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Rheumatoid Arthritis Assessment with Ultrasonography

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1. Introduction

Musculoskeletal ultrasound is a rapidly growing imaging modality used for the investigation and management of musculoskeletal disorders. The first report of musculoskeletal ultrasonography was published in 1958 by K. T. Dussik who measured the acoustic attenuation of articular and periarticular tissues including skin, adipose tissue, muscle, tendon, articular capsule, articular cartilage and bone (Dussik et al., 1958). It was first used in rheumatoid arthritis by Cooperberg in 1978 for the assessment of synovitis in the knee. (Cooperberg et al., 1978). De Flaviis made the first report of ultrasonography in the hand in rheumatoid arthritis in 1988, describing synovitis, tenosynovitis, and erosions (De Flaviis et al., 1988).

The first application of power Doppler in demonstrating soft tissue hyperaemia in musculoskeletal disease was reported in 1994 by J. S. Newman (Newman et al., 1994). Since, power Doppler has started to replace gray-scale ultrasonography as an indicator of inflammatory joint disease.

Ultrasonography has a number of advantages, including good patient tolerability and ability to scan multiple joints in a short period of time. Thanks to smaller high-frequency transducers that were better suited for superficial structures such as the small joints, many reports and studies have been published. However, there are scarce data regarding its validity, reproducibility, and responsiveness to change, making interpretation and comparison of studies difficult. In particular, there are limited data describing standardized scanning methodology and standardized definitions of ultrasonography pathologies.

2. Generalities

2.1 Technique

In contrast to conventional radiography, musculoskeletal ultrasonography can provide multiplanar images of cortical bone, synovium, tendons, muscles, ligaments, and nerves. It is a safe, portable and relatively inexpensive technique. Rheumatoid arthritis is the most studied inflammatory disease in rheumatologic ultrasonography.

Equipment is widely available and comparatively flexible. Examinations can be performed at the bedside. The mean price to acquire a machine is nowadays about 40 000 euros, but costs are decreasing.

In B mode ultrasound, a linear array of transducers simultaneously scans a plane through the body that can be viewed as a two-dimensional image on screen. It allows getting pictures of joints and periarticular structures. The higher the frequency is, the greater both the axial and the lateral resolution of image will be, but at the cost of reduced tissue penetration. Therefore, a higher-frequency transducer is best used for superficial structures, such as the small joints of the hand and feet (e.g. 7-18 MHz), and a low frequency transducer is used for deeper joints, such as the hip (e.g. 3-5 MHz).

Doppler mode makes use of the Doppler effect in measuring and visualizing blood flow. Power Doppler denotes only the amplitude of the Doppler signal, which is determined by the volume of blood present so it is better suited to the assessment of low-velocity flow in small vessels (e.g. synovium). This would be a way to assess joint inflammation.

Learning is quite short: D'agostino evaluated that five hours of theory and three months of practice (around 70 exams) are needed. The concordance between learners and teachers is good, approximately about 80 % (D'agostino et al., 2004).

2.2 Elementary lesions in rheumatoid arthritis

OMERACT stands for Outcome Measures in Rheumatology. It is an informal international network of working groups and gatherings interested in outcome measurement across the spectrum of rheumatology intervention studies. Thanks to Omeract, there is consensus on ultrasonography definitions for common pathological lesions seen in patients with inflammatory arthritis (Wakefield et al., 2006).

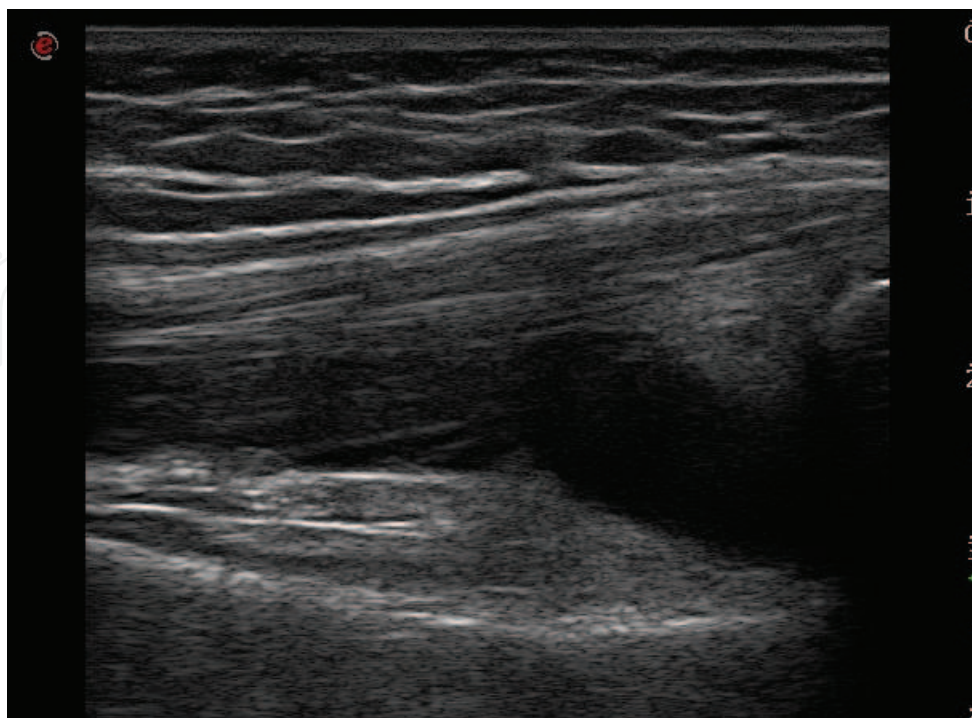


Fig. 1. Effusion of knee

Synovial fluid

Abnormal hypoechoic or anechoic (relative to subdermal fat, but sometimes may be isoechoic or hyperechoic) intraarticular material that is displaceable and compressible, but does not exhibit Doppler signal (Fig. 1).

Synovial hypertrophy

Abnormal hypoechoic (relative to subdermal fat, but sometimes may be isoechoic or hyperechoic) intraarticular tissue that is nondisplaceable and poorly compressible and which may exhibit Doppler signal (Figs. 2, 3).

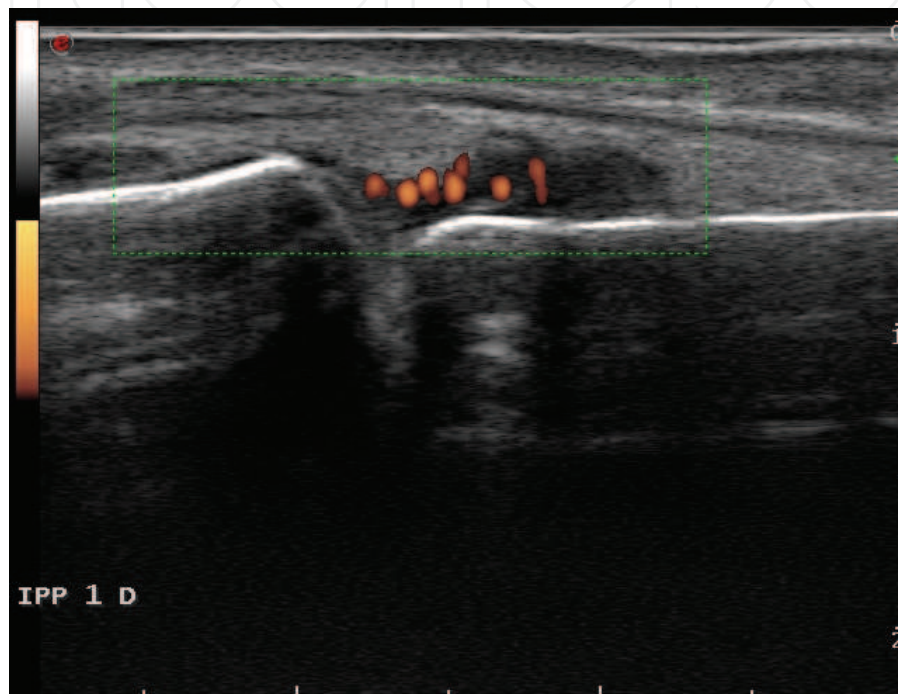


Fig. 2. MCP synovitis with power Doppler signal

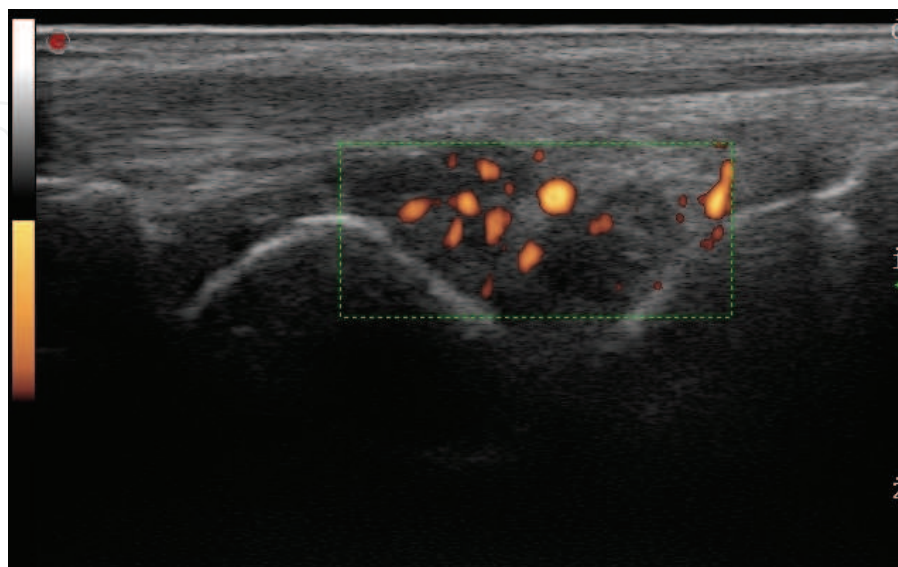


Fig. 3. Arthritis of the wrist

Tenosynovitis

Hypoechoic or anechoic thickened tissue with or without fluid within the tendon sheath, which is seen in 2 perpendicular planes and which may exhibit Doppler Signal (Fig. 4).

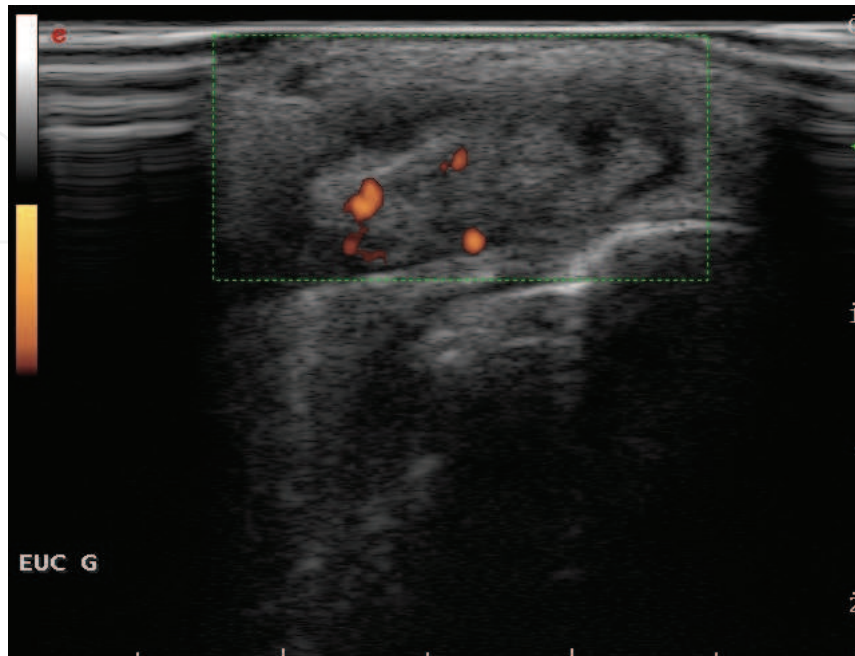


Fig. 4. Tenosynovitis of the left extensor carpi ulnaris tendon with power Doppler signal

Bone erosion

An intraarticular discontinuity of the bone surface that is visible in 2 perpendicular planes (Fig. 5).

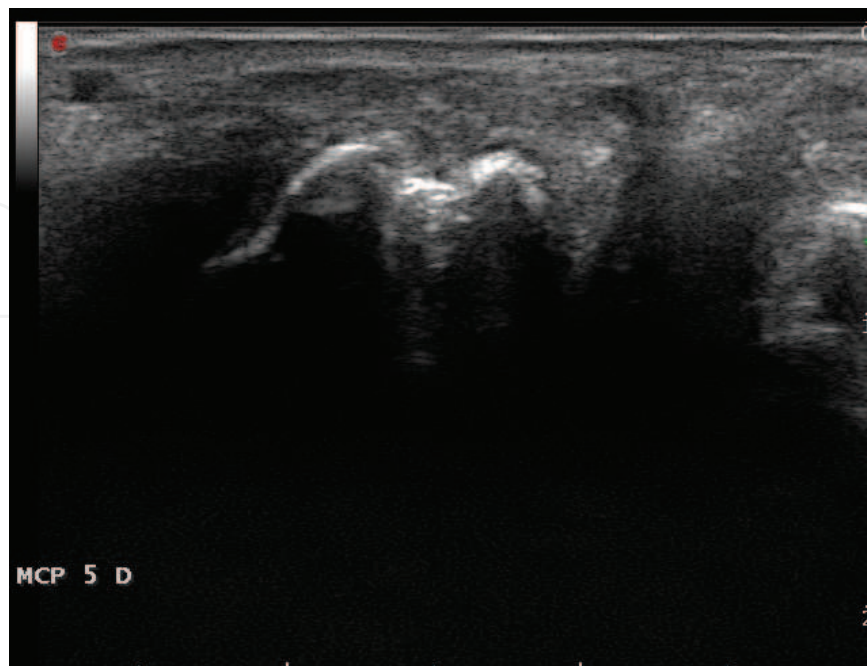


Fig. 5. Bone erosion in the head of the right fifth metacarpal (transversal plane)

2.3 Classification

Joint assessment can be binary (synovitis present or absent) or semi-quantitative. The first one is easily applicable in routine practice whereas the second is mostly used in trials. Szkudlarek described semi-quantitative scales for synovial hypertrophy, effusion Doppler signal and erosions (Szkudlarek et al., 2003).

Joint effusion was defined as a compressible anechoic intracapsular area (0=no effusion, 1=minimal amount of joint effusion, 2=moderate amount of joint effusion [without distension of the joint capsule], 3=extensive amount of joint effusion [with distension of the joint capsule]).

Synovitis was defined as a noncompressible hypoechoic intracapsular area (synovial thickening) (0=no synovial thickening, 1=minimal synovial thickening [filling the angle between the periarticular bones, without bulging over the line linking tops of the bones], 2=synovial thickening bulging over the line linking tops of the periarticular bones but without extension along the bone diaphysis, 3=synovial thickening bulging over the line linking tops of the periarticular bones and with extension to at least one of the bone diaphyses).

Bone erosions were defined as changes in the bone surface of the area adjacent to the joint (0=regular bone surface, 1=irregularity of the bone surface without formation of a defect seen in 2 planes, 2=formation of a defect in the surface of the bone seen in 2 planes, 3=bone defect creating extensive bone destruction).

Power Doppler signal was used to display flow signal in the synovium (0=no flow in the synovium, 1=single vessel signals, 2=confluent vessel signals in less than half of the area of the synovium, 3=vessel signals in more than half of the area of the synovium)

Omeract developed a semi-quantitative scale to assess synovitis in B Mode and power Doppler (Wakefield et al., 2005) (table 1). This score is also based on the assessment of effusion, synovial hypertrophy and Doppler flow.

B Mode	<ul style="list-style-type: none"> - Grade 0: Normal joint (no synovial hypertrophy, no joint effusion) - Grade 1: Minimal synovitis (minimal synovial hypertrophy, with or without minimal joint effusion) - Grade 2: Moderate synovitis (moderate synovial hypertrophy with or without minimal or moderate joint effusion) - Grade 3: Severe synovitis (severe synovial hypertrophy, with or without severe joint effusion)
Power Doppler	<ul style="list-style-type: none"> - Grade 0: no vessel in the synovium; - Grade 1: up to 3 single spots signals or 1 confluent spot + up to 2 single spots - Grade 2: vessel signals in less than half of the area of the synovium (< 50%) - Grade 3: vessel signals in more than half of the area of the synovium (> 50%)

Table 1. Omeract semi-quantitative scale for joint assessment

2.4 Scores

For the time being, there is no consensus on ultrasound score. There are comprehensive scores, which integrate the 44 joints of the Disease Activity Score (Wakefield et al., 2005);

there are reduced scores, like the one developed by Backhaus which assess only 7 joints (Backhaus et al., 2009). Actually, Omeract is working on a consensus score, which will be called Gloss (Global Omeract Sonography Scoring). It should be feasible, whereas bringing more information than clinical examination (D'Agostino et al., 2009).

2.5 Artefacts

Some artefacts have to be known:

Anisotropy: This is the effect that makes a tendon appear bright when it runs at 90 degrees to the ultrasound beam, but dark when the angle is changed.

Enhancement: Some structures however allow sound to pass through them more easily than others. The most dramatic example is watery fluid, such as in an effusion, or in a cyst. These are described as being translucent. Because only a minimal amount of energy is absorbed by the fluid, the region that lies behind will receive more sound than the processor expects for that depth. This area will therefore appear uniformly brighter.

Attenuation or Shadowing is the reverse effect, where some tissues absorb relatively more of the sound. The area of the image deep to this will appear darker. In the extreme almost no sound is transmitted, leaving a dark shadow behind the structure. This can be caused by a calcification for example.

3. Contribution of ultrasonography in the monitoring of rheumatoid arthritis

3.1 Synovitis

Ultrasound synovitis is not specific of rheumatoid arthritis. Synovial hypertrophy or effusion can be seen in other inflammatory rheumatism, and even in osteoarthritis (Rosenberg et al., 2009). Consequently, the interest for diagnosis of rheumatoid arthritis is poor, but it can help in presence of polyarthralgia. Van de Stadt studied 192 patients with polyarthralgia who had rheumatoid factor and / or CCP antibodies. Subclinical ultrasound anomaly of a joint was predictive of evolution toward authentic arthritis at joint level, but this wasn't true at patient level (Van de Stadt et al., 2010). Nevertheless, the topography of swollen joints and the other signs (like tenosynovitis and obviously erosions) may guide the diagnosis.

Actually, ultrasonography is important for rheumatoid arthritis monitoring. There are several studies that prove that ultrasonography is more sensitive than clinical examination for synovitis assessment. Szkudlarek studied small joints (Metacarpophalangeal MCP 2 and 3, Proximal Interphalangeal PIP 2, and Metatarsophalangeal MTP 1 and 2) in 30 rheumatoid arthritis patients and found approximately 50 % more synovitis with ultrasonography in B mode than with clinical assessment (Szkudlarek et al., 2003).

In other studies, by comparison with MRI, ultrasonography was found to be markedly more sensitive and accurate than clinical examination to search synovitis on the ten MTP joints (sensitivity respectively 0.87 versus 0.43) (Szkudlarek et al., 2004) and on the second to fifth MCP and IPP of the dominant hand (sensitivity respectively 0.7 versus 0.4) (Szkudlarek et al., 2006).

Ultrasonography is also more sensitive in early rheumatoid arthritis. In 44 patients whose rheumatoid arthritis duration was less than 2 years, Salaffi found a mean swollen joint count of 19.1 (+/-4.1) with ultrasonography and 12.6 (+/-3.6) with clinical examination. Power Doppler signal in the synovium was present in 43 joints, of which 60% showed clinical signs of inflammation (swelling and/or tenderness). Power Doppler signal in the synovium was absent in 107 joints, of which 36% presented clinical signs of inflammation (Salaffi et al., 2008).

Power Doppler permits assessment of low-velocity flow in small vessels and is considered to reflect disease acute inflammatory activity. In the Sea study, the use of Power Doppler dramatically reduced the number of arthritis in rheumatoid arthritis considered as active by clinicians (Marhadour et al., 2010). If the swollen joint count was based on ultrasonography result, disease activity index was lower than if based on clinician assessment.

3.2 Erosions

The detection of radiographic erosions in early disease is associated with a poor outcome (Van der Heijde et al., 1992) and may influence the timing and choice of disease-modifying antirheumatic drug therapy.

Erosion of hand in ultrasonography was first described in 1988, in 20 rheumatoid arthritis patients (De Flaviis et al., 1988) and then Grassi confirmed the ability of ultrasonography to show erosions in a controlled trial with 20 rheumatoid arthritis patients and 20 controls (Grassi et al., 1993).

Ultrasonography is more sensitive than X-Ray to detect erosion in rheumatoid arthritis. In 2000, Wakefield was the first to demonstrate that sonography detects more erosion on the MCP joints of rheumatoid arthritis patients than does conventional radiography, especially in early disease. He compared ultrasonography and X-Ray for erosion detection in the MCP joints of rheumatoid arthritis patients and studied its reliability. There were 100 rheumatoid arthritis patients who were split according to their disease duration. Those with disease duration of less than 12 months with no prior DMARD therapy were classified as having early disease, while those with disease duration of more than 2 months were classified as having late disease. The control group included 20 patients. In the early rheumatoid arthritis group, sonography detected a 6.5-fold increase in the number of erosions detected by sonography over that detected by radiography ($P=0.0001$), in 7.5-fold the number of patients. In the group with late rheumatoid arthritis, sonography detected a 3.4-fold increase ($P=0.0001$), in 2.7 fold the number of patients. Sonography detected more erosions than radiography in all MCP joints except the fourth, where it detected fewer (sonography detected proportionately more erosions where the transducer had good access, in particular, the first, second, and fifth joints). Significantly fewer of the small sonographic erosions (less than 2 mm) were visible on radiography ($P=0.0001$). In this study, MRI was used to validate the additional sonographic lesions not seen on radiography, giving some evidence of their pathologic specificity. Wakefield explained that there were two reasons why sonography detected more erosions than radiography in this study: first, the 3-dimensional capability of sonography allowed joints to be examined in several different planes; second, sonography was able to detect smaller erosions. Erosions were most frequently seen on either the radial or the ulnar aspect of the MCP joint, with relatively few occurring on the volar or dorsal surfaces (Wakefield et al., 2000).

Alasaarela assessed the value of ultrasonography, magnetic resonance imaging, computed tomography (CT) and plain radiography (PR) in detecting bone erosions on the humeral in 26 rheumatoid arthritis patients. MRI depicted humeral erosions in 25 (96%), ultrasonography in 24 (92%), CT in 20 (77%) and PR in 19 (73%) of the 26 shoulders. MRI and ultrasonography were superior to CT in detecting small erosions. Ultrasonography was the most sensitive method to show surface erosions on the greater tuberosity (Alasaarela et al., 1998).

Conventional radiography is based on attenuation of X-rays, and calcified tissues such as bone are readily depicted because of their markedly greater attenuation in comparison with the surrounding soft tissues. Because imaging with ultrasonography does not depend on X-rays, it has been speculated to which extent erosions detected using these modalities reflects true loss of calcified tissue, that is, are true erosions. Therefore, ultrasonography has been compared to computed tomography, which is considered as a gold standard. On 17 rheumatoid arthritis patients, ultrasonography exhibited high specificities (91 %) in detecting bone erosions in MCP joints, even in the radiographically non-erosive joints (92%). Although, sensitivity was moderate (42%) (Døhn et al., 2006).

Nevertheless, a recent study which evaluated bone erosion in 127 healthy subjects matched with a cohort of patients with early arthritis (the ESPOIR cohort) detected bone erosion in 11% of healthy subjects at metacarpo and metatarsophalangeal joint of both hands and feet. However, the combination of power Doppler signal plus bone erosion, on the same joint, was never seen in healthy subjects. A single case of bone erosion or synovial thickening in B-mode is common in healthy subjects. However, more than 1 case of synovial thickening in B-mode or bone erosion is a strong argument for the diagnosis of early inflammatory arthritis (Millot et al., 2010).

4. Outcome assessment validation strategy in rheumatoid arthritis

4.1 Generalities

Scientific rules must be respected when developing a measurement tool. Since ninety's, some consensus are growing in rheumatoid arthritis metrology, especially thanks to OMERACT, which developed a filter of 3 criteria:

1. *Truth*: is the measure truthful, does it measure what it intends to measure? Is the result unbiased and relevant? This criterion captures the issues of face, content, construct and criterion validity.
 - Face validity: It is the validity of a test at face value. In other words, a test can be said to have face validity if it "looks like" it is going to measure what it is supposed to measure
 - Content validity: Refers to the extent to which a measure represents all facets of a given phenomena.
 - Criterion validity: Criterion or concrete validity is the extent to which the measures are demonstrably related to concrete criteria in the "real" world, ie gold standard. For ultrasonography, gold standards are histology or surgical macroscopic findings.
 - Construct validity is achieved when measures agree with other measures that evaluate the same phenomenon. For ultrasonography, this can be other imaging techniques or laboratory and clinical data.
2. *Discrimination*: Does the measure discriminate between situations that are of interest? The situations can be states at one time (for classification or prognosis) or states at

different times (to measure change). This criterion captures the issues of reliability and sensitivity to change.

3. *Feasibility*: Can the measure be applied easily, given constraints of time, money, and interpretability? This criterion addresses the pragmatic reality of the use of the measure, one that may be decisive in determining a measure's success.

4.2 Application to ultrasonography

Despite increasing interest in ultrasonography, widespread application has been impeded by a perception that its use is unproven and unreliable. There was limited data describing standardized scanning methodology and standardized definitions of ultrasonography pathologies in addition to how to quantify these abnormalities.

Reliability of a test result is its ability to be reproduced. There are various ways of expressing reliability: Cohen's Kappa (the more the result is near from 1, the best is the agreement), intraclass correlation coefficient (ICC), coefficient of variation, overall agreement, and Kendall's W coefficient. In ultrasonography, it can be divided into the acquisition and the reading phases, as well as the reliability of one observer (intra observer) and multiple observers (interobserver) to reproduce the result. The scanning technique for each joints needs to be standardized, that's why position statements have been developed through consensus meetings (Backhaus, 2001). It is important to test the acquisition reliability of ultrasonography because of its multiplanar capability, and because the sonographer chooses the images he wants to save (even with standard imaging protocols).

Responsiveness is the ability of the tool to demonstrate change. Ultrasonography will be considered sensitive to change if it detects small variation in disease activity. This can be useful to demonstrate the action of a new treatment.

5. Is ultrasonography reliable for the monitoring of rheumatoid arthritis ?

5.1 Synovitis

A first systematic review was performed in 2007 by the Omeract Ultrasound Group on the metric properties of ultrasonography for the detection of synovitis in inflammatory arthritis (the major inflammatory condition studied was rheumatoid arthritis). The major joints assessed were the hand and knee. Few comparisons were done versus histology or surgical findings. Reliability was evaluated with a filter including intra/inter observer acquisition, intra/inter observer reading, sensitivity to change, criterion validity and construct validity. The authors concluded that there were major gaps in the reliability testing, primarily in the assessment of acquisition, and Omeract encouraged rheumatologists to perform more studies on reliability (Joshua et al., 2007).

A way to increase the quality of a reliability study is to multiply the number of examiners. The Sea study was realised in this purpose (Jousse-Joulin et al., 2010). 7 patients with rheumatoid arthritis were examined by 7 clinicians and then 7 sonographers examined each of the 7 patients twice, using B Mode and power Doppler OMERACT grading. The clinical reference standard was the presence of synovitis according to at least 50% of clinical examiners. Different standards were used for sonography (the sonographer with the best reliability, the presence of synovitis according to at least 50% of sonographers) using

different grade to define sonographic abnormalities [at least grade 1 (ALG1) or at least grade 2 (ALG2)]. Agreement was assessed by Cohen's kappa. Concerning intraobserver acquisition reliability for B mode, it was relatively good but varied upon the grade defining synovitis. In ALG1 the results varied to poor (for one sonographer) to fair agreement in 3 sonographers and good for 3 whereas using ALG2, the intraobserver reliability was better with a good agreement for 6:7 sonographers in B mode. The results were slightly lower using power Doppler in both ALG1 and ALG2, as only 2 of 7 sonographers had a good agreement. Interobserver acquisition reliability was also evaluated. The results of the detection of synovitis in B mode with ALG1 showed a fair agreement for 5 of 6 sonographers and only one sonographer has a good agreement. For ALG2, results were better as 4 of 6 sonographers had a good agreement. Using power Doppler with ALG1 we observed a poor agreement for 3 sonographers and a fair agreement for 3. Using ALG2, the power Doppler kappa values were quite similar with one good agreement, 3 fair, and one poor agreement. When we used grade 2 in B mode or in power Doppler, the intra and inter reliability was better. In our study, the reliability was not clearly different between the different sites.

Another systematic review was performed in 2010, focusing exclusively on rheumatoid arthritis (Cheung et al., 2010). 35 studies with a total of 1415 patients were analyzed. Intra and inter observer reliability for still images in B mode and power Doppler was high ($k=0.5-1$ for intraobserver in B mode; $k=0.59-1$ for intra observer in power Doppler; $k=0.49-1$ for inter observer in B mode; $k=0.66-1$ for inter observer in power Doppler). It appeared that still-image interpretation was more reliable than image acquisition. However, results of acquisition reliability were variable and sometimes poor with kappa values reaching 0.2, and very few studies assessed intraobserver acquisition reliability in either B-mode or power Doppler. Differences in the scanning technique and the lack of familiarity of the ultrasonography machine may also explain the poor results in reliability studies. In this review, few studies looked at the image acquisition reliability. Intraobserver reliability in this domain has been the least studied, and the time interval for retesting was as short as 30 minutes. Power Doppler interobserver reliability was higher than B-mode in still-image interpretation. This may be due to the fact that grading and detection of signal flow on still images would be less liable to variation than identification of hypochoic structures. Presence or absence of color signal is also easier to differentiate.

In his 2003's study, Szkudlarek evaluated interobserver agreement between ultrasonography investigators. For the detection of synovitis, the ICC and unweighted kappa estimations for the examined parameters showed a moderate-to-good correlation (0.61-0.81 and 0.48-0.68, respectively) between the ultrasonography investigators. The overall agreement was high (79-91%) (Szkudlarek et al., 2003).

The most important study to evaluate different scoring systems on three main groups of joints (20, 28 and 38) using both a count and a score (comparing the clinical, ultrasonography B mode and ultrasonography power Doppler techniques of acquisition resulting in 18 different global scoring systems) have been published in 2010 (Dougados et al., 2010). A systematic evaluation of the main psychometric/methodological properties in accordance to the OMERACT filter permitted an overview of the performances of these different scoring systems (intra-observer reliability using the intra-class coefficient of correlation, validity on 76 enrolled patients, face validity using the alpha Cronbach test and

external validity using the level of correlation between the scoring system and CRP, sensitivity to change was using the Standardized Response Mean in the 66 patients who completed 4 months of the study and discriminating capacity was using the Standardized Mean Differences in the patients considered by the physician as significantly improved or not at the end of the study). The obtained data suggest that the ultrasonography scoring systems are at least as valid as the conventional clinical ones. Moreover, the ultrasonography acquisition of synovitis appeared to be more objective and can be easily documented. Other studies are required in order to achieve an optimal ultrasonography scoring system endorsed by international societies for monitoring rheumatoid arthritis patients both in clinical trials and in daily practice.

5.2 Erosions

Because of the discrepancy between magnetic resonance and computed tomography concerning erosions, some authors noted that the absolute numbers and sizes of the erosions on the bone surface are not known. To resolve this problem, Koski assessed the ability of ultrasound imaging to detect erosions in a bone phantom model (Koski et al., 2010). 21 bovine lower leg bones were prepared and then were examined by 4 sonographers. The mean correlation coefficient for a correct result in terms of the number of erosions detected was 0.88 (0.75 - 0.75). The overall Cohen's kappa coefficient for interobserver agreement was 0.683 in terms of discrimination between healthy bones and bones with erosions. Ultrasound can be considered as a valid and reliable to detect cortical bone erosions in vitro, when the round erosion is at least 1 mm deep and 1.5 mm wide.

When Wakefield compared ultrasonography to X-rays for the detection of erosion, he assessed intra and inter observer agreement. The intraobserver kappa value for agreement for the detection of cortical bone erosions on the second MCP joint of 55 rheumatoid arthritis patients was 0.75. The interobserver kappa value for agreement between 2 observers for the detection of cortical bone erosions on MCP joints 2-5 in 40 rheumatoid arthritis patients (160 joints) was 0.76. These good results confirmed that ultrasonography is a reliable technique for detecting MCP joint erosions (Wakefield 2000).

Rahmani compared ultrasonography to X-rays and MRI in early rheumatoid arthritis. In 12 patients, 120 first to fifth metacarpophalangeal joints and 96 second to fifth proximal interphalangeal joints were examined. The overall sensitivity and specificity of ultrasonography compared to MRI in detecting bone erosion were 0.63 and 0.98, respectively with a considerable agreement (kappa = 0.68, $p < 0.001$). In patients with more active disease, the sensitivity and specificity were 0.67 and 0.99 (kappa = 0.74, $p < 0.001$) compared to 0.59 and 0.97 (kappa = 0.61, $p < 0.001$) for the rest of patients according to DAS28. Therefore, ultrasonography might be considered as a valuable tool for early detection of bone erosion. (Rahmani et al., 2010).

Not only can ultrasonography be seen as reliable for bone erosion, but also for cartilage damage assessment, as Filippucci demonstrated. Two rheumatologists performed ultrasonography examination on 80 MCP joints of 20 rheumatoid arthritis patients. There was moderate to good interobserver reproducibility, using a semiquantitative scoring. Unweighted k values were 0.561, 0.366 and 0.766 at dorsal, lateral and volar quadrants respectively (Filippucci et al, 2010).

6. Conclusion

Ultrasonography is a powerful tool to assess rheumatoid arthritis activity. It is widely available, can be performed at the bedside, is not expensive and non ionizing. It is more sensitive than clinical examination to detect synovitis and more sensitive than x-rays to detect erosions. Even though more and more studies have been published to prove its reliability, more consensus are needed for images acquisition. The next step will be to assess its sensitivity to change, which will expand its use for treatment monitoring.

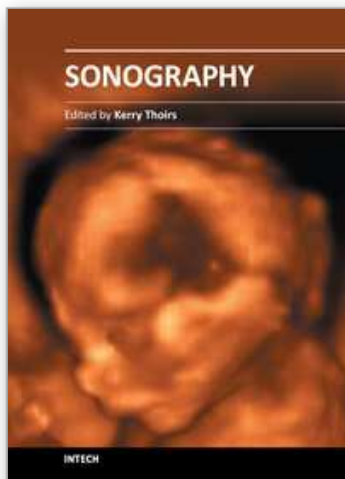
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Medical sonography is a medical imaging modality used across many medical disciplines. Its use is growing, probably due to its relative low cost and easy accessibility. There are now many high quality ultrasound imaging systems available that are easily transportable, making it a diagnostic tool amenable for bedside and office scanning. This book includes applications of sonography that can be used across a number of medical disciplines including radiology, thoracic medicine, urology, rheumatology, obstetrics and fetal medicine and neurology. The book revisits established applications in medical sonography such as biliary, testicular and breast sonography and sonography in early pregnancy, and also outlines some interesting new and advanced applications of sonography.

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