M. Albtoush**

Medical education is a continuous process that should take into consideration changing demands in every medical field in order to keep learning attractive and keep learning objectives up to the expected standards.

Radiology is considered one of the most rapidly expanding fields of medical science, due to its intimate link with the technical development of radiological equipment, as well as the accelerated invention of applied imaging techniques.

The traditional textbook-based teaching approach represents an important strategy for teaching medical sciences during all stages of graduate and postgraduate medical learning, though it faces many challenges, including the unremitting expansion of radiological science as well as the need to keep learning motivation as high as possible. Scarcity of learning motivation can be a serious constraint when aiming to cover continuously expanding teaching targets, which for radiology registrars, for example, have to be met during the duration of residency.

It is widely agreed that discussion of interesting radiological cases is an attractive learning strategy, but it has the drawbacks of delivering a message that is limited to the presented work and being easily forgotten by the audience, especially when they lack well-structured, supporting information. However, a little extra work from the presenter could overcome these obstacles, resulting in the communication of more information and a more memorable experience for the attendee. That extra work could be accomplished by presenting interesting cases to catch the audience's attention, then proceeding with systematic descriptions of other related entities in 'case-based simulations'. This approach encompasses a well-organised teaching plan by giving related supporting information in order to construct a theme-related scheme.

In order to test the value of case-based simulations in teaching a musculoskeletal imaging theme (stress fractures of the lower limb) among junior residents in my department, we carried out a teaching test to objectively compare the outcome of different teaching strategies. One article was used as a reference in order to unify reading options for participating residents[1].

Three groups of residents were included; the first group were asked to read an article about the topic; the second group were invited to a case presentation about stress fractures at the femur neck and at the end of the presentation asked to read about other common locations of stress fractures involving the lower limb; and the third group were invited to the same case presentation, which was followed by descriptions of other common locations of stress fractures involving the lower limb.

After three months, the three groups were each given an unannounced test. The test showed the same entities outlined in the given article. The results showed that the third group was 23% more able to diagnose cases of stress fractures of the lower limb than the first two groups (Figure 1).

Musculoskeletal radiology encompasses a wide range of subspecialised entities related to sport, paediatrics, oncology and rheumatology. A musculoskeletal radiologist has to be familiar with different entities due to the fact that many diseases share common radiological manifestations between many subspecialties. Thus, case-based simulations could aid continuous medical education for postgraduate musculoskeletal radiologists by helping them to keep their knowledge about advances in all aspects of musculoskeletal imaging up to date, not only those related to their field of interest.

By starting from the clinical aspect in a case presentation and proceeding to the

FIGURE 1

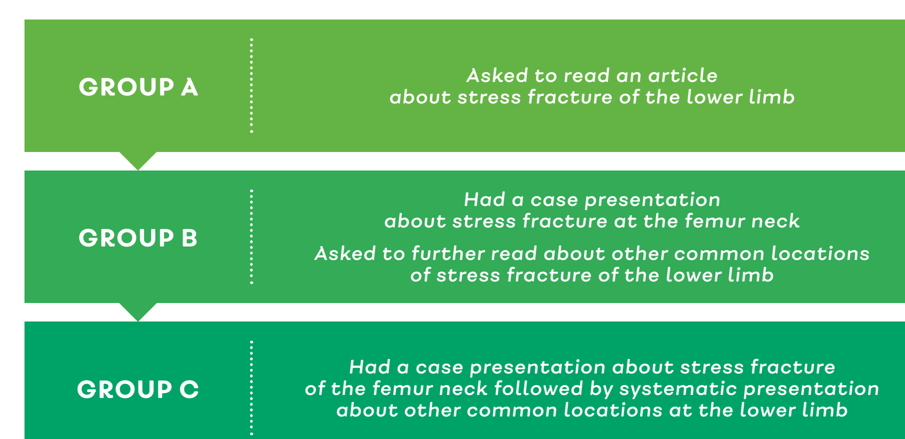
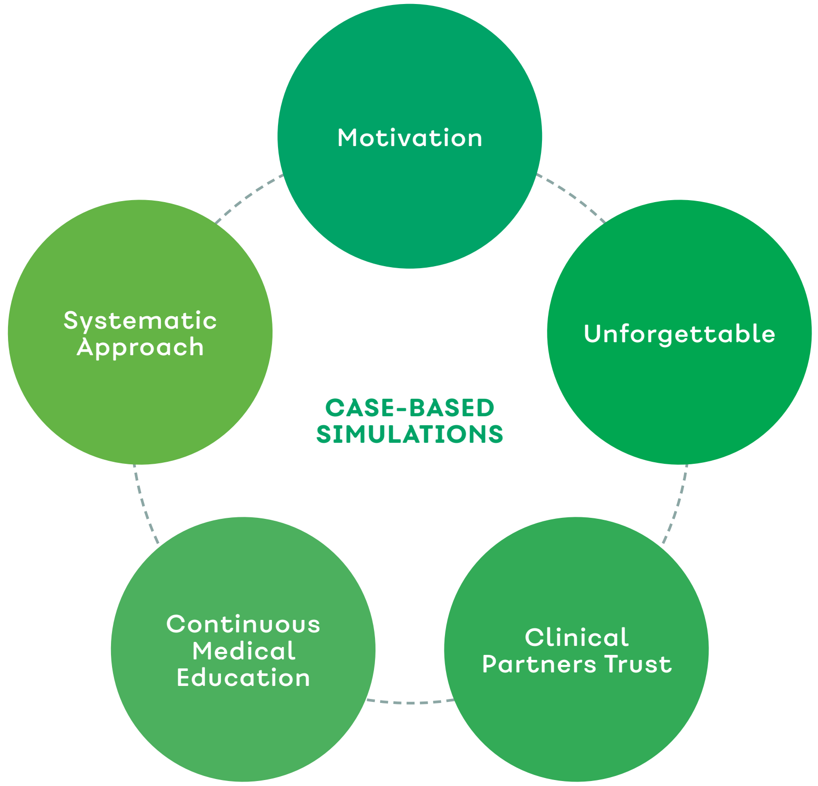


FIGURE 2



radiological manifestations, then trying to solve the presented work, followed by a systematic illustration of the linked entities, case-based simulations could help in strengthening our position in so-called turf battles, by convincing our clinical partners to trust our multimodal approach.

In conclusion, a future plan for more comprehensive incorporation of case-based simulations in teaching strategies in departmental and interdepartmental meetings, conferences, and continuous medical education in musculoskeletal imaging is important to enhance and guarantee the building and maintenance of learning motivation, besides the establishment of trust with our clinical partners about our coherent approach (Figure 2).

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33

MSK EDUCATION

BRINGING MSK KNOWLEDGE AND SKILLS TO THE POINT OF CARE

MSK radiology education

By **Miraude Adriaensen, Christiane Nyhsen** and **Carlo Martinoli**

INTRODUCTION

In the wake of unavoidable integration of artificial intelligence into our practice, with significant work flow changes surely impending, we realise again how fast our work is evolving. We will ultimately have no choice but to adapt and lead these changes, so that we can continue to provide an excellent service for our patients in sustainable working conditions.

Radiology conferences play an integral role in updating radiologists and radiographers. However, due to financial and time constraints, only a limited number will be able to attend these. This is why online lectures and other training materials are very important and the development of further resources for learners at all levels is highly desirable.

MSK RADIOLOGY EDUCATION

Education in MSK radiology can occur at any stage during a radiologist's career: during medical school, during residency, during subspecialty programmes and as part of CME/CPD (continuing medical education/continuing professional development). Up-to-date MSK radiology curricula are already available for medical school, residency and subspecialty programmes, but the largest group to be reached are practicing radiologists, both general and subspecialised.

The European Training Curriculum (ETC) for Radiology contains MSK curricula for the undergraduate level (U-curriculum), and for radiology residents (level 1 and level 2) as well as requirements for subspecialist training (level 3). Obtained knowledge and skills can be certified through the European Diploma in Radiology (EDiR, level 1 and 2) and the ESSR Diploma in Radiology (level 3). In addition, the European School of Radiology (ESOR) offers many valuable courses and the opportunity to train at centres of excellence.

A high standard of initial training is an important part of ensuring there is a workforce of competent radiologists across Europe. Work remains to be done to harmonise radiology training across Europe.

Following on from specialist training, continuous professional development is very important. Lifelong learning is and should remain an integral part of educational efforts. Practicing radiologists may have to adapt to workplace changes or take on new roles that require additional competencies. All radiologists will benefit from 'refresher sessions' to recognise those rarer findings, not commonly seen outside subspecialist university centres. Furthermore, increasing mobility throughout Europe and other workforce issues may mean radiologists need to retrain in other fields throughout their careers.

A large number of radiologists already access educational materials provided at conferences and published in a wide array of journals. However, not every working radiologist has the financial resources to attend lectures or subscribe to journals. Developing free accessible online training materials is therefore a very valuable task. New trends in education, which increasingly implement a multimedia approach with interactive elements, will render these more enjoyable and probably more effective.

Furthermore, current workforce shortages mean that radiologists work more, with a reduction in granted study leave, and therefore less spare time and energy for education. For this reason we promote the delivery of short, online modules. 'How to' tutorials or sessions like 'important points', 'top tips', and 'learning from mistakes' are great formats that are digestible even in the evening after a long day at work. It should also be possible to break up longer tutorials, to pause and return to later.

Recording CME credits that are accepted throughout Europe, demonstrating that our profession has a profound interest in keeping up to date, will reassure patients and healthcare providers. Radiologists should take the lead in this respect, preventing imposed recertification through exams. Educational materials should have the learning needs of users in mind and the wisdom of Albert Einstein that "education is not the learning of facts, but the training of the mind to think". So CME-assessment at the end of a module should not consist of formal exam questions. It should be part of the learning process, a reinforcement of newly acquired knowledge and skills with instant feedback, explaining why an answer is correct or not.

CONCLUSION

Radiology technology is evolving at a fast pace, so lifelong learning will remain essential for all radiologists and radiographers.

ESSR EDUCATIONAL COMMITTEE

AUTHORS

Miraude Adriaensen, Danoob Dalili, Elena Drakonaki, Roar Pedersen, Herwig Imhof, Philip Robinson, Filip Vanhoenacker, Carlo Martinoli

The Educational Committee of the ESSR (European Society of Musculoskeletal Radiology) was founded on the 1st of January 2003

CHAIRS

2003-2006: Prof H. Imhof
2006-2009: Prof F. Vanhoenacker
2009-2012: Prof P. Robinson
2012-2018: Prof C. Martinoli
2018-present: M. Adriaensen

MISSION

The vision and ethos of the committee is to enhance the profile and recognition of subspecialist musculoskeletal radiology throughout Europe through promoting standards of excellence in education and training.

TASKS AND RESPONSIBILITIES OF THE COMMITTEE INCLUDE

Managing the Diploma of the European Society of Musculoskeletal Radiology
https://www.essr.org/diploma/

Actively providing MSK examination questions for the EDiR (European Diploma in Radiology)
https://www.myebr.org/edir/certification-of-excellence

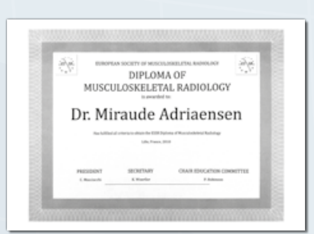
Co-directing the ESSR Webinar Program
https://www.essr.org/education/webinars/

Representing the ESSR in the Educational Committee of the ESR (European Society of Radiology)
https://www.myesr.org/about/organisation/statutory-committees/education-committee

Regularly updating the chapters of the European Training Curricula for Radiology related to musculoskeletal radiology
https://www.myesr.org/education/training-curricula

Participating in the Evaluation Committee of the Exchange Program for Musculoskeletal Radiology Fellowship of the ESOR (European School of Radiology)
http://www.esor.org/cms/website.php?id=/1802/en/programmes/exchange_programmes_for_fellowships/musculoskeletal_radiology.htm

Ex-officio member of the ESSR's 'Young Club'
https://www.essr.org/society/young-club/



Diploma Certificate, awarded 2010

ESSR Diploma holders

Total number of ESSR Old diploma holders: 148 members

Total number of ESSR New diploma holders: 26 members (since 2015)

Radiologists need to lead this process by example, thus avoiding the implementation of recertification exams by governments or healthcare providers, and to reassure patients. Focused education at the point of care, with online free accessibility is at least as important, if not more so, than high-end subspecialist publications. Designing online resources to be short and to the point, with interactive elements and feedback if possible, will increase use among learners. Concrete tips and tricks, provided by experts and applicable to daily practice, will be the most valuable for trainees and general radiologists, as well as those retraining due to workforce changes. Like Albert Einstein stated, our "Intellectual growth should commence at birth and cease only at death".

FURTHER READING

https://www.myesr.org/education/training-curricula

https://www.myebr.org/edir/certification-of-excellence

https://www.essr.org/diploma/

http://www.esor.org/cms/website.php?id=/1802/en/programmes/exchange_programmes_for_fellowships/musculoskeletal_radiology.htm

https://www.essr.org/education/webinars/

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is a radiologist (since 2009) and chief educator in musculoskeletal radiology (since 2012) at Zuyderland Medical Center in Heerlen, the Netherlands. After receiving her MSc in Health Services Research and her master's degree in medicine, both in the summer of 2000, Dr. Adriaensen spent a year as research fellow at Massachusetts General Hospital (MGH) and was appointed as a member of the professional staff of MGH and Harvard Officer at Harvard University. Upon receiving her MD at Erasmus University Rotterdam in 2003, she started her residency at University Medical Center Utrecht in February 2004. From January 2007 onwards, she was trained at Meander Medical Center.

In 2008, she registered as a radiologist and she was the first Dutch resident in radiology to receive a visiting scholarship offered by the European School of Radiology (ESOR). In 2010, she received the diploma of the European Society of Musculoskeletal Radiology. In 2011, she completed her PhD thesis at the University of Utrecht. Since 2012, she has been registered as an epidemiologist (highest level) at SMBWO (Foundation for Biomedical Scientific Research Training). She is currently the chair of the Education Committee of the ESSR, Member-at-Large of the Executive Board of the UEMS Radiology Section, a member of the Standards Committee of the European Board of Radiology, and a member of the Policy Committee of the Accreditation Council in Imaging.

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PROF. CARLO MARTINOLI, MD

has been known for more than 20 years as one of the most prominent teachers in musculoskeletal ultrasound. Prof. Martinoli is a co-author of 'Ultrasound of the Musculoskeletal System', still one of the most popular reference books on MSK ultrasound, which has sold more than 7,000 copies since its first publication in 2007.

Prof. Martinoli is Assistant Professor of Radiology and Associate Professor of Radiology at the University of Genoa. He has published more than 200 scientific articles in international medical journals and has held more than 1,000 invited lectures at international courses or congresses. He is the current ESSR delegate of the ESR Education Committee.

In 2012, Prof. Martinoli founded the International Society of Peripheral Neurophysiological Imaging (ISPNI), a multidisciplinary society that aims to advance global education and research in peripheral nerve imaging. He developed the Haemophilia Early Arthropathy Detection with Ultrasound System (HEAD-US system), a point-of-care ultrasound system for screening synovial joints in haemophiliac patients, which is currently the global standard for identifying subclinical haemophilia and influencing treatment options. He is also a member of the Imaging Expert Working Group of the International Prophylaxis Study Group (IPSG) for Haemophilic Arthropathy.

34

TURF WARS

Turf wars in MSK radiology

By **David John Wilson**

INTRODUCTION

Since the days of Asclepius, son of Apollo and the first doctor-demigod in Greek mythology, there has been collaboration, conflict and rivalry in medicine. It is inevitable that when Hippocrates trained in the Asclepion (a healing temple) on the island of Kos, he clashed with other healthcare professionals. Open and supportive collaboration is how medical practice works best, but this easily breaks down.

THE DIAGNOSTIC ROLE OF RADIOLOGISTS

Our profession developed from a desire to understand and use Wilhelm Conrad Röntgen's discovery. The pioneers of Roentgenology/skiagraphy/radiology, as it was variously known, were unique in medicine because they owned the equipment and understood machines generating ionising radiation. Nowadays, surgeons and many other professionals routinely use imaging equipment that is easy to use and requires little training to employ safely. They will become more experienced in their field than a diagnostic radiologist who must cover a range of disease processes. Our profession may become less valued[1].

We must firmly argue our case for the routine involvement of radiologists in image interpretation, based on our broad knowledge of radiological abnormalities and medicine. As the radiologist in trauma meetings, I rarely added to the understanding of the surgeon who had seen the patient, reviewed images and was planning the operation. However, by detecting the malignancy or metabolic bone disease, I added value to the patient's care. I found that when I mentioned the shadow on the lung to the treating surgeon before the multidisciplinary team meeting, they showed the assembled team the lesion without acknowledging my involvement. I realised that it would be better to wait until the surgical team were about to move onto discussion of the next case before raising my hand and saying, "what are you going to do about the lung cancer?"

We must continually educate our colleagues and promote the importance of our independent analysis of images at multidisciplinary team meetings. To do this we must provide sound, structured reporting and regular and published audits of the quality of our practice[2, 3].

If we do not understand what the clinician needs to know, how they might treat the patient and what is the up-to-date medical environment then we become of little service. The radiologist who understands modern treatment methods and visits the operating theatre will gain the respect of their colleagues and will be more useful.

A warning that we are not up to date is when we issue a report that reads 'Position as shown surgery'. This is a world apart from 'There has been internal fixation of the fracture with an intra-medullary nail looked at both ends. There is no evidence of complications of the surgery. The length of the treated limb is the same as the opposite side and is no change in rotation since the preoperative images'.

THE MULTIDISCIPLINARY TEAM

The radiologist sitting at a workstation reviewing images from hospitals on the other side of the country may easily forget that they are a doctor with direct responsibility to the patient. On detecting abnormalities, we must communicate the information in a timely and effective way. This means that the radiologist must know what treatment is practical and how soon it should be delivered. This is where the multidisciplinary process is essential, by meeting in person or electronically with the whole team. Radiologists, surgeons, sports physicians, pathologists, physical therapists, nurses, and other healthcare professionals need to know what imaging investigations work, what treatment is possible, and what other investigations are needed. No one practitioner can have all this knowledge, but each must understand their colleagues' roles and skills.

We must be involved in continued education, teaching the value of collaboration, helping health service administrators to understand the need to fund the multidisciplinary team process.

When this process breaks down, outcome and the quality and value of our practice are diminished.

THE CLINICAL ROLE OF RADIOLOGISTS

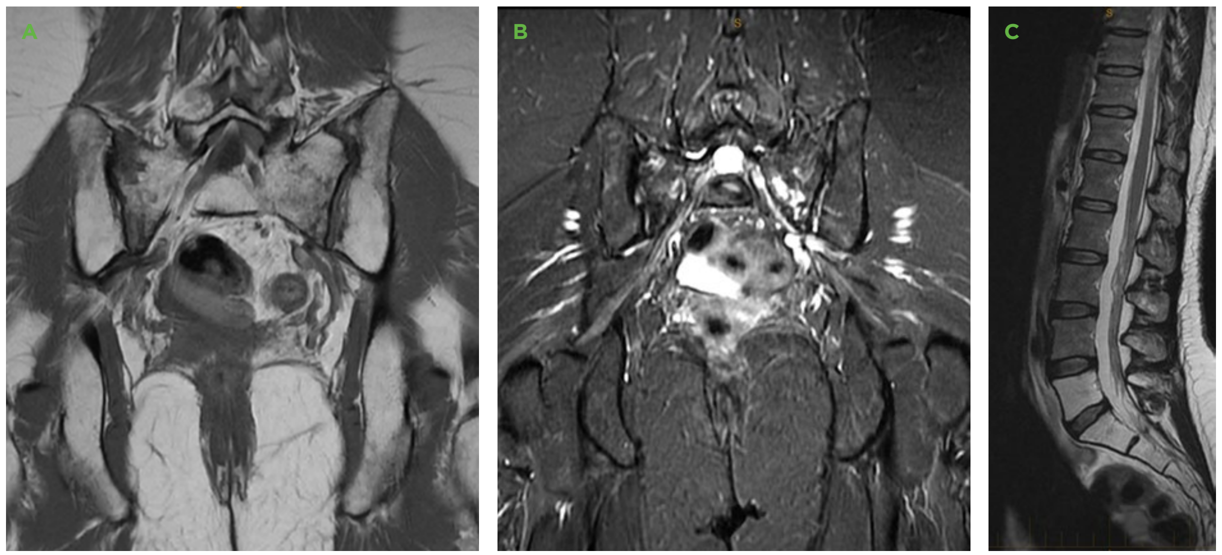
Interventional radiologists are skilled in three-dimensional image interpretation, providing a greater understanding of depth, direction and anatomical relationships. Most chose the specialty of radiology because they have this skill and it is not necessarily one that can be learnt by those in other specialties.

However, there are substantial pitfalls when using the workflow used in diagnostic interpretation for interventional practice. The diagnostic radiologist receives a message asking for an examination with a brief description of the clinical background. If we use the same process for intervention, we do not know enough about the patient to be safe. We have not engaged with the patient personally. It is quite possible that the referring clinician is not sure what the radiological intervention involves and may not know all the risks.

The decision to undertake an image-guided procedure requires a wide knowledge of the patient's history and background, physical examination and laboratory investigations. Interventional radiologists must select the best procedure and communicate with the patient. There must be a plan for different outcomes,

FIGURE 1

A 42-year-old woman complaining of pain in the low back after running. MRI demonstrates insufficiency fractures of the sacrum (A, B). The sagittal projection of the lumbar spine (C) shows marrow changes resulting from previous radiation therapy for cervical carcinoma ten years earlier. The fractures are the result of radiation induced osteonecrosis.



including failure. The interventionalist must take responsibility for the outcome and decisions on what to do next, meaning that the interventional radiologist should regard referrals from a clinician as a suggestion not an instruction. This necessitates outpatient consultation with follow-up of patients.

For example, the most effective treatment of Achilles tendinopathy is physiotherapy, it is not appropriate to use injections when this has not been tried first.

THE REPORTING NURSE OR RADIOGRAPHER

There has been an exponential increase in imaging recently[4]. Training radiologists has not kept up in many parts of the world. This and financial constraints create pressure to train other professionals to interpret images.

For trauma radiographs there is considerable published evidence that the radiographer reporter can produce reports with sometimes better accuracy than radiologists[5]. In many countries, ultrasound examinations are performed and reported by sonographers who are not radiologists[6]. What does the medically qualified radiologist have that a trained and experienced non-medical practitioner does not? I believe this is a broad knowledge of disease processes and treatments. For example, identifying radiation necrosis as the cause of stress fractures (Figure 1).

It used to be desirable that those entering radiology had had some experience of medical or surgical practice, but many now start radiology

training without this experience. This trend means that it is debatable whether nurse or radiographer reporters are less skilled.

Currently litigation applies the same standards to the non-medically qualified reporter and radiologists. However, if there is failure to offer a diagnosis outside the referring specialty, an 'off-piste diagnosis', it will be harder to argue that those without a medical degree should be held to the same standards.

LESSONS FOR THE FUTURE

In writing this essay I have identified important principles:

- Communication between healthcare practitioners is mandatory for good medical practice.
- We must all appreciate and understand the skills and treatment methods of other specialties.
- Audit of our diagnoses and treatment outcomes is a fundamental part of practice.
- We are never fully trained; reading and education should be a lifelong process.

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He has considerable experience in all aspects of musculoskeletal imaging and is the editor of the principle textbook on MSK imaging. As a former President of the British Society of Skeletal Radiologists, former president of the British Institute of Radiology and a previous Medical Director of the Nuffield Orthopaedic Centre he has wide clinical, administrative and research experience.

Dr. Wilson is the father of six children and grandfather of five. He has a long career as an elite oarsman and is currently trustee of the local rowing club. He is an amateur viola player, preferring Baroque music.

35

LIFESTYLE AND CAREER

LIFESTYLE AND CAREER:
Insights into the life of a musculo-skeletal radiologist

By **Danoob Dalili, Ana C. Viera** and **Iris Kilsdonk**

INTRODUCTION

Often perceived as the more glamorous of subspecialties in radiology, musculoskeletal radiology has evolved with the emergence of new imaging modalities, protocol optimisation and image-guided diagnostic, therapeutic and palliative procedures, and it continues to do so.

Within the subspecialty, and as with medicine generally, there are further opportunities to subspecialise, which may be encouraged, depending on the institution. One may decide to pursue a career in sports imaging, primary bone and soft tissue tumours, metabolic disorders or rheumatological musculoskeletal disease.

However, the path to a career in musculoskeletal radiology is often neither straightforward nor simple. The road may be arduous, often challenging and 'character building', thus this chapter is forged on our experiences as young, budding, future musculoskeletal radiologists from around Europe. It is written to inspire and influence the next generation, derived from our successes, achievements and mistakes, offering insight to our future colleagues.

TRAINING

Radiology is considered the fastest advancing specialty in medicine, owing to its technological dependency. It is also one of the most attractive, with high competition ratios to acquire a place in a training programme, but with high likelihood of employment upon completion. Residency programmes vary from country to country. In the UK and Netherlands for example, the first three years are considered 'core' training, rotating through different modalities (US/CT/MR/plain film/fluoroscopy) and subspecialties (neuro, chest/cardiac, gastrointestinal, genitourinary, interventional, musculoskeletal, paediatric, oncology). Following this, subspecialty training commences in the final two years, with more sessions weighted towards the chosen subspecialty. Following training, depending on one's competency, skills and exposure, one may decide to pursue more higher level training in the form of a dedicated musculoskeletal fellowship, where designated time is spent developing or building on one's confidence in reporting imaging, performing image-guided procedures and further exposure to more complex disease entities.

The ESSR, in association with the European School of Radiology (ESOR), also provides opportunities for qualified residents from European countries to gain experience in another training environment and to kick off a subspecialist interest. The visiting scholarship programmes are primarily aimed at third to fifth year residents, keen to benefit from fellowship-style or modular training in a specific area of diagnostic radiology in a country other than their own, free of charge for three to twelve months. These are excellent opportunities to work supervised by specialist tutors, often passionate teachers and leaders in their respective fields from around Europe, whilst observing various practices in a chosen speciality and further developing skills and knowledge[1].

WHERE TO BEGIN?

Gaining exposure to radiology, particularly MSK radiology, early will allow you to envision your goals. In the Netherlands, medical students can choose an optional radiology internship after the regular rotations, to gain insight into the work and life of a radiologist. Increasingly, radiology is becoming part of the curriculum in medical schools and rotations obligatory, particularly in the UK. Alternatively, in the preliminary clinical years, one can gain exposure and insight in the form of 'taster weeks'. Seek role models in the subspecialty and endeavour to learn from them. Study their journey and set achievable, short-term and long-term goals for yourself.

1. Form a strong foundation of knowledge in anatomy and terminology for musculoskeletal pathology. In our opinion, there are several books and online resources which are essential tools for any budding musculoskeletal radiologist:

- Webinars: subscribe to the ESSR online webinars
- X-ray/CT/MR: *Fundamentals of Skeletal Radiology* by Clyde A. Helms, Elsevier Saunders, ISBN 1455751545
- US: *Ultrasound of the Musculoskeletal System* by S. Bianchi and C. Martinoli, ISBN 9783540281634
- MR: *MRI of the Knee, Elbow, Shoulder, Hip,* the book series written by the ESSR Sports Subcommittee
- https://breitenseher.eu/books-de.php
- MR: *Musculoskeletal MRI* by Clyde A. Helms, Saunders/Elsevier, ISBN 1416055347

- MR: *MRI Essentials* by Fischer, ISBN 9783981649130
- Website: https://radiologycorelectures.org/msk/ Musculoskeletal Core Lecture Series presented by the International Skeletal Society (ISS) and Society of Skeletal Radiology (SSR)

2. Participate in European courses and congresses. This helps you to gain more knowledge, but also to meet new colleagues and friends from different countries and exchange experiences and ideas:

- ESSR annual meeting
- ESSR periodic webinars
- ESSR winter and summer schools
- ESSR outreach courses
- ESSR subcommittee meetings (sports, ultrasound, tumour, and do not forget to join the ESSR Young Club Courses)
- EMRI Erasmus Course on Musculoskeletal Imaging
- ESOR Asklepios Course on Musculoskeletal Radiology
- IDKD Musculoskeletal Diseases

EXAMINATIONS

The European Diploma in Musculoskeletal Radiology (EDiMSK) could be a valuable tool in your curriculum as a young MSK radiologist. It is a recognised European qualification for MSK radiologists, endorsed by the European Society of Radiology (ESR), and represents a recognised qualification in musculoskeletal imaging that will assist you in the promotion of your skills and experience when dealing with other clinical colleagues and with the general public and patients[2, 3].

RESEARCH

With most residency programmes, research is encouraged but not enforced. Should all radiologists participate in research? Statistically, institutions that participate in research have been shown to have better patient outcomes. Engagement in research may or may not necessarily make you better in your day-to-day job when analysing and reporting images, depending on the type of research. It does, however, force you to keep up with the most recent literature and to think laterally, beyond the daily practice guidelines, ultimately finding ways to improve patient care. Research in the field of musculoskeletal imaging is important, with projects ranging from refinement of existing techniques to the development of new imaging technologies that can be used in patients for diagnostic or treatment monitoring purposes, or as instruments to increase our understanding of diseases. Academically oriented musculoskeletal radiologists may frame their own research groups. In a less demanding manner than other medical specialties, as a radiologist, you can easily engage with other departments and their ongoing research projects that require radiology support as part of their research trials.

FORGING THE ‘BULLETPROOF’ CV

Consistency is key. Whilst not essential, attending various courses over the period running up to applications or during residency, demonstrating a continued commitment to the specialty, will provide you an ‘edge’ against your peers. Participating in practical courses early will inevitably improve confidence in developing ultrasound skills, whilst you will invariably develop an awareness of the benefits and limitations of each imaging modality, a cornerstone of a well-rounded MSK radiologist.

Contributions to the European Congress of Radiology (ECR) and the ESSR annual conferences are also favourable, in the form of educational or scientific posters, scientific abstracts and EPOS (the ESR's Electronic Presentation Online System) presentations. Here, the resident has the opportunity to showcase the work of their institution or department on an international platform, gaining credibility and a track record as a solid foundation and investment.

Creating a poster can be very time consuming and should not be taken lightly, yet it provides an invaluable learning experience and an excellent starting point to build upon. Here you will learn the skills and discipline to write case reports, pictorial reviews and review articles. Since 2008, EPOS posters have had unique traceable DOIs. This educational platform provides the foundations for methods which, once mastered, can be applied to scientific studies, presentations and publications.

A DAY IN THE LIFE OF A MUSCULOSKELETAL RADIOLOGIST

The day-to-day practice of a musculoskeletal radiologist varies substantially depending on the type of hospital one decides to work in. In a small institution, one may be a part of a team of radiologists serving a small population, with everyone ‘chipping in’ to the ‘general’ work, whilst maintaining several sessions or hours during the week for musculoskeletal-specific imaging practices, including US, CT and MRI. In larger specialist orthopaedic hospitals, radiologists are subspecialised, predominantly focusing on MSK diagnostic reporting and procedures, such as diagnostic and therapeutic injections, aspirations, biopsies, cementoplasty and ablation techniques.

Besides reporting and performing image-guided interventions, the MSK radiologist plays a role of paramount importance in multidisciplinary meetings. For instance, in daily trauma, malignant bone tumour, soft tissue tumour, rheumatology and sports meetings, specific patients are discussed and treatment plans are made together with clinicians: sports physicians, physiotherapists, trauma and orthopaedic surgeons, oncologists, rheumatologists and even pathologists, all of whom depend upon the opinion of the radiologist.

A LOOK TO THE FUTURE …

With an aging population, demand for musculoskeletal imaging and intervention is continuing to rise. With this increase, we can predict or hypothesise that there will be an endemic of degenerative joint disease. There will also be demand for palliative procedures in musculoskeletal oncology, as precision medicine is beginning to emerge, leading to longevity in life expectancy in the fight against cancer. With the development of imaging technology, new MR sequences and (ultra)high field magnets, imaging will invariably increase in speed and diagnostic quality; the former leading to a greater demand for radiologists, particularly in the field of musculoskeletal imaging[4].

The advent of artificial intelligence remains a rather elusive phenomenon, but we are convinced that sooner than later these interesting deep learning systems will help us to improve diagnostic clinical care. We, as young radiologists, take into account that artificial intelligence will possibly lead to alternate workflows for the musculoskeletal radiologist.

All in all, the ongoing development of new imaging technologies and interventions, the arrival of artificial intelligence, the rising demand for musculoskeletal imaging in the future, together with the possibility to unite with other musculoskeletal residents, fellows and radiologists from different European countries, make us proud to have chosen the lifestyle of an MSK radiologist; hopefully this chapter will be of inspiration and guidance to our future colleagues.

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36

SOCIAL **MEDIA**

Social media in musculo-skeletal radiology

By Žiga Snoj and Franz Kainberger

In musculoskeletal radiology, the trends towards more prevention, the use of advanced biochemical and high-resolution imaging techniques, and artificial intelligence will be associated with the routine use of social media.

Under the umbrella of this term, we include all forms of interactive web-based communication, i.e. social networks (Facebook, Twitter, Instagram, etc.) and in a broader sense all other forms of discussion-like forums for solving challenging cases, etc. (Table 1)[1, 2]. With regard to sports medicine and sporting lifestyles, numerous applications exist for fitness tracking, online competition with friends, training programmes and educational material, and for advertising commercial products. Since radiologists spend a lot of time at workstations and therefore often live in the virtual world rather than in the real environment of their institute or department, the use of social media is made easy for them[3]. In social media, the use of images and multimedia plays an important role, making such platforms ideal for use and further development to improve communication, education and research.

SHARING EXPERIENCES

Living with social media is part of a certain culture and lifestyle, and health professionals are responsible for using it in a way that avoids the negative effects of sedentary behaviour and psychological distress[4, 5]. Receiving information on a smartphone or tablet PC and sharing it with colleagues and friends is simpler and may be more efficient than travelling to a meeting or reading a scientific paper[5]. Being aware of the strong drawbacks and limitations of social media in terms of data protection, commercial interests and copyright, medical societies are obliged

FIGURE 1

Quality aspects of how to communicate in social media.

to define clear guidelines[3, 4, 5]. Medical societies provide the forum for discussion of new advances which is gradually being enhanced by social media. The role of medical societies and other institutions is not only to provide such information at predefined high levels of quality, but also to integrate these communication tools into the culture of workplace habits, education and research programmes, career planning etc.[4]. The implementation of social media in a society's workflow offers quicker distribution of news and more transparency between officers and members[4, 5]. However, several quality aspects need to be considered when using social media (Figure 1).

A recent survey study on the usage of social media by radiologists showed that 85% of all survey participants are using social media, mostly for a mixture of private and professional reasons and 82% of participants are using social media for educational purposes[6]. The most popular interactive platform is the Radiopaedia Facebook page. Most European participants mentioned the myESR Facebook page as their second choice[6].

During the Radiological Society of North America (RSNA) 2017 session on social media, doctors from Cincinnati Children's Hospital shared their experience of how their departments use social media to engage with patients, families and the professional community. They pointed out that a social media editorial team needs to be formed with everybody providing the content. They even provided the information on the required input – running the Instagram account alone involves one hour of scheduling and one hour of content creation every week.

During the European Congress of Radiology (ECR) 2019 there was a dedicated session on social media with experts sharing their views and experience. Interesting information was presented, such as the fact that blogs are outdated in comparison to other social media platforms and the fact that scientific papers published on social media receive noticeable boosts in citations.

Since 2012, the European Society of Radiology has provided a 'social media wall' during the ECR, bringing together ECR-related posts and comments from various social media sources in one convenient 'stream'[4].

A recent article concluded that the 30% increase in the use of Twitter during the 2011 and 2012 RSNA annual meetings presents an opportunity to leverage this technology to improve scientific sessions, engage meeting attendees, and increase collaboration at national radiology meetings[7].

SHARING KNOWLEDGE

The subjective experience of the users of social media is that they receive information in a way which is embedded in their daily lives and by which they feel informed of what is happening in their community[3, 4, 5]. For educational purposes, small or larger chunks of knowledge can be provided by giving summaries of recently published research, meeting news, or commentaries from opinion leaders[3, 4, 5].

Moreover, in terms of value-based medicine, the learning efficacy has to be taken into account. There is a huge difference between what we take up passively and what we reflect and share actively within a community[3, 4, 5]. We know from applications in the industry, that the cost effectiveness of training employees worldwide with e-learning and keeping them informed with social media and online meetings is higher than bringing them to face-to-face meetings[3, 4, 5].

TABLE 1

Types and platforms in social media with useful links for musculoskeletal radiologists

TYPE	PLATFORMS	USEFUL LINKS
Social and professional networking	Facebook, Linkedin	ESSR profile (https://facebook.com/www.essr.org/) SSR profile (https://facebook.com/ssrbone/)
Scientific networking	ResearchGate, Mendeley, Academia.edu, BiomedExperts	
Blogging	Tumblr, Blogger, WordPress	Radiopaedia blog (http://radiopaedia.org/blog)
Microblogging	Twitter	ESSR profile (https://twitter.com/essrmsk) SSR profile (https://twitter.com/ssrbone)
Podcasts, videos	YouTube, iTunes	myESR YouTube channel (https://youtube.com/myesr) The Radiology Channel (https://youtube.com/RadiologyChannel)
Clinical cases and images	Instagram, Facebook,	American College of Radiology profile (https://instagram.com/radiologyacr/) Radiopaedia profile (https://instagram.com/radiopaedia)
Sharing relevant content	SlideShare	

SUPPORTING RESEARCH

Knowledge management and research trends are driven by the way that scientific publications are accepted in the community. Therefore, social media posts of or about journal articles are associated with increased web views of these publications[6].

In conclusion, radiologists with a strong interest in all forms of advances in technology may be open-minded to the rapid development of social media and to their use as instruments for improving our performance[1, 2, 3, 4]. Currently, social media offer radiologists sitting at their workstations an easy way to stay informed about current trends and relevant information exchanged within their community[1, 2, 3, 4]. With regard to musculoskeletal imaging, the specific aspects of culture and lifestyle with respect to sports should be made more available. For the future, once the value of social media in case-based learning and in comparison to other forms of information delivery have been defined, their wider use to support more efficient education and research may be expected[4, 8].

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37

FORENSIC ANTHRO-POLOGY

Radiology and forensic anthropology

By **Giuseppe Guglielmi, Francesco Pio Cafarelli** and **Giuseppe Bertozzi**

Forensic anthropology is a complex discipline, the main task of which is to provide sufficient data to allow cadavers to be identified. In particular, it plays a pivotal role in cases where cadaver identification is not otherwise possible; for example, where there is a need to establish whether the remains are human, where the face's physiognomy has been altered or where typical external identifying features are absent.

For a long time, cadaveric identification depended on direct and entirely subjective visual evaluation of the remains, sometimes based entirely on photographic data, in the search for less common details such as tattoos or other significant body marks. However, in recent years, like forensic pathology, forensic anthropology has successfully harnessed imaging methods. Given that the use of radiology has long been established for planning the subsequent autoptic approach in cases of homicides, suspicious deaths and even with cadavers where there is no external damage pointing to the cause of death, it comes as no surprise that the use of imaging is now considered a must when remains are beyond all recognition; where, that is, preliminary assessment cannot establish whether the remains are human or belong, instead, to another species[1-4].

Thanks to 2D and 3D radiological techniques, multi-planar reconstructions (MPR) and surface-shaded display, radiology applied to forensic anthropology has developed a series of reliable and reproducible methods that identify morphometric anatomical features and dental morphology, and which provide details of fine trabecular bone lesions that support identification based on data that is more scientific and less subjective. Obviously, these assessments need to be adjusted in the light of the countless bias-inducing factors that condition forensic analysis, such as the special circumstances in which the remains may be found: advanced state of decomposition, carbonisation, charring, saponification, mummification, as well as mutilation, dismemberment and decay.

There are basically two main methods of identification: the comparative and reconstructive approaches. The first explores the somatic characteristics of known subjects, through which comparisons can then be made: scars, pigmentations, fingerprints, footprints, orthoses and tattoos. However, such analyses are only possible in cases where the state of conservation allows this type of observation to be made; all too often a rare event (Figure 1).

The use, in this case, of digital radiology or MSCT with normal or pathological pre and post-mortem images allows extremely useful comparisons to be made, providing, as Murphy points out, precise identification in 42% of cases[5, 6]. Forensic dentistry also provides significant data on dentition, dental and bone pathologies, including the presence of prosthetic elements, which constitute anatomical landmarks and one-off morpho-structural features. The second approach, reconstructive identification, represents, on the other hand, a greater challenge for anthropology and forensic radiology as it attempts to identify the subject by means of a bio-morphological profile relating to sex, geographical origin, age at death and stature, using a step-wise procedure that seeks first to clarify whether we are dealing with human or animal remains, as well as the approximate number of individuals involved, and which only subsequently determines the other features we have mentioned so far.

In the field of radiology, numerous authors have established radiographic differences that allow a correct research approach to be followed. Thus, in human bones, the spongiosa and medullary canal, well documented with CT, will be quite regular, with rounded, ovoid spaces between coarse primary trabeculae and finer secondary trabeculae, whereas in animals the spongiosa will be coarser with evidence of spicules or cortical invaginations which may extend into the medullary canal[7]. Obviously, these aspects will vary considerably, especially in the case of metabolic bone diseases or systemic diseases, which need to be taken into consideration.

Where bare bones are available, several methods have been developed by physical

FIGURE 1

X-ray of an unidentified cadaver. Teeth findings, skull characteristics and other aspects of bone morphology assist recognition.

FIGURE 2

CT of bones found in a sinkhole.

anthropologists to assess race or population ancestry, above all thanks to radiographic evaluation of the skull, intercondylar shelf angle, long bones and stature.

However, by far the most important anthropological piece of evidence in the identification of a corpse is age determination, which can easily be performed with great precision using radiography. In this sense, the radiological study of the skeleton has always been a focal point for the determination of bone age. Where possible, the evaluation of the nuclei of ossifications in the bones of the human skeleton allows a fairly accurate estimate.

For example, in foetal age, this type of analysis is essential when identifying gestational age. Borrowed from ultrasound obstetrics, this technique is now an essential part of forensic evaluation. In extra-uterine life, centres of primary ossification in the lower and, above all, upper limbs can be used for correct dating of a cadaver's bone age. However,

the great variability in skeletal maturation means that several techniques need to be applied in order to obtain the most faithful estimate of possible bone age. This is particularly true when skeletal remains from different subjects with similar or different bone ages are involved.

The standard development of the knee, foot, ankle and, in particular, the hand and wrist are reliable anatomical landmarks in such cases[8]. Obviously, from the age of about 25, when maturation of the growth muscles is complete, essential identifiers are the external aspect of skull sutures, and evaluation of the pubic symphysis and ribs. In this case, radiological evaluation, especially with the CT volume rendering technique, makes accurate study of fine bone details possible (Figure 2).

A final aspect to be considered is pathological variability arising, for example, from 'wear and tear' damage to the body or from the influence of sex on skeletal development and bone morphology[9]. Compared to males, female skeletal maturation is faster, especially after the third or fourth year of life. However, before puberty, differentiation of the sexes by skeletal radiology is unreliable as sexual characteristics based on skeletal and extra-skeletal findings relating to the pelvis, skull and jaw are radiographically recognisable only after this stage of development.

In conclusion, the identification of cadavers involves specific skillsets that are the province of many different professional figures, whose collaboration within a multidisciplinary approach is undoubtedly crucial.

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38

ADVANCING ROLES OF RADIO-
GRAPHERS

Advancing roles and high-impact responsibilities of radiographers and radiological technologists during MSK imaging

By **Peachy S. Luna**

INTRODUCTION

Medical imaging is a form of technology that has transformed the medical field in the past century and has revolutionised the way healthcare is delivered in modern times. Musculoskeletal imaging is one of its branches that has seen increased implementation in recent years[1]. Defined as the imaging of the bones, joints, and connected soft tissues using an extensive array of modalities such as conventional radiography, computed tomography (CT), ultrasonography, and magnetic resonance imaging (MRI), it is a field which is constantly evolving to offer timely and useful information about musculoskeletal anomalies to experts to enhance the continuum of patient care, from detection and diagnosis to post-treatment supervision[2].

EVOLUTION OF THE SPECIALTY AND TRENDS IN IMAGING

The first x-ray, taken in 1895, laid the foundation for diagnostic radiology and marked the beginning of musculoskeletal imaging, which has continuously evolved into an enhanced subspecialty. Significant advances in diagnosis, research and the growth of cross-sectional imaging are pivotal in furthering the evolving practice of MSK radiology. The specialty is vast and encompasses diagnosis and image-guided therapy for all kinds of ailments affecting the musculoskeletal system, including congenital deformities, infections of bone and soft tissue, cancers, rheumatological diseases and trauma – both accidental and sports related. The specialty includes interventional and therapeutic radiology pertaining to the musculoskeletal system in the form of ultrasound, fluoroscopy and CT-guided procedures, which range from biopsies to injecting therapeutic drugs at specific targeted locations[2].

Advances continue in the field of musculoskeletal imaging. There are emerging trends that add immense value to patient care, thus greatly improving the capabilities and accuracy of musculoskeletal imaging[3], such as:

- Digital x-rays
- Cartilage imaging
- PET/CT
- Diffusion-weighted sequences on MRI
- MR arthrography
- 3 Tesla MRI
- 3D MRI
- High resolution ultrasound
- Portable ultrasound
- Dynamic CT
- 9 to 21 Tesla MRIs

PIVOTAL ROLES AND HIGH IMPACT RESPONSIBILITIES

Advances in imaging technology and the increasing role of interventional procedures in musculoskeletal imaging have continued to stimulate radiological technologists over recent years. While radiographers have been viewed by some in the Philippines and other nations as technicians, in others their role has advanced significantly with their increasing knowledge, experience and responsibility, with some working as advanced practitioners or the equivalent of consultant radiographers.

Radiographers are a key part of radiology and are crucial to modern state-of-the-art diagnostic or therapeutic services being provided by radiology departments. It is vital that radiographers are the experts in terms of the technology that is at the heart of a modern radiology department and radiographers have the key role to play in optimising the use of that technology[5]. Radiographers have high impact responsibilities, as they work closely with their patients; they interact with them on a daily basis and have an important role to play in patient care and patient safety in a modern imaging department. They make sure the radiation dose to the patient is minimised.

Besides being seen as a technician, they also need to be seen as the expert in that area who can really get the most out of the technology and play that important role in patient care and patient management in a safe way.

When more opportunities like education and training are given to radiological technologists, and when they are utilised more effectively, challenged, and allowed to take more advanced roles, improved patient outcomes can be achieved.

In a team approach, closer collaboration with other health professionals remains important to radiographers in terms of achieving patient safety and the best clinical outcomes.

IMPROVING PATIENT OUTCOMES

It is important to remember there is a patient behind every exam, and that a patient's comfort and well-being should determine the technology and practices used to get every image right, every time. The caring process for our patients begins the moment they enter our facility and lasts until they leave, and the technology we use must be designed with the entire patient journey in mind. Solutions that focus on patient satisfaction inevitably enhance patient outcomes[8]. Some key principles to follow are:

1. Speed: quality images in the shortest amount of time.

2. Accuracy: accurate images must be provided with a minimal amount of distortion and the maximum amount of recorded detail.

3. Quality: the patient's condition should not be used as an excuse for careless positioning and accepting less than high-quality images.

4. Positioning: careful precautions must be taken to ensure that performance of the imaging procedure does not exacerbate the patient's injuries.

5. Practice of standard precautions: all equipment and accessory devices should be kept clean and ready for use.

6. Immobilisation: proper immobilisation and support must be ensured to increase patient comfort and to minimise the risk of motion.

7. Anticipation: the radiographer/technologist should be prepared for and understand the necessity of additional procedures and images, as this instils confidence in, and creates an appreciation for, the role of the radiographer in the emergency setting.

8. Attention to detail: the patient should never be left unattended during imaging procedures.

9. Attention to department protocol and scope of practice: the radiographer/technologist should know department protocols, and practice only within his or her own competence and abilities.

10. Professionalism: codes of ethics and practice standards should always be adhered to and the radiographer/technologist should be aware of the people present or nearby at all times when discussing a patient's care.

CHALLENGES AND THE WAY FORWARD

The fact that high quality musculoskeletal radiology is not widely available in the Philippines is a reflection of the country's priorities as a developing country where improving basic services and infrastructure has been the focus. The Philippines has only in recent years been seeing a steady rise in sports and fitness interests[7]. In the Philippines, in major city and town areas, newer x-ray and MRI modalities have managed to penetrate across the board. Radiological technologists face the challenge of honing their skills while rising to the upcoming healthcare demands. They need to be able to utilise new modalities and make the most of their capabilities to provide images with high diagnostic quality, while also continuing to spend more time with patients than the technology.

The Philippines aims to be on a par with most developed nations. However, the necessary MSK imaging technologies and expertise that are required to produce more detailed images and use advanced imaging technologies, vary from excellent to adequate. Steps have been taken by some hospitals to address this. Premier hospitals with advanced facilities create awareness about current trends in musculoskeletal imaging by organising seminars and conferences in collaboration with musculoskeletal specialists and inviting radiological technologists.

Learning about injuries in contact sports or even non-contact sports, trauma, and non- trauma involving the musculoskeletal system enables professionals like radiological technologists to provide the necessary high-quality care for patients. Providing suboptimal care can have drastic career implications that can impact the technologist's quality of life both physically and financially.

In today's technology-driven world, quick and easy access to musculoskeletal radiological technologists should be possible. Educating radiological technologists could play a key role. A dramatic increase in musculoskeletal radiology educational programmes can be seen throughout the Philippines and internationally. Thus, it is evident that musculoskeletal imaging is finding accelerating usage aided by increasing research on new imaging techniques and application of the proven techniques.

CONCLUSION

MSK imaging is here to stay and, as time passes, the depth of knowledge and level of skill will increase and help radiological technologists understand and effectively utilise the technologies in musculoskeletal imaging. It is also important that radiographers – whether diagnostic or therapeutic – work to raise the profile of their profession among the public and other health-care providers. Receiving consistent levels of education and training remains an important challenge as radiological technologists continue to play an increasingly pivotal role in patient care and patient safety.

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Imaging of MOTION & PERFORMANCE STRESS & STRAIN

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INTERNATIONAL DAY OF RADIOLOGY

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AND RSNA

Published by
The European Society of Radiology (ESR)
October 2019

In cooperation with
The European Society of Musculoskeletal Radiology (ESSR)

Editors:
Alberto Vieira, Luca Sconfienza, Franz Kainberger

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ISBN: 978-3-9504388-6-4

EUROPEAN SOCIETY
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