What the practising rheumatologist needs to know about the technical fundamentals of ultrasonography

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A transducer generates ultrasound waves and emits them into the body. Boundaries in or between tissues reflect the waves, and the transducer receives the reflected waves. A computer converts the information into images that are displayed on a monitor. Image resolution is greater with higher frequencies, and penetration is greater with lower frequencies. Linear probes with frequencies between 5 and 20 MHz are mainly used for musculoskeletal ultrasound.

Image quality and resolution have improved significantly. Tissue harmonic imaging and cross-beam technology aid in differentiating between anatomical structures, although borders appear artificially thickened. Three-dimensional ultrasound provides additional coronary planes, and contrast agents increase the sensitivity for synovial blood flow in inflamed joints.

This chapter provides further information regarding which ultrasound technology is the best for purchase by a rheumatology unit, how to organize ultrasound clinics, and how best to perform ultrasonography in daily practice, including the most important indications for ultrasound in rheumatology.

Key words: ultrasonography; color Doppler ultrasonography; 3D ultrasonography; rheumatoid arthritis; Sjögren’s syndrome; giant cell arteritis; technology.

THE PHYSICAL BASIS

The term ‘ultrasound’ is somewhat self-explanatory. It refers to sound which is above the acoustic spectrum that can be heard by a human being. Humans are capable of

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hearing sounds with a frequency between 20 Hertz (Hz) and 20,000 Hz. Medical diagnostic ultrasound applies frequencies of 1–25 MHz (1 MHz = 1,000,000 Hz).

Sound waves travel with a velocity of 1540 m/s. This means that they reach a distance of 10 cm after 0.000065 s. Within 1 s, approximately 1000 ultrasound waves can be emitted and received from an object at a distance of 10 cm from the ultrasound probe.

Frequency (f) and wavelength (λ) are inversely proportional to each other, i.e. $f = \frac{1}{\lambda}$. A higher frequency of sound waves leads to lesser penetration but higher resolution of structures. A lower frequency with longer wavelength leads to greater penetration in the body, but a decrease in resolution. The physical frontier for discrimination between two interfaces lying closely together is a minimum distance of more than half a wavelength between the two interfaces.

Ultrasound waves are generated by a transducer which consists of a disc with crystals of lead zirconate titanate. These crystals show a marked piezo-electric effect. They transform electrical potentials into mechanical vibrations and vice versa. Every time an electrical current is passed through the crystals, the disc generates an ultrasound pulse. Conversely, when the disc receives an ultrasound wave that returns from the tissue, it will deform and a voltage is generated on the transducer surface. In order to produce a well-directed beam, the transducer disc is mounted at the end of a cylindrical tube, also called a ‘probe’. At the other end of the tube, dampening materials are mounted to damp down the ultrasonic waves generated at the rear side of the disc.

The emitted waves are subject to transmission and reflection. Transmission occurs when a pulse passes through one tissue into another. Reflection back to the source of the pulse occurs when an ultrasound pulse is reflected at a boundary. The more two tissues differ in density from one another, the higher the amount of reflection; the more similar they are, the higher the amount of transmission. The mathematical relationship determining the amount of reflection and transmission is given by the speed of sound $c$ and the specific acoustic impedance $Z$ of the tissue. The impedance of sound in air is low. It is 10,000 times higher in muscle compared with air, and 50,000 times higher in bone compared with air. This leads to the phenomenon that the sound beam does not penetrate bone at all.

The boundary between two different tissues is called an ‘acoustic interface’. A marked interface exists between air and skin. If the transducer is placed on the skin surface without use of a coupling medium, i.e. ultrasound gel, only 0.1% of the ultrasound pulse is transmitted into the skin tissue and 99.9% is reflected off the skin surface. Ultrasound gel has an impedance similar to human tissue. Therefore, with the use of ultrasound gel or water, a much higher amount of the ultrasound pulse penetrates the tissue under examination. Liquids, like blood, urine or synovial fluid, do not reflect sound waves.

When the surface of an object is flat and no air is present between the source and the object, almost all of the ultrasound waves are reflected from the object at right angles; the returning echoes are then detected by the transducer. The crystal converts the returning ultrasound wave – with the same wavelength as the emitted wave – into an electronic potential. Subsequently, the electronic potential is converted by a computer into an ultrasound image. The transducer functions as a receiver of returning ultrasound echoes for approximately 99.9% of the time. The remaining 0.1% of the time it acts as an emitter of sound waves.

Computer technology converts the information into images. Therefore, this technique is often also called ‘ultrasonography’ or ‘sonography’. It distinguishes itself from therapeutic ultrasound by the amount of energy, as the energy of therapeutic ultrasound is much greater. This leads to a considerable implication of warmth in the tissue of the
body, and therefore it is widely used in the treatment of rheumatic diseases. Diagnostic ultrasound also causes warming of human tissue, particularly when used as colour or power Doppler ultrasonography, but this is to a much lesser degree. In general, ultrasound is supposed to be safe although data on long-term substantive outcomes in obstetrics are lacking. Physicians have been asked to be careful when examining the uterus of a pregnant woman extensively with colour Doppler ultrasonography.

Ultrasound loses its energy as it propagates through the tissue. This loss of energy is called ‘attenuation’. There are three causes of attenuation: diffraction, scattering and absorption. Diffraction refers to the bending of waves when they interact with obstacles in their path. Scattering means that waves are forced to deviate by non-uniformities of the tissue, such as density fluctuations in fluids and inhomogeneous organs. Absorption means that acoustic energy is converted into heat energy. A material or surface that absorbs sound waves does not reflect them. Absorption of a given material is frequency dependent. Attenuation results in echoes from deep body tissues being displayed less intensively than those returning from superficial structures. A function of the ultrasound system called ‘time-gain control’ corrects the attenuation and technically intensifies the echoes returning from deeper structures.

**TERMINOLOGY FOR ULTRASOUND**

The rheumatologist who is using ultrasound equipment in his practice should know several terms that are in use in conjunction with ultrasound.

**A-mode**

This is the simplest type of ultrasound. A single transducer scans a line through the body. Along this line, the echoes are displayed on the screen as a function of depth. This mode is still sometimes used in ophthalmology to determine distances in the eye.

**B-mode**

‘B’ stands for ‘brightness’. This is the most commonly used mode in musculoskeletal ultrasound. It is also called ‘grey-scale ultrasound’. An array of transducers simultaneously scan a plane through the body. The information is displayed as a two-dimensional image on the monitor.

**M-mode**

‘M’ stands for motion. This mode is most commonly used in echocardiography to determine the movement of cardiac structures. Furthermore, M-mode studies can delineate the pulsation of an artery. M-mode displays the depth of echo-producing interfaces along one axis and time along the second axis, recording motion of the interfaces towards and away from the transducer. M-mode images can be displayed on the screen at the same time as B-mode images.

**Doppler mode**

This mode applies the Doppler effect. The Doppler principle states that sound waves increase in frequency when they reflect from objects (e.g. red blood cells) moving...
towards the transducer, and decrease in frequency when they reflect from objects moving away from the transducer. This information is transferred into sound. Furthermore, it is possible to delineate flow curves and to determinate the direction of blood flow.

**Continuous wave Doppler**

Continuous wave (CW) Doppler only assesses flow without providing anatomical images. This method detects all the information of an axis through the body. The information is converted into sound or curves that are displayed on a screen. CW Doppler does not provide information on distances.

**Pulsed wave Doppler**

Pulsed wave Doppler is more advanced than CW Doppler. This mode detects the information in a selected anatomical region of the Doppler beam axis. The anatomical region is selected on the grey-scale image or the colour Doppler image.

**Colour Doppler mode**

This mode combines the Doppler effect with real-time imaging. The real-time image is created by rapid movement of the ultrasound beam. The information from Doppler ultrasound is integrated in the grey-scale image as a colour signal. This signal indicates the direction of blood flow. Red signals indicate flow that is directed towards the ultrasound probe, and blue signals indicate flow that is directed away from the probe.

**Duplex mode**

This is the combination of real-time imaging and Doppler ultrasound. It depicts both the anatomical image with colour signals and the Doppler curves. In addition, this technique allows estimation of the velocity of flow from the Doppler shift frequency in combination with an angle correction programme.

**Power Doppler mode**

In this mode, the total integrated Doppler power is displayed in colour. It increases the machine sensitivity, particularly for small vessels and slow blood flow. Most ultrasound machines provide unidirectional images with only one colour, independent of the direction of blood flow. Some equipment provides bidirectional information as described for colour Doppler ultrasound. Power Doppler ultrasound in rheumatology is particularly important for determining blood flow in joints, in and around tendons and in entheses. Sensitivity is higher using the power Doppler mode than the colour Doppler mode in most machines. In some machines, there is no great difference.3,4

**ULTRASOUND EQUIPMENT**

An ultrasound machine consists of a computer, a monitor, a keyboard and probes. Figure 1 shows the main features of an ultrasound machine. A probe is also called
a ‘transducer’. The transducer is the centrepiece of the equipment as it incorporates the disc with crystals of lead zirconate titanate which sends and receives the ultrasound waves.

There are several types of transducer (Figure 2): linear probes, curved array probes, sector array probes and pencil array probes.

Linear probes are capable of covering all indications for musculoskeletal ultrasound. Probes can be as long as 6 cm and as short as 2 cm. Longer probes provide a good overview. This applies, in particular, for larger joints such as hip joints, and for stability testing, which can be done, for instance, in knees and shoulders. Short probes are often called ‘hockey stick’ or ‘footprint’ probes because of their shape. They were originally developed for intra-operative examinations, but they are also excellent for the examination of small superficial structures and for the assessment of regions that are difficult to reach, such as determination of metacarpophalangeal (MCP) joint pathologies in hammer toes.

Curved array probes have a curved shape. Therefore, they delineate a greater region in deeper anatomical structures compared with more superficial anatomical structures. These probes are mainly used for abdominal ultrasound. They also provide a better overview of hip joints in large patients. Most probes provide frequencies of 2–8 MHz.

Sector array probes have a small surface providing an even greater angle, i.e. they delineate an even larger area in deeper regions. Application of these probes includes
echocardiography and transcranial ultrasound to examine cerebral vessels. The small
probe allows passage of the rather small intercostal space to delineate the heart below. Some sonographers have applied these probes for examination of the menisci. Nevertheless, resolution of these probes is rather low because of their low frequency, and the diagnostic accuracy of meniscal ultrasound is poor. Most probes provide frequencies of 1–4 MHz.

Pencil array probes are in use for CW Doppler ultrasound to examine vascular flow characteristics, such as determining the direction of flow in the supratrochlear arteries before temporal artery biopsy to exclude collateral flow via the temporal arteries in case of internal artery stenosis or occlusion.

A higher frequency leads to a better resolution, and a lower frequency provides greater penetration. Ten to twenty years ago, the 7.5 MHz linear probe was the standard probe for musculoskeletal ultrasound as it was a compromise with regard to resolution and penetration. Nowadays, most probes offer a range of frequencies, e.g. 10–25 MHz, 8–18 MHz, 5–12 MHz or 3–9 MHz. Figure 3 shows which frequencies are preferable to assess the different joint regions. Several probes allow examination of all regions with one probe. High-frequency probes may cause problems with penetration at hip joints, at the posterior aspects of the glenohumeral and ankle joints in large patients. Therefore, some rheumatologists prefer to work with two linear probes. The authors use a high-frequency probe (6–18 MHz) for nearly all musculoskeletal applications, and also to examine salivary glands, finger arteries and temporal arteries; and a lower frequency probe (3–9 MHz) for examination of the hips, the veins of the lower extremities and the arteries of the neck, particularly the proximal vertebral arteries. Furthermore, the authors also apply the lower frequency probe for the posterior aspects of the shoulders in large patients, and to provide a better overview in stability tests because it is longer than the higher frequency probe. In addition, it is convenient to have a curved array probe and a sector array probe available at the same ultrasound machine in order to provide abdominal ultrasound and echocardiography to address related medical questions that often occur in rheumatic diseases.
NEW TECHNICAL DEVELOPMENTS

Image quality and resolution have improved significantly within the last years, so ultrasound is now able to differentiate between tiny anatomical structures. Furthermore, newer technologies such as cross-beam technology (also called ‘sono-CT’ or ‘compound imaging’) have enabled neighbouring structures to be delineated. The probe sends and receives sound waves that are not only parallel to each other in the tissue but in different directions at the same time.

Tissue harmonic imaging relies on the fact that the transducer sends out sound waves but receives the waves with the same frequency, and the double frequency generates better images. This technology aids in the differentiation of structures, but also makes the borders between structures appear artificially thickened.

Modern three-dimensional (3D) probes can be placed in a region of interest. They automatically generate 3D images without moving the probe. This procedure provides a third, coronary, plane, e.g. one can look at anatomical structures, such as rotator cuff ruptures or erosions, from a different perspective. Furthermore, the physician may look at the images after they have been generated. Nevertheless, one of the great advantages of musculoskeletal ultrasound is its direct application by the rheumatologist, together with history and clinical examination. Furthermore, 3D probes are much heavier than modern two-dimensional probes. Real-time 3D ultrasound has been termed ‘four-dimensional ultrasound’.

Ultrasound contrast agents are gas-filled micro bubbles that are administered intravenously. These bubbles are destroyed when they are hit by an ultrasound beam, and provide a high degree of echogenicity when being reflected. Thus, ultrasound contrast agent increases sensitivity for the detection of synovial blood flow. It allows better quantification of inflammatory activity by estimating signal intensity changes. This technology is of particular interest for clinical studies to monitor new anti-inflammatory drugs in rheumatoid arthritis.

WHICH ULTRASOUND MACHINE DO I NEED FOR MY PRACTICE?

The only way to become proficient with ultrasound is to use it in daily clinical practice. For this reason, it is necessary to have regular access to ultrasound equipment. The
How much money am I willing or able to spend?

A new ultrasound machine costs between 7000 and 150 000 Euro depending on its quality and technical features. Second-hand machines are obviously cheaper than new machines. If a new machine is bought, it should include the option of regular software upgrades. This option helps considerably with increasing the image quality within the years following purchase.

Ultrasound machines that cost between 7000 and 12 000 Euros offer basic features that are often sufficient to determine most of the points that are necessary to answer questions in daily clinical rheumatological practice. Many of these cheap machines do not offer a colour or power mode. Whilst these modes are helpful to determine the inflammatory activity of joints, tendons and entheses, ‘black and white’ equipment is better than no equipment at all.

Second-hand equipment is an alternative. Usually, software upgrades are not available for these machines. Furthermore, one has to be sure if image quality is comparable with modern equipment. Image quality may be inferior in machines that are more than 5 years old.

Some modern ultrasound equipment that costs between 12 000 and 25 000 Euros has reasonably high image quality with regard to grey-scale images, but colour Doppler is often rather poor. However, this does allow determination of major inflammation. The detection of small structures and fingers and toes, like small nodules and tiny erosions in early arthritis, may be difficult.

Mid-range equipment that costs between 25 000 and 50 000 Euros provides good quality colour and grey-scale images. Many of these machines allow adequate delineation of tiny structures such as fingers, finger arteries and temporal arteries.

Very good equipment costs between 50 000 and 80 000 Euros. Grey-scale and colour images are of excellent quality. An experienced sonographer can use this equipment for all indications in rheumatology. This includes the evaluation of small nerves and ligaments and small arteries such as the temporal, occipital and finger arteries.

High-end equipment may cost up to 150 000 Euros and includes all conceivable technological highlights, together with excellent image quality.

What am I going to use the ultrasound machine for?

Most rheumatologists want to assess joints, tendons and soft tissue lesions including small structures at fingers and toes. For this, they need high-frequency linear probes. For most cases, one linear probe with a frequency of 5–12 or 4–13 MHz will cover nearly all indications.

Those who have enough money to spend and who want to receive excellent imaging of superficial and deep structures may purchase two probes; one with a very high
frequency range and one with a low frequency range. High-frequency probes are particularly useful for the assessment of temporal and finger arteries and small structures such as fingers and toes.

If possible, the rheumatologist should have access to colour or power Doppler functions for the assessment of inflammatory activity and to perform vascular ultrasound. It is also practical to provide echocardiography and abdominal ultrasound at the same session if necessary, but this is subject to national and educational aspects.

**Do I need stationary or portable equipment?**

Within recent years, small portable ultrasound machines of increasing quality have been developed. Some machines include nearly all of the features that are found in high-end machines.

Portable equipment is particularly useful if a physician practices in different offices and takes his machine to the different locations. Portable equipment is in use at sports events to diagnose injuries quickly. Many rheumatologists who are working in the same institution may share one ultrasound machine which is then moved to their respective office when needed. Portable machines fit into small offices. They may have smaller monitors, and the chance of theft is greater. Nevertheless, an increasing number of rheumatologists use these small and very practical machines.

Stationary ultrasound equipment is useful for physicians who mainly practice from the same office. Large institutions offer ultrasound clinics, where different rheumatologists send the patients to the ultrasound room. Monitors are larger, and some companies only offer high-quality equipment together with stationary ultrasound machines.

**Do I know the pros and cons of different ultrasound machines?**

Before buying ultrasound equipment, one should have checked at least three machines. Most business representatives are willing to bring a machine to the rheumatologist's office to be tested for a day or so. If one company agrees to provide a machine for some time and another does not, this is a good argument to decide in favour of the more collaborative company. Furthermore, some companies are more interested in rheumatology than others, which may be an indicator that their products have strengths in musculoskeletal imaging.

**Does the ultrasound company offer technical services close to my institution?**

Technical support is particularly necessary if one has to rely on a single machine in one's department. It should be possible to reach a representative of the company in the country on all working days (at least), and, ideally, close to where the office is located.

**HOW TO ORGANIZE AN ULTRASOUND ROOM AND AN ULTRASOUND CLINIC**

Nearly all physicians carry a stethoscope. It would be fantastic if every rheumatologist's office was equipped with an ultrasound machine. This is, of course, unrealistic from an economic point of view. Nevertheless, some rheumatologists have their
equipment in their own office, and others share machines. They either have a separate
room in their institution and move to the room together with their patient, or they
have a machine which they can move into their office. Large institutions have ultra-
sound clinics. The sonographer, who is often a rheumatologist, performs scheduled
and spontaneous examinations. He collaborates with nurses who organize transporta-
tion for in- and outpatients and perform further administrative work. This work can
also be combined with other specialized work, such as joint injections, infusion clinics,
osteodensitometry, etc.

An ultrasound room does not have to be completely dark. Modern machines offer
rather bright images on their screen. Nevertheless, there should be a possibility for
darkening the room, particularly on sunny days.

HOW DO I SIT AND HOLD THE PROBE?

Ultrasound is a safe imaging technique for the patient, but the sonographer may de-
velop medical problems because of inappropriate posture when performing ultrasound
on a regular basis.\textsuperscript{11} The sonographer should sit comfortably on a chair. Ideally, the
chair should revolve and should have arm rests. The monitor should be at or below
eye level. It should be adjusted in a way that both the sonographer and the patient
can see the ultrasound image. The sonographer's hand that is holding the probe should
rest comfortably on the patient. It is important to hold the probe firmly with the first
four fingers, and place the fifth finger and the ulnar part of the hand on the patient. The
sonographer should be aware of holding the arm comfortably to avoid rotator cuff
problems of his own shoulders.

WHAT IS WHERE ON AN ULTRASOUND IMAGE?

Each anatomical structure should be scanned in two planes that are perpendicular to
one another. EULAR (European League against Rheumatism) guidelines provide stan-
dardized probe positions.\textsuperscript{12} Scans longitudinal to the axis of the body should show
proximal anatomical structures on the left side of the monitor. Distal anatomical struc-
tures are displayed on the right side of the monitor. Transverse scans show structures
on the left side of the monitor that are localized left to the sonographer. Alternatively,
structures that are located on the medial, ulnar or tibial side can be depicted on the
left side of the monitor, and structures located on the lateral, radial or fibular side can
be depicted on the right side of the monitor (Figure 4).

HOW DO ANATOMICAL STRUCTURES APPEAR ON AN ULTRA-
SOUND IMAGE?

Figure 5 shows a dorsal longitudinal scan of an MCP joint displaying important anatom-
ical structures. Structures can be isoechoic to subcutaneous fat tissue, hyperechoic
(brighter), hypoechoic (darker) or anechoic (black).\textsuperscript{13} Skin, fat and connective tissue
are inhomogeneous. Skin is hyperechoic, and connective tissue is isoechoic. Tendons
show a fibrillar pattern in longitudinal views (Figure 6). They are hyperechoic if located
parallel to the probe, and hypoechoic when insonation is not perpendicular because the
reflected waves divert and miss the transducer. This phenomenon is called ‘anisotropy’
(Figure 7).\textsuperscript{14} Nerves are hypoechoic with a more dotted appearance than tendons (Fig-
ure 6). Fluid is anechoic or hypoechoic. Ultrasound may display physiological amounts of
fluid in normal joints, or pathological amounts of fluid (effusions) in inflamed joints. Synovium and synovial proliferations are hypoechoic. Cartilage is hypoechoic or anechoic. The bone surface is hyperechoic. Transducers that are in use for musculoskeletal ultrasound do not depict structures that localize below the bone surface.

**Figure 4.** Orientation on the ultrasound monitor in longitudinal and transverse scans.

**Figure 5.** Anatomical structures and their echogenicity on a dorsal longitudinal image of an metacarpophalangeal joint with effusion.
DIFFERENTIATION BETWEEN SOFT TISSUE AND BONE LESIONS BY MUSCULOSKELETAL ULTRASONOGRAPHY

Inflammatory soft tissue lesions include synovitis with effusion, synovial proliferation, tenosynovitis with effusion and/or synovial proliferation of the tendon sheath, as well

Figure 6. Median nerve and flexor digitorum tendon in a longitudinal view (A) and a transverse view (B). The nerve in the longitudinal view is thickened in carpal tunnel syndrome.

Figure 7. The cause of anisotropy.
as bursitis with effusion and/or synovial proliferation. Synovial proliferation of the joint capsule often occurs in combination with inflammatory effusion. The combination of both is also called 'synovitis'. During the 7th OMERACT Conference, an international expert group defined pathological sonographic findings as follows.13

- **Effusion**: abnormal hypoechoic or anechoic intra-articular material that is displaceable and compressible but does not exhibit Doppler signal.
- **Synovial hypertrophy**: abnormal hypoechoic intra-articular tissue that is non-displaceable and poorly compressible, and which may exhibit Doppler signal.
- **Tenosynovitis**: hypoechoic or anechoic thickened tissue with or without fluid within the tendon sheath which is seen in two perpendicular planes and which may exhibit Doppler signal.
- **Enthesopathy**: abnormally hypoechoic (loss of normal fibrillar architecture) and/or thickened tendon or ligament at its bony attachment seen in two perpendicular planes which may exhibit Doppler signal and/or bony changes including enthesophytes, erosions or irregularity. It may occasionally contain hyperechoic foci consistent with calcification.
- **Erosion**: an intra-articular discontinuity of the bone surface which is visible in two perpendicular planes.
- **Bursitis**: cyst formation with abnormal hypoechoic or anechoic material with or without fluid inside a bursa seen in two perpendicular planes and which may exhibit Doppler signal.

**APPLICATION IN CLINICAL PRACTICE: INDICATIONS FOR MUSCULOSKELETAL ULTRASOUND IN RHEUMATOLOGY**

**Detection of effusion and synovitis (Figure 5)**

Musculoskeletal ultrasound can detect very small fluid collections at each peripheral joint. Clinical studies have shown that it is more sensitive for the detection of inflammation than clinical examination.16 Ultrasound detects synovitis more frequently in the palmar proximal area of the finger joints [proximal interphalangeal (PIP) and MCP] than at the dorsal aspect.17 Synovitis scores have been developed for the finger joints in arthritis.17,18 The synovitis score according to Szkudlarek18 grades the inflammatory soft tissue lesions separately for effusion and synovial proliferation. The synovitis score according to Scheel and Backhaus combines both the effusion and the synovial proliferation in one scoring system.17 The best results for joint combinations were achieved using the ‘sum of four fingers’ (second through fifth MCP and PIP joints) and ‘sum of three fingers’ (second through fourth MCP and PIP joints) methods. Comparison of magnetic resonance imaging results with semiquantitative ultrasound scores (grade 0 = normal, grade 1 = minimal effusion/synovial hypertrophy, grade 2 = moderate effusion/synovial hypertrophy, grade 3 = severe effusion/synovial hypertrophy) revealed high concordance with quantitative synovitis scores (measurements of joint capsule distance to bone margin in millimetres).

**Detection of tenosynovitis, tendonitis and enthesitis**

Tenosynovitis of the extensor carpi ulnaris tendon is an early inflammatory sign in rheumatoid arthritis which can be detected easily by ultrasound.19 Furthermore,
patients with rheumatoid arthritis often exhibit tenosynovitis of the flexor or extensor tendons of wrist and fingers (Figure 8A). Biceps tenosynovitis is a typical finding in patients with various inflammatory conditions. Tendonitis or enthesitis of Achilles tendons occur frequently in patients with spondyloarthritides (Figure 8B).

Detection of bursitis

Popliteal cysts often occur in inflammatory or degenerative diseases with knee involvement. Ultrasound allows good differentiation of bursitis from other entities that lead to swelling of the lower leg, such as thrombosis or muscle rupture. Even small cysts are detectable by dynamic imaging of the knee at the anterior infrapatellar region for deep or superficial infrapatellar bursitis. Ultrasound also detects subdeltoid bursitis, olecranon bursitis, trochanteric and retrocalcaneal bursitis (Figure 8B).

Detection of erosions and osteophytes

Erosive bone lesions are detectable in some wrist and finger joints at an earlier stage using ultrasound than conventional radiography. The exact anatomical classification of bone lesions in the wrist is sometimes difficult with ultrasound. On the other hand, erosions can be detected readily by ultrasound in the finger joints, especially from

Figure 8. (A) Tenosynovitis. Arrows show fluid around the finger flexor tendon. (B) Achilles tendonitis and retrocalcaneal bursitis (arrows). (C) Two erosions (arrows) at radial aspect of metacarpophalangeal joint in rheumatoid arthritis. (D) Calcium pyrophosphate crystal deposition (arrow) in the cartilage of the posterior femoral epicondyle in a longitudinal view.
the radial aspect of the second MCP joint and the ulnar aspect of the fifth MCP joint (Figure 8C). High-resolution transducers can detect more erosive bone lesions on PIP joints than low-field magnetic resonance imaging. Synovitis and erosions are also evident on toes, especially in MTP joints. Many other joints can, of course, be examined for the presence of synovitis with ultrasound. Osteophytes are seen in knee osteoarthritis at the femoral condyle in a flexed knee position, or at the joint space as a small hyperechoic structure with dorsal reflex shadow. Ultrasound also delineates osteophytes in smaller joints. It may be more sensitive than conventional radiography for detection of osteophytes in finger joints, as it delineates more osteophytes that are localized dorsally.

**Detection of cartilage damage**

Ultrasound is able to depict cartilage. Hyaline cartilage is irregular with a reduced diameter in osteoarthritis. Calcium pyrophosphate dihydrate crystals localize within the cartilage. Ultrasound delineates them as hyperechoic dots or lines (Figure 8C).

**Detection of crystal deposition**

In contrast to calcium pyrophosphate crystals, monosodium urate crystals localize either at the interface between cartilage and synovium, in the synovium or in the soft tissue around the joint as hyperechoic material that may cause shadows in the area below. Findings are rather specific for gout.

**Ultrasound-guided injections**

Ultrasound improves needle placement within joints, bursae and tendons. The sonographer may either mark the region of interest before injection, or monitor the needle position with ultrasound during the injection procedure.

**OTHER INDICATIONS IN RHEUMATOLOGY**

Rheumatology includes a wide spectrum of medical aspects. Therefore, if a rheumatologist has access to ultrasound equipment, he may use this to address further questions that are relevant for his clinical practice.

**Sjögren’s syndrome**

Ultrasound of the salivary glands can be performed quickly and easily using the same equipment as for musculoskeletal ultrasound. Linear scanners with a frequency of 5–15 MHz provide clear images of the submandibular and parotid glands. Normal glands are homogeneous and appear slightly hyperechoic compared with the surrounding soft tissue. The image is comparable with that of a normal thyroid. In Sjögren’s syndrome, the submandibular and parotid glands become inhomogenous and hypoechoic compared with the surrounding soft tissue, as is found in chronic thyreoiditis. The submandibular glands become atrophic with a sagittal diameter of <0.8 cm, and the parotid glands are sometimes enlarged with a sagittal diameter of >2.0 cm. The sensitivity of salivary gland ultrasound for diagnosis in terms of fulfilling international classification criteria is 63%, and the specificity is 99% if two or more of the four glands show this
Raynaud's phenomenon

Rheumatologists see many patients with Raynaud's phenomenon. They need to differentiate between primary and secondary Raynaud's phenomenon. In contrast to angiography, ultrasound can identify finger arteries in a faster, non-invasive manner. Acute finger artery occlusion can occur in vasculitis, antiphospholipid syndrome, embolism and thromboangiitis obliterans. In systemic sclerosis, finger arteries become narrowed and occluded more slowly. One needs a high-frequency probe that includes colour Doppler ultrasound to depict the two proper palmar digital arteries that localize at the volar lateral side of each finger between the MCP and PIP joints and between the PIP and distal interphalangeal joints. Furthermore, one can examine the common palmar digital arteries, the superficial palmar arch, and the radial and ulnar arteries. The ulnar arteries are more frequently occluded than the radial arteries in connective tissue diseases and vasculitides.

Vasculitis

Ultrasound displays homogeneous, circumferential wall swelling in cases of vasculitis. In addition, stenoses or acute occlusions often occur. Many studies including a meta-analysis have investigated the use of duplex ultrasound of the temporal artery in the diagnosis of giant cell arteritis, with sensitivities of approximately 85% and specificities of more than 95%. The sonographer needs at least modern mid-range equipment with a high-frequency linear probe that provides a frequency of at least 10 MHz and the option to perform colour Doppler ultrasound. Hypoechoic wall swelling (halo) disappears with steroid treatment within 2–3 weeks in most patients.

Ultrasound may also detect vasculitic wall swelling in other arteries, such as the facial, occipital, vertebral and common carotid arteries. The axillary arteries are more commonly affected in giant cell arteritis than previously assumed. The axillary region can be examined with all probes that are in use for musculoskeletal ultrasound. Of course, colour Doppler facilitates the examination. Axillary vasculitis (‘large-vessel giant cell arteritis’) can occur in patients with classic temporal arteritis, polymyalgia rheumatica, pyrexia of unknown origin or arm claudication. Approximately 60% of patients with large-vessel giant cell arteritis exhibit vasculitis of the temporal arteries. Wall swelling resolves more slowly than in the temporal arteries with treatment.

Takayasu arteritis occurs in patients aged ≤40 years and involves the aorta and its branches, most commonly the subclavian and carotid arteries. The ultrasound appearance is similar to that described in large-vessel giant cell arteritis. Most parts of the thoracic aorta can only be examined with transoesophageal ultrasound.

SUMMARY

Transducers generate and emit ultrasound waves. Waves that have been reflected from boundaries in or between tissues return to the transducer. A computer converts the information so that it can be seen as an image on a monitor. Image resolution increases and penetration decreases with higher frequencies. Multi-frequency linear probes that cover frequencies of, for example, 5–10 MHz or 8–18 MHz are in use for musculoskeletal ultrasound.
Tissue harmonic imaging and cross-beam technology aid in differentiating between anatomical structures. 3D ultrasound provides additional coronary planes which may be useful for delineating erosions and rotator cuff lesions. Contrast agents increase the sensitivity for synovial blood flow in inflamed joints. It may aid in monitoring the effect of new anti-inflammatory drugs on synovitis.

Grey-scale equipment is available at a reasonable price and provides important basic information. Colour and power Doppler aid in determination of the inflammatory activity. More expensive equipment provides better resolution of small anatomical structures and higher Doppler quality. Portable equipment is useful if ultrasound is performed in various locations.

The sonographer should sit comfortably on a revolving chair with arm rests. The monitor should be at or below eye level, and the sonographer’s arm should rest comfortably with a firmly held probe.

There are many indications for performing ultrasound in rheumatology, including:
to detect effusion, synovitis, tenosynovitis, tendonitis, enthesitis, bursitis, erosions, osteophytes, cartilage damage and crystal deposition; to perform ultrasound-guided injection; to differentiate between primary and secondary Raynaud’s phenomenon; and to diagnose Sjögren’s syndrome and large-vessel vasculitis.

### Practice points

**New developments in ultrasonography**
- cross-beam technology: improved distinction of neighbouring structures
- harmonic imaging: improved distinction of neighbouring structures
- 3D ultrasound: additional, coronary plain, e.g. for erosions and rotator cuff tears
- ultrasound contrast agent: increased sensitivity for the detection of synovial blood flow

**How to sit and hold the probe**
- the sonographer should sit comfortably on a revolving chair with arm rests
- the monitor should be at or below eye level
- the sonographer’s arm should rest comfortably on the patient or on the arm rest
- the sonographer should hold the probe firmly with the ulnar side of the hand resting on the patient

**Common indications for musculoskeletal ultrasonography in rheumatology**
- detection of effusion, synovitis, tenosynovitis, tendonitis, enthesitis, bursitis, erosions, osteophytes, cartilage damage and crystal deposition
- ultrasound-guided injections

**Other indications for ultrasound in rheumatology**
- Sjögren’s syndrome: specific finding of hypoechoic, inhomogeneous salivary glands
- Raynaud’s phenomenon: detection of acute or chronic finger artery occlusions
- vasculitis: detection of hypoechoic wall swelling in temporal and axillary arteries
### References


### Research Agenda

#### Using new technologies in rheumatology
- compare images with and without cross-beam technology or harmonic imaging to delineate joint pathology, e.g. to detect shoulder effusions
- does 3D ultrasound improve diagnosis of erosions and rotator cuff lesions?
- monitor the effect of new anti-inflammatory drugs on synovial blood flow with contrast enhanced power Doppler ultrasonography

#### New indications for musculoskeletal ultrasound
- does ultrasound aid in the diagnosis of early arthritis?
- does ultrasound lead to therapeutic decisions?
- are there further new indications for ultrasound in the broad field of rheumatology?


