Ultrasound imaging for the rheumatologist

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ABSTRACT

Over the last few years, technological advances have resulted in dramatic improvements in quality and resolution of ultrasonography (US), allowing it to become a very powerful tool in rheumatological clinical practice. Despite the fact that the impact of US on final diagnosis or therapeutic options for rheumatic patients has not yet been defined, there is now growing evidence that US improves clinical diagnosis and intervention skills.

This review discusses the most important issues connected with the practice of US in rheumatology including: basic requirements, scanning technique, clinical applications, training and future developments. Moreover, it provides a general overview of both US anatomy and pathology relevant for the rheumatologist.

Introduction

Important advances have been made in the field of musculoskeletal ultrasonography (US) over the past few years allowing it to become a very powerful tool in rheumatological clinical practice (1, 2). The use of US to image tendons, joints, nerves, muscles, skin and blood vessels is increasing rapidly. Currently the influence of US on final diagnosis or therapeutic options for rheumatic patients has not yet been defined, however it is evident that US evaluation can depict the extent of anatomical change.

Initial applications of US were limited because of the low resolution of the first 3.5 and 5 MHz transducers. Recent advances in US technology have resulted in dramatic improvements in quality and resolution of the imagery. High frequency transducers provide good image resolution and allow the depiction of details of <1 mm. At present there is unanimous consensus on the fact that US requires high quality equipment (3). As a consequence this has resulted in high initial costs and therefore a barrier to the diffusion of this imaging modality in rheumatological practice (4).

Basic requirements for US in rheumatology

Basic requirements for developing expertise in US in rheumatology are listed in Table I. Standard transducers with frequencies of 7.5-10 MHz are required for conventional examination.

Table I. The ABCDE of basic requirements for ultrasound (US) in rheumatology.

A	Anatomy: detailed knowledge of US-orientated anatomy.
B	B-mode: basic knowledge of the physics and main findings of US in rheumatology.
C	Clinical setting: ability to evaluate the US findings in the clinical setting.
D	Doppler: basic knowledge of colour and/or power Doppler technique.
E	Equipment: basic technical knowledge of the US equipment.

Higher frequency transducers (>10 MHz) are necessary to depict fine details of more superficial tissues. Stand off pads of different thickness, sledge devices to support needles during US guided injection or biopsy, sterile gel and needles are recommended.

US scanning modes

US equipment providing high quality grey-scale imaging is essential and in fact, the majority of clinically relevant US findings in rheumatology are obtained with grey-scale US.

Doppler techniques, in general, should also be considered an integral part of the basic armamentarium for US in rheumatology (5). They enable the evaluation of blood flow in different

tissues (i.e. synovium, tendon and muscle) and are of practical value in the detection and monitoring of soft tissue and joint inflammation. Continuing technological advances are improving the performance of Doppler techniques relating both to acquisition and interpretation.
Contrast media allow further characterisation of minimal changes of low flow at both intra- and peri-articular soft tissue levels. In spite of these benefits, the application of contrast media tends mainly to be in the field of research at present (6).

Scanning technique

Proper US examination depends on detailed attention to several factors. A standard scanning protocol should be followed with the patient maintaining a position which optimises US visualisation of the anatomical structures under examination. Spatial resolution should reflect the anatomical region examined. Large joints require the use of low frequency probes in order to explore deep structures, with a consequent loss of finer detail owing to lower spatial resolution. The converse is true for exploration of more superficial tissues.
Appropriate setting of the US equipment (i.e. gain, focus, maps, second harmonic, depth and zoom) is needed so that different soft tissues are visualised at the best contrast and magnification level. An adequate number of appropriate views is required in order to obtain a complete assessment of the anatomical site under examination. This means documentation of US findings on at least two perpendicular scanning planes, right-left comparison and dynamic examination where appropriate (Table II).

Table II. Standard scanning protocol.

Patient position
Probe choice
US equipment setting
Standard scans sequence
Right-left comparison
Dynamic examination

Table III. Soft tissue and joint US anatomy.

Soft tissue	Shape		Texture	
Synovial tissue	Not visualised in normal joints		Not visualised in normal joints	
Synovial fluid	The shape of the cavity it fills		Anechoic	
Articular cartilage	Curved layer with sharp and continuous hyperechoic margins		Anechoic or homogeneously hypoechoic	
Tendon	*Longitudinal*	*Transverse*	*Longitudinal*	*Transverse*
	Band with sharp and continuous hyperechoic margins	Oval or rounded areas	Fibrillar	Densely packed hyperechoic spots
Bone profile	Thin band		Hyperechoic	
Peripheral nerve	*Longitudinal*	*Transverse*	*Longitudinal*	*Transverse*
	Band	Oval or rounded areas	Fascicular	Scattered hyperechoic tracts

US anatomy

US allows accurate distinction of soft tissues and pattern recognition in healthy subjects (Table III).

Joints

In healthy subjects the joint cavity is generally a virtual space. A minimal amount of synovial fluid may be detectable in some joints such as metatarsophalangeal, wrist, hip and knee.
The profile of the joint capsule can only usually be visualised indirectly by dynamic assessment (active or passive movement of the joint). Bony landmarks, fat pads, articular cartilage and tendons are very useful points of references in the selection of the best approach to the joint. The intra-articular fat pad is a hypoechoic, inverted core of tissue which occupies the joint space in healthy subjects. Articular cartilage appears as a homogeneously anechoic layer sharply defined by the outer and inner margins. The outer chondro-synovial margin is a thin hyperechoic layer and the inner osteo-chondral margin is generally thicker.

Tendons

In longitudinal scans normal tendons are characterized by a typical "fibrillar" pattern generated by the tight arrangement of parallel collagen fibres. In transverse scans, tendons appear as round or oval structures, characterised by numerous closely joined dots that are homogeneously distributed and correspond to the intra-tendineous connective fibres. The US characteristics of tendons in healthy subjects are fairly homogeneous and have limited intra- and inter-individual variability (7, 8). The tendon sheath, when present, is not always easily detectable. Dynamic movement of the tendons however, distinguishes it as a thin hyperechoic line which does not follow the movements of the collagen fibres. With the use of very high frequency transducers a subtle anechoic rim corresponding to the physiological layer of the synovial fluid can be detected.
If the ultrasound beam and the major axis of the tendon are not perfectly perpendicular, certain areas of the tendon appear anechoic (anisotropy artefacts) and thus may be mistakenly interpreted as possible tendon ruptures.

Bone

The US beam does not pass through cortical bone. The bony cortex appears as a continuous sharp hyper-echoic line which generates an acoustic shadow.

Nerves

Normal nerve has a typical "fascicular" pattern due to a discontinuous cluster of linear echoes on longitudinal scans. These echoes are generated by intraneural connective fibres and are clearly detectable on a hypoechoic background. The distribution of connective tissue along the nerve is not so regular and homogeneous as in tendon. Thus, the morpho-structural pattern of the nerve may show considerable variation (9).

US pathology

Joints

Joint space widening is the most characteristic US feature of joint inflammation. US permits accurate distinction between joint effusion and synovial proliferation which is characterised by clusters of soft echoes (bushy and villous appearance) and/or homogeneous synovial thickening (10-12).

Patients with rheumatoid arthritis (RA) show a wide range of sonographic joint changes. Early RA is characterised by homogeneously anechoic space widening of small joints. By virtue of its high resolution and its multi-planar capability, US is more sensitive than X-ray in the detection of bone erosions at MCP joint level in RA (13, 14). Erosions occur in several forms of inflammatory arthritis including RA, sero-negative arthritis and crystalline arthropathy.

Several cartilaginous abnormalities can be observed in various rheumatic disorders. These include loss of cartilage transparency, loss of the sharpness of the cartilage-soft tissues interface and cartilaginous thinning. Various combinations of these changes are clearly detectable in late osteoarthritis (15).

Tendons

The spectrum of pathologic changes within tendons includes tenosynovitis (exudative or proliferative), swelling, tears, dislocation and fibrosis. US is able to clearly depict all these changes (7, 8).

Sonographic findings indicating a tendon lesion include irregularity of the tendon margin, loss of the normal fibrillar echotexture, tearing of the tendon and tendon sheath widening. The echotexture of the sheath content allows the distinction between exudative tenosynovitis (homogeneous hypo- or anechoic pattern) and proliferative tenosynovitis (irregular thickening of the synovial layer). Tendon sheath widening is one of the most commonly encountered sonographic abnormalities in patients with RA.

In tendons without a synovial sheath, one of the first features of inflammation is focal or diffuse thickening of the tendon, which is associated with alteration in echogenicity which varies according to the duration of the process, its location and the anatomical characteristics of the tendon. Tendon thickening is a typical feature of chronic tendonitis and is almost invariably associated with various intra-substance changes that include loss of fibrillar echotexture and patchy hypoechogenicity. An extended and heterogeneous change of echogenicity is the main sonographic feature of definite tendinosis and is also a key finding in patients with familial hypercholesterolaemia.

Tendon tears appear as fragmentation of small groups of contiguous fibrils, which determines a characteristic loss of the normal fibrillar echotexture of the tendon (Fig. 1A-B). In more advanced stages of structural damage, tendons can be subjected to large partial tears or complete rupture.

Bone

Due to the very high spatial resolution of US, even minimal interruptions or irregularities of this line should be regarded as pathological. US can be particularly informative in cases of suspected fracture both as an adjunct to conventional X-ray and for diagnostic purposes in cases of occult fracture such as rib and metatarsal fractures. The classical appearance of a fracture on US is a distinct break in the hyperechoic line often with surrounding hypoechoic haematoma within the soft tissues.

Nerves

The most clinically relevant application for US in assessment of peripheral nerves is in entrapment neuropathies. Several recent reports have proposed diagnostic criteria for diagnosing carpal tunnel syndrome (CTS), the most important being a mean cross sectional area of > 10 mm^2 (16). In addition US is useful in the detection of secondary causes of CTS i.e. tenosynovitis of the finger flexor tendons, urate and amyloidosis deposits, aberrant muscles within the tunnel and arthrogenic cysts.

Clinical applications of US

US should be performed when it is expected to add valuable information to history and physical examination of rheumatic patients. It is particularly useful in the context of a complex clinical and radiographic setting (17). Moreover, US has potential in the monitoring of disease activity and progression (18-20). US as the initial diagnostic tool can replace other invasive and expensive tests, shorten examination times and improve efficiency at rheumatology units.

An important hidden benefit of US in rheumatology is the further development of the doctor-patient relationship. Patients are frequently fascinated by the imagery provided by US and the modality can expand their understanding of their disease. US can also precede and guide local injection therapy (21), whenever possible, especially in anatomical areas at risk of potential damage from the sharp point of a needle (i.e. arteries, tendons, nerves and articular cartilage) (22). It is also useful to confirm the correct placement of intra-lesional therapy with US (Fig. 1C).

US training

Guidelines for appropriate training have not yet been introduced into general rheumatological training internationally. Different approaches to overcoming the steep learning curve have been reported (23, 24). At present, however, it is clear that US training in rheumatology should ideally include the following elements:

1. Full immersion program of normal anatomy and histopathology of rheumatic diseases
2. High quality US equipment
3. Continuous interaction with an experienced tutor
4. Time devoted to the practice of US

US is often described as the most operator dependant imaging modality and this commonly acts as a barrier to rheumatologists attempting to learn the technique for themselves. In reality, the operator dependency of US is no greater than other practical elements within the repertoire of a clinical rheumatologist (i.e., taking a concise medical history and taking blood pressure). Relevant basic findings such as joint cavity widening, cysts, bursitis, gross tendon pathology are relatively easy to obtain by a skilled clinical rheumatologist with basic US training (23, 24). The clinical relevance of the result of US examination depends upon the skill of the operator particularly when the underlying pathologic process involves complex regional anatomy (i.e. rotator cuff).

US and other imaging modalities

US should be viewed as an adjunct to the widespread use of conventional X-ray in the evaluation of rheumatic disease. In the investigation of regional pain syndromes, US delivers valuable anatomical information which is not available by X-ray (25,26). In addition, US is able to demonstrate the presence of bone erosions in the early phase of RA when X-rays appear otherwise unremarkable (13,14, 27).

Compared with magnetic resonance imaging (MRI), US appears to be more accurate in the diagnosis of tendon changes. An additional benefit over MRI is the possibility to explore other relevant anatomical areas (i.e. the contra-lateral side). There are also fewer contra-indications to the performance of US compared with MRI. It is important to view these drawbacks of MRI in the light of its inherent advantages over US, particularly in relation to visualising bone oedema and the standardisation of the technique (28).

The main advantages and disadvantages of US are summarised in Table IV.

Table IV. Advantages and disadvantages.

Advantages	Disadvantages
- safe and no contra-indications	- operator dependent
- no radiation hazards	- long learning curve
- widely available	- incorporation to clinical time
- non-invasive	- limited acoustic windows
- well-accepted by patients	- high initial costs
- low running costs	
- short examination time	
- multi-regional assessment	

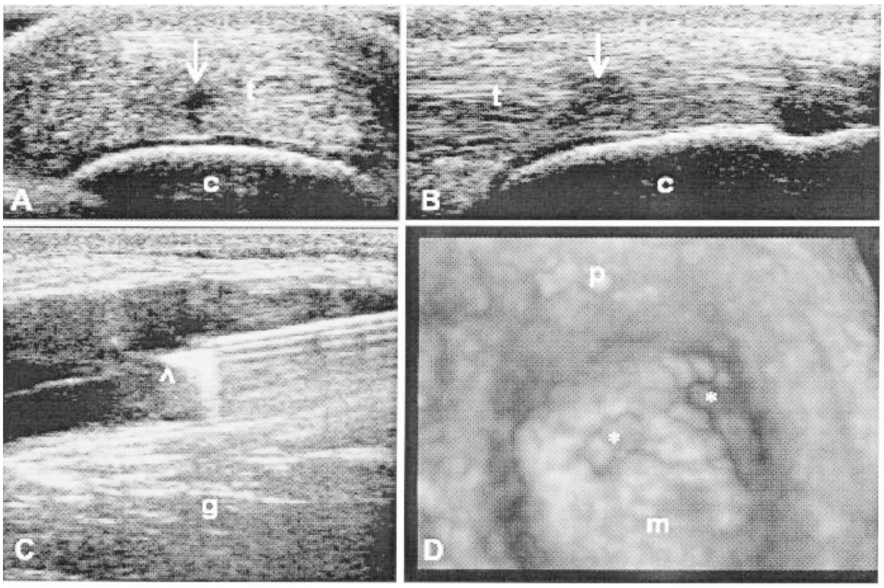

Fig. 1. Representative examples of sonographic pathological findings. Partial tear (**arrow**) of the Achilles tendon in sero-negative spondyloarthritis: (**A**) transverse and (**B**) longitudinal scans (**t**: Achilles tendon). (**C**) Sonographic guided aspiration of a popliteal cyst in knee osteoarthritis. (**>**) tip of the needle (**g:** gastrocnemius). (**D**) 3D view of second metacarpal head with clearly defined erosions (**asterisk**) in rheumatoid arthritis (**m**: metacarpal head, **p:** proximal phalanx).
For further ultrasound images, please go to www.clinexprheumatol.org

Future developments in US

Among the more significant innovations which have emerged in recent years within US, three-dimensional (3D) imaging is one of the most interesting (Fig.1D). The revolutionary approach offered by 3D US relies on the fact that a volume of echoes is acquired automatically with a single placement of the probe over the targeted region (29). The most promising application of 3D imaging is in the monitoring of synovial perfusion using power Doppler. This relates both to the acquisition of a complete volumetric study of synovial perfusion in one manoeuvre and also the ability to suppress grey scale background to display power Doppler signal alone.

Automatic 3D US is machine dependant but operator independent. This means that the quality of the images obtained do not rely entirely upon the skills of the operator thereby bypassing the potentially lengthy learning curve for all novices in US. Even if 3D US is a novel and still expensive technology which requires further development, the first generation 3D equipment is impressive in the quality of the information obtained.

Further innovations will focus on higher-frequency and multi-frequency transducers, methods for the reconstruction of 3D images, elastography, colour and power Doppler sensitivity.

Conclusions

US is still in the developmental stage but has so many potential advantages for it to be regarded as a highly valuable tool for rheumatologists. Clinical applications of US are growing rapidly accompanied by the desire of rheumatologists to perform their own US scanning. Several questions remain to be addressed and will almost certainly form the basis of future research agendas. They centre upon the role of serial US examination in therapy monitoring and in the formal assessment of the extent and severity of several important rheumatic diseases. Future developments in research involving US in rheumatology are keenly awaited by rheumatologists.

Link

For further ultrasound images, go to www.clinexprheumatol.org/ultrasound

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