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The development and clinical applications of musculoskeletal ultrasound

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Abstract Musculoskeletal ultrasound has come a long way in 40 years. Reflecting changes in computer technology, ultrasound equipment has developed from machines that have filled examination rooms with mechanical probes linked by hinged arms for spatial localisation, to high-resolution machines that are the size of laptops using compact hand-held probes designed for both external and internal imaging.

Keywords Ultrasound tendon muscle joint Doppler· Tendon · Muscle · Joint · Doppler

The early years

The story begins in Europe with the discovery of the piezoelectric effect by Pierre Curie in 1880. The principle that electrical stimulation of certain crystals produces a sound wave is the basis of ultrasound generation. The earliest applications in medicine were reported from Germany and Austria in the 1930s and 1940s. The scene then shifts to North America with the production of the earliest B mode imagers. The first American device, developed by an ex-pat British scientist for breast scanning, was a real-time, mechanical, linear, contact, B-scanner working at 15 MHz. Some of the more primitive systems required the patient to be completely immersed in water (in the machine gun housing of a B52 bomber), but they were capable of producing recognizable cross-sectional images, precursors of the type of examination we see today. The first papers on this type of scanning began to appear in the 1950s. Engineering developments over the next 10 years resulted in the development of more probes that were capable of producing images by direct contact with the patient. Motorised, hinged arms were employed and the first commercial systems were made available in the early 1960s.

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The earliest clinical applications were in abdominal and in particular breast, obstetric and gynaecological imaging and much of this early work took place in Scotland in the 1960s. In 1976, a case report of a rectus sheath haematoma appeared in the *American Journal of Obstetrics and Gynaecology* [1]. Several other reports on this entity appeared in the years to follow. The images were carried out using B mode scanners and transducers in the 2- to 3-MHz range.

Given the emphasis on abdominal and obstetrical imaging, the work of Zweymueller and Kratochwil [2] is particularly noteworthy as they published on the ultrasound diagnosis of bone and soft tissue tumours in 1975, 1 year earlier. The first publication in *Skeletal Radiology* was in 1979 with a report on the ultrasound appearance of myositis ossificans (Fig. 1) [3]. The ultrasound images were acquired using a 3.5-MHz transducer of both quadriceps regions and compared with radiographs. An abnormal mass was identified in the region of the vastus intermedius, but it was not possible to confirm an interface between the mass and the underlying femoral cortex. Plain radiographic correlation was required to confirm this with certainty.

Imaging of muscle remained the principal focus in the early stages with further reports on muscle haematoma in

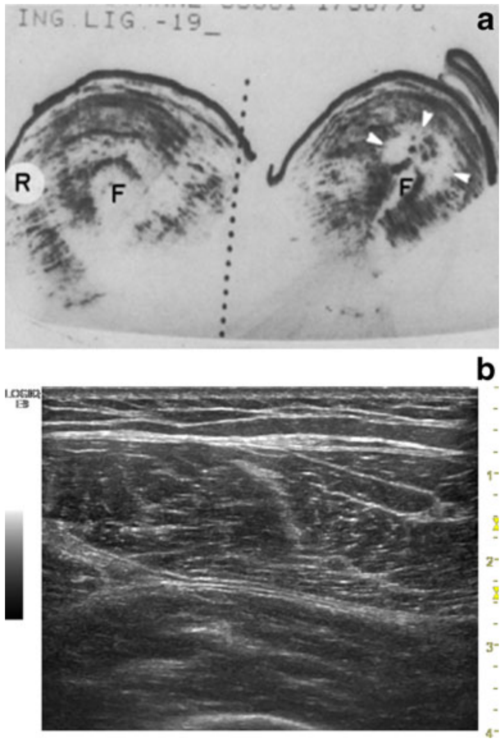

Fig. 1 **a** First ultrasound image in *Skeletal Radiology.* Transverse sections through the right and left thighs with an area of myositis ossificans (*arrowheads*). The image is reversed compared with the modern display protocol. It describes distortion of the soft tissues and stippled bright areas within it (represented by the *black dots*). The *white area* is where sound has not penetrated. There is a corresponding area on the asymptomatic side representing the vastus intermedius, where presumably the sound waves have insufficient penetration. **b** Corresponding transverse image of the thigh using modern equipment. Fine detail of the muscle fibre and the endomysial structure is apparent. (Reproduced by permission editor, skeletal radiology and the International Skeletal Society)

haemophilia patients, abdominal wall abscess and muscular dystrophies [4–8]. Ultrasound was used to assess quadriceps wasting in patients with knee disorders and muscle atrophy associated with progressive muscular dystrophy. The earliest reports of tendon imaging came from the USA and Germany where, in 1981 Maner and Marsh [9] and in 1984 Mayer et al. reported the ultrasound findings in patients with Achilles rupture [10]. Technical developments meant that a 5-MHz transducer was now available. Over the next few years, tendon imaging developed and ultrasound of the tendons of the fingers, hand and foot were added to the list of possible applications [11–15].

Development of musculoskeletal ultrasound

Particular developments important in the advancement of musculoskeletal ultrasound include the change from electromechanical curved sector probes to linear array probes. Underlying this development was the ability to electrically stimulate groups of crystals arranged in a linear array so that the ensuing beam was perpendicular to the footprint of the probe. This was very important to MSK ultrasound as substantial artefact results if the ultrasound beam is not perpendicular to the structure under interrogation. This anisotropic artefact particularly affected tendons and ligaments and could never be removed from sector images produced by curvilinear probes.

The second development of great importance was the shift from analogue to digital signal analysis. This paved the way for significant improvements in signal to noise, improved near field focussing and resolution, as well as many other software improvements that allowed for enhancements such as beam steering, compound, harmonic and panoramic imaging (Fig. 2).

Beam steering allowed the entire output of the transducer to be directed 30–40° away from the central axis of the transducer, improving the imaging of curved tendons. Panoramic images are obtained by moving the probe slowly in the direction of the scan plane along the area of interest. The software is able to recognise particular locations and build up a wide field of view image in a manner similar to stitching a series of photographs together to create a panoramic scene. Multiple focal zones improve resolution at the expense of processing time, a factor improved by enhanced digital processing. Videos could now also be acquired in real time, significantly advancing diagnosis, as tissue relationships could now be studied under movement.

Later developments included harmonic and compound imaging. Harmonic imaging uses the tissue-generated echoes to contribute to image formation. This has less impact in MSK, however, as the waves from superficial structures have less time to distort. Compound imaging uses software enhancements to make better use of reflected echoes especially from superficial tissues. Deriving useful data from ultrasound scatter is used to improve near-field resolution.

Dynamic ultrasound

The primary role of the musculoskeletal system is to provide support for movement. The ability to observe musculoskeletal tissues both statically and under controlled movement is one of the fundamental advantages of musculoskeletal ultrasound.

Abnormalities of movement include tendon clicks and snaps, and no other imaging technique is capable of directly demonstrating these. Friction between different structures may lead to impingement and there are multiple impingement syndromes throughout the body. The best known is subacromial impingement, where a thickened subacromial

Fig. 2 Panoramic image of the Achilles tendon in the long axis. The probe has been swept from just above the level of the soleus muscle incorporation to below the enthesis

subdeltoid bursa is trapped within the coracoacromial arch, particularly where it abuts the coracoacromial ligament. To acquire quality MR images, the patient must remain still. In an ultrasound examination, not only is the patient able to move, but they should be encouraged to do so. A slightly thickened subacromial subdeltoid bursa may become much larger on abduction as it impinges and bunches against the coracoacromial ligament. This finding cannot be appreciated on MRI. The movement of the superficial fibres of the bursal surface of the tendon are distinctly different from the movement of synovial thickening and fluid within the bursa. This feature helps to differentiate bursitis from bursal surface partial tears. It is interesting and noteworthy that reports in the literature of the accuracy of ultrasound in the detection of partial rotator cuff tears rarely describe the use of dynamic imaging findings and thus miss out on a useful diagnostic manoeuvre.

Another often-underused component of dynamic ultrasound imaging is sonopalpation. Normal tendon ligament tissue is difficult to compress with the ultrasound probe. As the tendon begins to degenerate and particularly when areas of focal degeneration or partial tears appear within it, it becomes softer and more compressible. Similarly, joint fluid under compression displaces away from the probe; synovial thickening is not so easily displaced.

Imaging blood flow

For many years ultrasound systems have had the ability to identify and quantify colour flow in large vessels. Applications in musculoskeletal imaging have been, by comparison, relatively recent. In imaging, the movements of tissues and the linked change in pitch of the reflected echoes (the Doppler effect) are detected by monitoring the changes in echoes from one scan line to the next. Two or more pulses are sent in the same direction, and the reflected lines of echoes are subtracted from one another. If nothing moves, the lines are identical and the subtraction results in a cancelled out line. If a target does move, then it will show up on the subtracted line and is shown as a “Doppler shift”. The technical developments that have improved this technique result from the development of “shoot-em-up” video games. Handling (adding and subtracting) lots of bits of data fast are just what these gaming computers do very well. The very fast computer boards have been hi-jacked by ultrasound developers. It is now possible to subtract lines very quickly and accurately. Early Doppler systems were colour Doppler: here the subtracted lines were coded into the average speed and direction. Later power Doppler was introduced: the colours now show the size of the reflections. but not their direction. The early power Doppler systems, while more sensitive than colour Doppler, were relatively insensitive and did not allow visualisation of slow flow in the minute vessels that could be found in association with tendon pathology.

Tendon apoptosis stimulates the formation of abnormal vessels by a variety of stimulatory factors, although vascular endothelial growth factor (VEGF) has been specifically implicated. New vessels are accompanied by abnormal nerves (angio-neuro-neogenesis) and correlation has been demonstrated between the presence of these vessels and pain. Identifying angiogenesis offers a significant improvement in MSK diagnosis and for the first time is able to specifically relate imaging findings to the patient’s symptoms. This in turn has led to treatments targeting these vessels, such as sclerotherapy.

The ability to detect low blood flow in pathological musculoskeletal tissues has been augmented by the addition of contrast agents. The earliest contrast agents were formulated to release microbubbles of air following injection. Second and subsequent generation contrast agents demonstrate improved persistence within the vascular system, as they are subject to less break-up by the insonating waves. Software enhancements also allow echoes from the surrounding tissue to be subtracted from the image, improving visualisation of the vascular tree itself. Much of this work has been in abdominal imaging and the clinical impact on musculoskeletal disease has yet to be fully defined.

Current status

The question of where musculoskeletal ultrasound lies in the field of musculoskeletal imaging depends very much where in the world it is practised. There are very different approaches in Europe and North America for example and, even within Europe. In some countries, such as Germany, musculoskeletal ultrasound remains largely the domain of clinicians rather than radiologists. In the UK, radiologists mostly practise MSK ultrasound, although rheumatologists, anaesthesiologists and sports physicians recognise the importance of this imaging technique in their areas and have adopted its use with relish. In North America, several areas of musculoskeletal ultrasound excellence notwithstanding, MRI remains the dominant force in MSK imaging. A variety of reasons have been suggested as to why MSK ultrasound has not achieved the success that it has in Europe, although it is likely that lower reimbursement for an ultrasound examination compared with MRI is the principle reason. Difficulties with training contribute and it has also been recognised that unless the musculoskeletal radiology community corrects this, other specialities will take advantage of what MSK ultrasound has to offer. Increased efforts at educating fellow radiologists by both individual groups and the specialist societies, including the Asian, European, and, more recently, the International Skeletal Society, have helped.

Indications

Rectus abdominis haematoma and popliteal cyst imaging dominated the early reports of musculoskeletal ultrasound, but other applications quickly followed. Although a full review of all of these is beyond the scope of this retrospective, it would be useful to review some of the important applications and emphasise where ultrasound can be particularly helpful in patients with musculoskeletal disorders.

Shoulder

Ultrasound of the rotator cuff is one of the commonest musculoskeletal ultrasound examinations performed. Many patients with shoulder problems can be categorized into one of a small number of syndromes by good clinical examination. In some of these, such as glenohumeral arthritis and recurrent dislocation, ultrasound has little role to play. In patients with impingement, however, ultrasound can be very useful in guiding clinical decision-making by reliably differentiating the intact from the significantly torn rotator cuff [16]. This form of targeted clinical question is typical of how ultrasound is applied. Both MRI and ultrasound struggle with the diagnosis of partial tendon tears; however, the accuracy of ultrasound is well supported by the more recent clinical studies [17, 18]. MRI is of course capable of demonstrating abnormalities within the joint, ultrasound is not, but in most patients with impingement this is not necessary.

As previously outlined, MRI is a static imaging technique and does not have the same capability as ultrasound in demonstrating bunching of the bursa against the coracoacromial ligament with arm abduction (Fig. 3). This can be a useful supporting finding in patients with an atypical clinical picture. Similarly, ultrasound-guided injections of the subacromial subdeltoid bursa with local anaesthetic, resulting in symptom ablation, is also a useful diagnostic tool. The injectate frequently also includes a long-acting corticosteroid to help provide longer term relief. Guided injection techniques also include injections of the biceps tendon sheath, the acromioclavicular and glenohumeral joints, as well as distension arthrography for patients with frozen shoulder.

Elbow

Although there are many potential causes of elbow pain, a frequent cause is common flexor or extensor enthesopathy. Although the literature suggests that MRI is superior to ultrasound in the diagnosis of common extensor origin disease[19], few studies have used Doppler changes in diagnosis. In the author's institution, ultrasound remains the primary technique in the assessment of patients with these symptoms and detecting abnormal Doppler flow is important in diagnosis. In addition, ultrasound offers the advantage of guiding therapy. Steroid injections have largely been replaced by dry needling, autologous blood, and platelet-rich plasma injections.

Ultrasound is an excellent method of demonstrating joint effusion and intra-articular loose bodies. Conversely, ultra-

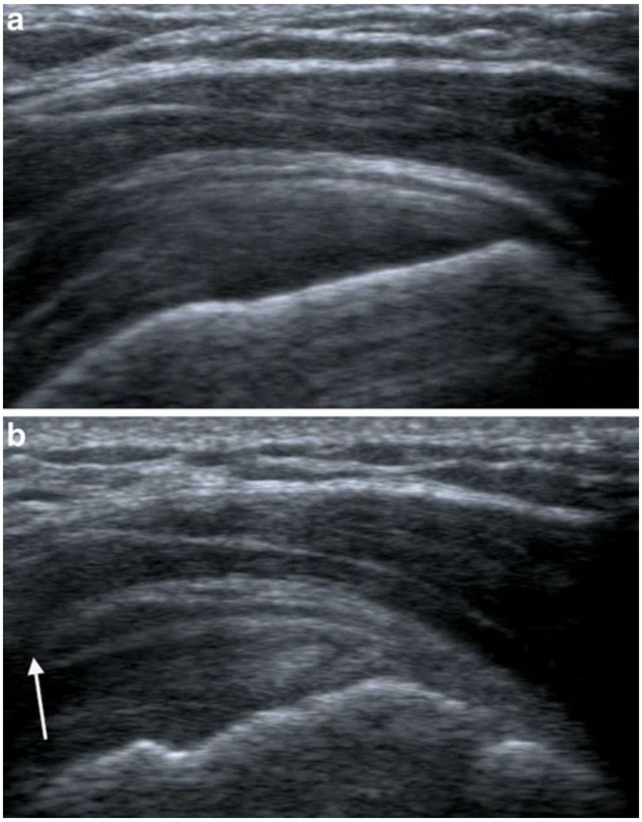

Fig. 3 **a** Thickened subacromial subdeltoid bursa with the shoulder in the adducted position. **b** On abduction, the bursa becomes bunched up against the coracoacromial ligament

sound cannot reliably assess elbow articular cartilage, although in many young patients with osteoarthritis of the capitellum, the lesion is sufficiently far anterior to be detected.

Wrist and hand

Careful clinical examination often results in a narrow differential diagnosis and when there is focal pain and tenderness, ultrasound can be very useful. When symptoms are more diffuse or non-specific, MRI becomes the investigation of choice. Common applications for ultrasound include the detection and diagnosis of occult ganglion, tendon, ligament disease and synovial disease of small joints [20–23]. There are some specific advantages of ultrasound over MRI, notably identification of the thickened retinaculum that is an early feature of de Quervain's tenosynovitis and in the assessment of tendon motion following surgery.

Ultrasound provides good visualisation of the dorsal aspect of the scapholunate ligament at rest and under dynamic stress. Where MRI is better is in its ability to detect other components of wrist internal derangement, notably injuries to the triangular fibrocartilage complex (TFCC), which frequently coexist with intrinsic ligament injury. Despite valiant effort, ultrasound has not established itself as a good method for looking at the articular disc.

Injuries to the ligament and retinacular structures of the fingers are common and imaging is not usually required. Advantage can be taken of ultrasound's dynamic capabilities in the assessment of injuries to the flexor pulley system [24, 25], the extensor retinaculum/dorsal hood and, to a lesser extent, collateral ligament injuries.

Ultrasound for small joint synovitis has attracted considerable attention in recent years and much of the published work has appeared in rheumatological rather than imaging journals. It is well established that MRI and ultrasound are both far superior to radiographs in the detection of synovitis and bone erosion [26]. There is also evidence that both are superior to the clinical assessment of synovitis, although some of this "improvment" may be due to the detection of non-specific joint effusion, which is commonly found in asymptomatic individuals, typically in the first metatarsal phalangeal joints.

The clinical advantages of ultrasound over MRI in the detection of early synovitis are relatively few. Patient interaction can target the examination and joints that have become symptomatic, since the imaging referral can be included in an ultrasound examination. This is particularly useful in children, in whom multiple joints can be assessed for effusion with ease. Obvious disadvantages of ultrasound are that not all parts of the joint are easily visualised and a significant proportion of articular cartilage cannot be seen at all. Standardised images for research are easier to achieve with ultrasound [23].

Hip

Hip ultrasound plays a very important role in neonates with its ability to demonstrate unossified acetabular and femoral head cartilage. This represents a paradigm shift in that, previous to this, the detection of developmental dysplasia depended on detecting a subluxing or dislocating hip by clinical examination. Stable but dysplastic hips had no clinical findings and radiographic criteria for their diagnosis were unreliable. Ultrasound was able to demonstrate the important anatomy in its entirety and the relationship between the femoral head and the acetabulum could now be properly defined with direct imaging and measurement rather than relying upon indirect measurement of the ossified bony structures [27].

In the adult, the depth of the hip joint means that ultrasound is frequently going to play a subservient role to MRI in patients with hip and groin pain. In sports-related groin pain ultrasound and MRI are frequently combined to demonstrate all of the potential pathology. For example, contrast-enhanced MRI is used to detect the majority of injuries related to the rectus and abductor insertions, pubic symphysis, iliopsoas tendons and adjacent hip joints. MRI is poor at identifying reduced inguinal hernias and not all abnormalities detected by MRI are clinically relevant. Dynamic ultrasound demonstrates direct and indirect inguinal and other hernias with relative ease [28], as well as tendon snaps. Sonopalpation, the term used for compressing tissues with the ultrasound probe, can be helpful in identifying the location of symptoms and can determine whether the abnormalities demonstrated by MRI are clinically relevant and guide therapy. Ultrasound0guided selective block of the obturator and ilio-inguinal nerves can also be employed to help with the differential diagnosis.

The roles of MRI and ultrasound in assessing muscle injury are also complementary. MRI is more sensitive and will detect muscle oedema in many patients when ultrasound is normal. However, in some cases when marked oedema is present, ultrasound can demonstrate fibre disruption that is obscured by oedema on MRI. Calcification in myositis ossificans is also detected earlier on ultrasound than either radiographs or MRI. Ultrasound-guided haematoma aspiration and injection of haematoma and muscle tear with proliferant is a useful adjunct to diagnosis.

Knee

Knee imaging remains predominantly the domain of MRI. Some patients with superficial masses, areas of focal tenderness and patients with quadriceps or patellar tendon disorders may be completely assessed with ultrasound alone. There have been some efforts at proposing a role for ultrasound in the detection of meniscal tears [29]. Whilst ultrasound appears to have a good positive predictive value, its negative predictive value is suspect.

Popliteal artery compression by anomalous muscle bands or muscle hypertrophy can be demonstrated by dynamic ultrasound. Tendon therapy with dry needling, autologous blood and PRP injection, and aspiration of implanted joints, are useful adjunctive roles.

Ankle and foot

Like the wrist and hand, focal symptoms are often adequately assessed with ultrasound. Patients with more diffuse pain, pain in multiple areas or pain thought to relate to underlying joint disease is better assessed using MRI. Specific applications where ultrasound has demonstrated superiority to MRI once again relate to dynamic examination or guided injection therapy. The most common tendon subluxation at the ankle involves the peroneal tendons. Dynamic assessment of the Achilles tendon following tendon rupture is the best imaging method for assessing healing. When the tendon ends have united, gentle movement demonstrates synchronicity between the proximal and distal portions.

Although dynamic techniques are also often employed to demonstrate the medial and lateral ligaments in patients with chronic ankle pain, ultrasound cannot visualise the osteochondral injury of the talar dome, which may be contributing to symptoms in this clinical context. Once this lesion has been ruled out, ultrasound is useful at assessing ligament function or guiding therapy for chronic enthesopathy and its associated impingement syndromes.

The combination of diagnostic and therapeutic ultrasound are particularly useful in the management of Morton's neuroma. Many are asymptomatic and ultrasound affords the additional advantage of inducing symptoms by compressing the neuroma and can distinguish symptomatic from asymptomatic lesions. Once confirmed, ultrasound-guided therapy with either alcohol or corticosteroid is possible.

Nerves

Ultrasound has a very distinct advantage over MRI in the detection of nerve lesions, as the entire length of a nerve can be examined easily. MRI is superior at detecting early denervation changes within affected muscles. Ultrasound can be used to guide nerve blocks. The technique is quicker and more accurate than using nerve stimulators.

Masses

Ultrasound is used to distinguish between true masses and normal variants, such as muscle hypertrophy or prominent bony margins. If a mass is confirmed, ultrasound differentiates solid and cystic lesions. If cystic, aspiration can be carried out and the patient usually discharged. In many solid masses, ultrasound permits confident diagnosis based on the morphology of the lesion. Examples include superficial lipoma, neural tumours, vascular tumours and fibromata. Many other lesions require MRI for full evaluation, reverting to ultrasound-guided biopsy when staging is complete.

Recent developments

The previous section has discussed the bread and butter applications in MSK ultrasound imaging and these will cater for the majority of clinical scenarios. A number of recent developments in other areas of ultrasound have attracted interest as they may provide additional information. These developments include 3D imaging, image fusion and elastography.

3D imaging

Three-dimensional imaging works by storing sets of adjacent 2D slices to create, in the computer memory, an ultrasound volume. The adjacent 2D slices are captured either by the operator moving a 2D probe by hand over the tissue volume to be scanned or by the operator placing a relatively bulky 3D probe over the volume and holding it there while the mechanics or electronics of the probe cause multiple side-by-side 2D slices to be scanned. 4D probes are 3D probes that collect volumes very rapidly, the fourth dimension is "time". When the ultrasound echoes have been stored the volume can be viewed in several ways. The constant depth (or C-scan) is one that cannot be scanned in real life, but there is no consistent evidence that the additional plane offers any advantage in diagnosis. Viewing the whole volume at once is more complicated and needs some kind of highlighting for regions of interest to stand out. For example, blood vessels can be highlighted and the echoes around them dimmed so that the view of the block shows the course and bifurcations of vessels (Fig. 4).

3D has only been applied to musculoskeletal imaging more recently and the value of 3D and 4D views in MSK imaging is unclear. The scans take longer, there is no real-time element allowing the effects of sonopalpation to be assessed and the time taken by the operator for post-scan review of the image blocks can be significant. On the other hand, relatively unskilled personnel can acquire the data and reviews can be performed later by skilled radiologists. In a study of supraspinatus tears, very good agreement was recorded between two skilled MSK radiologists reporting on 3D data, only one of whom had been involved with the examination [30]. This suggests that data acquired by one individual can reasonably be reported by another. One in vitro study on experimentally induced rotator cuff tears in cadavers suggested some advantage of 3D over 2D [31]. The 2D images acquired in this study were recognised by the authors as being of poor quality. In health economies where radiologist time is at a premium and reimbursements for ultrasound examinations are low, off-line ultrasound examinations may be attractive. Disadvantages include losing valuable clinical information that might be gleaned, not from the ultrasound image, but from interaction with the patient.

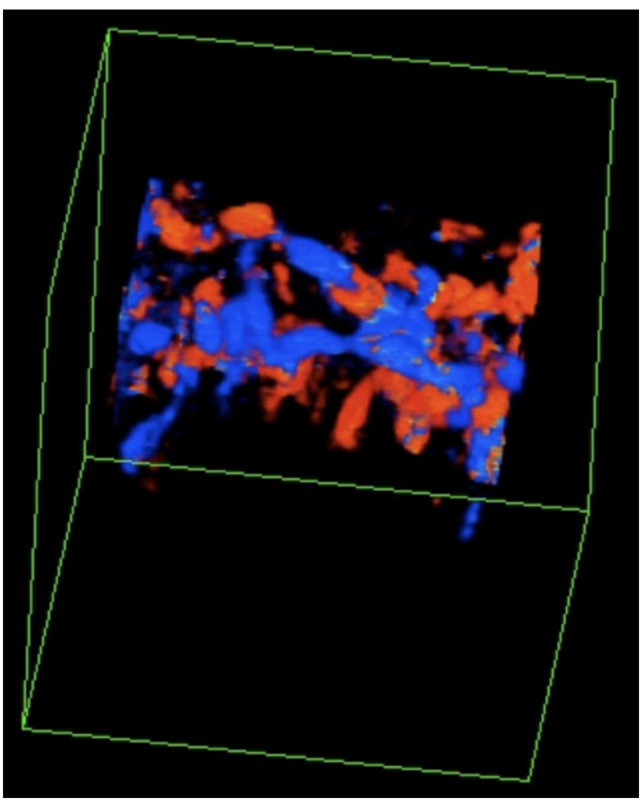

Fig. 4 3D image of vessels within a mass. The soft tissue has been subtracted to allow the vascular tree to be scrutinised to look for malignant features. The image is taken from a workstation where 3D rotation is feasible

Image fusion

Image fusion seeks to take advantage of the combination of high contrast resolution images such as CT or MRI and the high spatial resolution and dynamic aspects of ultrasound. Cross-sectional images can be imported into some ultrasound platforms. The ultrasound image is registered to these data by cross-referencing some easily recognisable ultrasound landmarks. The ultrasound image is then superimposed on the imported CT or MRI. Some systems use a magnetic positioning sensor on the ultrasound probe. Changes in angulation and orientation of the probe are detected and the virtual CT or MR image changes to match the probe's position.

Hybrid ultrasound imaging has also been proposed as a method of improving the accuracy of biopsy and deep injections. Using these systems, needles can be tracked in all three planes and specific areas of the tumour, such as those areas more active on Doppler, may be targeted.

Elastography

Elastography images are acquired by comparing two frames of ultrasound information before and after movement (usually probe compression) has been applied [32]. Tissue displacement can be calculated by noting the timeshift between the corresponding echoes of the before and after images. The data are augmented by repeating the displacement in a cyclical fashion to improve the signal-to-noise ratio. The most common method employed is called quasi static elastography. In this, the subject remains still and the probe is used to achieve compression. Quasi static compression should be approximately 1% tissue compres-

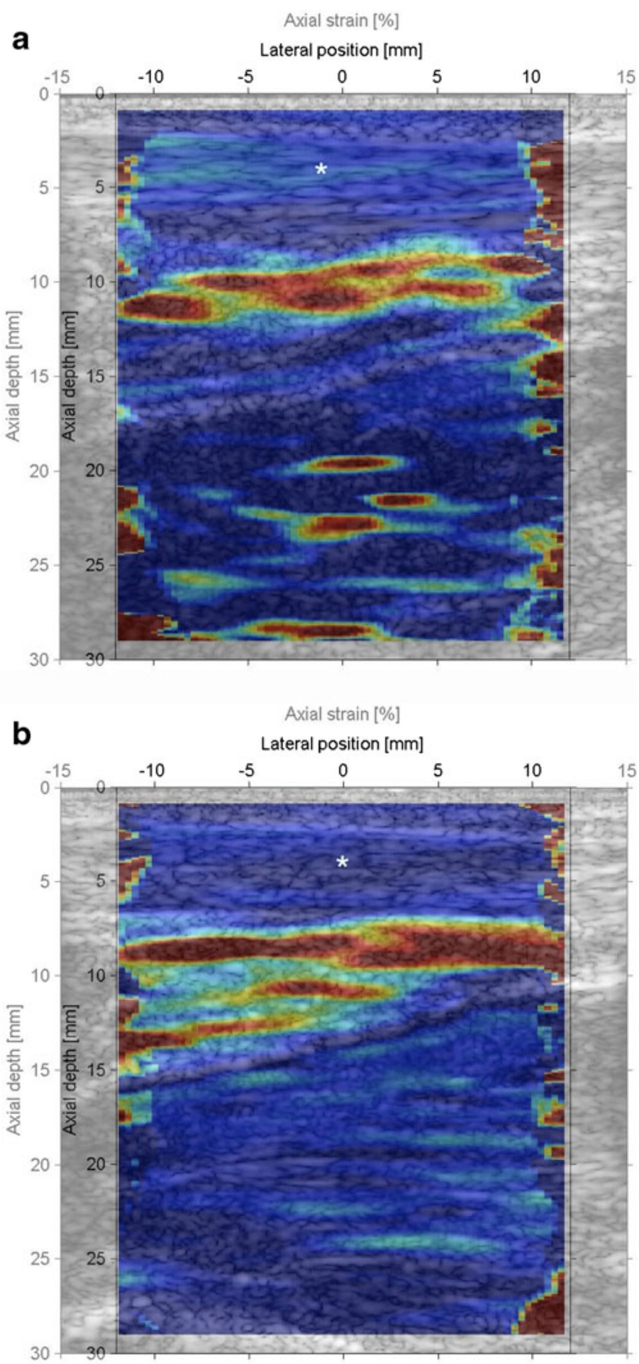

Fig. 5 **a** Transverse and **b** longitudinal elastography of a normal Achilles tendon. The normal tendon tissue is hard and returns signal at the *blue* end of the spectrum. Kager's triangle beneath it is soft and registers as *red* and *yellow*, in addition to firmer connective tissue components

sion and repeated cycles around 7/s, to as uniform a depth as is possible to achieve. An alternative method is for the probe to be held still and the tissue under interrogation move, either in a controlled or uncontrolled (freestyle) way. Controlled movement can be achieved by placing the joint in some form of dynamic jig. Although somewhat more cumbersome, controlled interrogation is likely to significantly reduce artefacts to which the freehand technique is particularly susceptible.

Soft structures compress more than hard structures and the degree of compression is referred to as strain. The strain of a particular area within the image can be colour-coded and the resultant colour superimposed on the greyscale ultrasound image (Fig. 5). Normal tendon tissue is hard and incompressible and is generally trans-coded to blue or green. With disease, tendon tissue becomes softer and more compressible, appearing as yellow and red areas on an elastographic image.

Sonoelastography has been applied in a number of different clinical scenarios, with breast imaging receiving the most interest. Commercial systems now include the technology on their platforms largely developed for this application. Several efforts have been made to extend to tendon imaging and the lateral epicondyle and Achilles tendons have received particular attention [33, 34]. Preliminary work shows that it is technically feasible to obtain elastograms superimposed upon B mode images of these structures. Elastography in abnormal tendons shows areas of tendon softening corresponding to focal defects on standard B mode images. These findings at least suggest that there is a correlation between areas of tendon damage demonstrated by conventional ultrasound images and mechanical strain properties detected by elastography.

As has been previously mentioned in the section Dynamic ultrasound above, sonopalpation (without formal elastography) is used in routine MSK ultrasound assessment. These techniques recognise that pathological tissue is softer and behaves differently when manually compressed by the probe. Although it appears likely that the addition of elastography algorithms will make this process more sensitive, this has yet to be properly evaluated by directly comparing sonopalpation with elastography in a double blinded study. Furthermore, elastography appears to be prone to variation in the appearance of normal, possible experimental error. For example, there have been several studies of the normal elastographic appearance of the Achilles tendon with significantly different findings. De Zordo et al. found areas of softening (grade 3, red signal) in only 1.3% of normal tendons [33], whereas Drakonaki et al. found areas of red signal indicating tendon softening in 62% of their group of asymptomatic normal controls [35]. In addition, areas that are not under direct scrutiny in the various studies, for example, subcutaneous fat, show a variable and inconsistent elastographic pattern. It is likely that some of these differences arise as a result of experimental error. Most of the published work involves manual compression of the probe, which may be variably applied. Other possible causes include poor technique and possibly inappropriate elastogram algorithms designed for other indications. Sensitivity, specificity and most particularly inter- and intraobserver variation, have also yet to be fully investigated. Drakonaki et al. suggested that the technique had good reproducibility; however, this was on the reproducibility of region of interest measurements taken from the elastograms rather than the reproducibility of the elastograms themselves. Therefore, although the technique appears to provide insight into the mechanical properties of musculoskeletal tissues, until it has been properly validated and the advantages over routine sonopalpation confirmed, its role remains uncertain.

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