Ultrasound imaging for the rheumatologist XVII. Role of colour Doppler and power Doppler

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ABSTRACT

The use of Doppler ultrasound in rheumatology has grown in recent years. This is partly due to the increasing number of rheumatologists who perform US in their daily clinical practise and also to the technological advances of US systems. Both colour Doppler and power Doppler are used to evaluate the degree of intra- and peri-articular soft tissue inflammation. Moreover, Doppler US has been found to be of help in the assessment of vascular pathologies such as the vasculitides. In this review we provide an update of the data regarding the use of colour Doppler and power Doppler in rheumatology.

Introduction

Ultrasonography (US) has rapidly come to the fore in recent years as one of the most important tools that can be used by rheumatologists to study several rheumatic conditions (1). The role of Doppler US has expanded in the last decade with the improvement of both the hardware and software of US machines. There is now no doubt that Doppler US plays a key role in the assessment of tissue perfusion in several pathological conditions (*i.e.*, synovitis, tenosynovitis, bursitis, enthesitis, vasculitis) in rheumatology (2-9). Both colour Doppler (CD) and power Doppler (PD) are valuable techniques to show the level of vascularisation of the musculoskeletal structures, in order to evaluate inflammation and to monitor treatment response in joints and periarticular soft tissues. In this review we discuss the current data relating to the application of CD and PD in rheumatology.

What is Doppler US?

Essentially, this is a technology based upon the "Doppler effect", first described by the Austrian physicist Christian Doppler in 1842. It is a change in the frequency of a sound wave due to the movement of either its source or receiver. US medical systems use the "Doppler effect" generated by the movement of the erythrocytes in the vascular system and provide information on blood flow velocity and direction (8, 10, 11). At least five different types of Doppler techniques are now available, including continuous-wave Doppler, pulsed-wave Doppler, Duplex, CD and PD US.

CD and PD are the most studied and widely used in rheumatology because they allow the simultaneous visualisation of grey-scale and Doppler findings providing information on the exact anatomic distribution and the entity of the blood flow.

CD displays the direction and the mean velocity of blood flow, while PD has been developed in order to increase sensitivity of low blood flow, without displaying either direction or velocity. For the assessment of pathologic conditions such as synovitis or enthesitis, the detection of even minimal abnormal vascularisation is more important to the rheumatologist than the acquisition of information on flow direction and/or velocity.

Thus, the higher sensitivity of PD US and its more user-friendly application (it is independent of the US beam direction and does not generate aliasing) has made it more popular among rheumatologists.

In the latest generation US systems, the difference between CD and PD US is not so evident because CD has gained in sensitivity and PD provides information also on the flow direction.

Indications and clinical applications of Doppler US

Doppler US techniques provide a sensitive detection of blood flow both in small and large vessels.

In patients with chronic arthritis, PD US allows an estimation of disease activity at joint level as well as in tendons and entheses (3, 12-14). In patients with vasculitis, CD evaluation of involved large vessels may reveal blood flow abnormalities both in its direction and velocity.

Recent studies suggested that US short term monitoring provides information on therapy efficacy, disease progression and remission (15-22).

A significant statistical reduction of intra-articular PD signal can be documented, at least 6 weeks (18) to 3 months (16) in RA patients receiving biologic therapy, while a shorter period (no longer than 2 weeks) is required to depict sometimes even relevant decreases of PD signal after intra-articular steroid injection treatment in patients with chronic arthritis (19).

In a placebo-controlled double-blind randomized study conducted on 24 consecutive patients with early rheumatoid arthritis, PD US assessment of joint inflammation was compared with the rate of radiographic damage at one year. After 18 weeks of follow-up, PD US findings at metacarpophalangeal joint level were found successful in discriminating the group with the lower rate of radiographic progression of bony erosions (15). Moreover, in a recent longitudinal study carried out on 42 patients with early rheumatoid arthritis, a positive correlation was found between the persistence of intra-articular PD US signal obtained in the 28 joints of the 28-joint Disease Activity Score and the radiographic progression at one year (21).

The role of PD US in revealing subclinical joint inflammation was investigated in a cohort of 107 RA patients in clinical remission and in 43% of asymptomatic patients with clinically normal joints, abnormal intra-articular PD signal was found at the level of the wrist and MCP joints of the dominant hand (22).

Table I. PD setting.

Doppler frequency	Higher for the study of small joints and superficial tissues (7.5-12 MHz), lower for deep structures (5-7 MHz).
Pulse repetition frequency (PRF)	Lowest possible. The most commonly PRF value used in rheumatology is between 0.5 and 1.0 KHz.
Colour Doppler gain	Just below the level that causes the appearance of noise artefacts.
Persistence	Lowest possible.
Focus	Positioned at the level of the region of interest.
Wall filter	Lowest possible.
Colour box (position and size)	Adjusting a small colour box avoids slowing down the moving flow; in fact, frame rate decreases when colour is added and small box contains less colour. However, to avoid misinterpretation due to reverberation artefacts, it is recommended enlarging the box to upper part of the image.

Table II. US artefacts.

Aliasing	Occurs only while using CD and spectral Doppler. Aliased signals appear when the Doppler shift is higher than half of the PRF. Due to aliasing, the wrong colour of flow direction and incorrect relative velocity of flow are reported.
Blooming	When a vessel appears larger than its actual size.
Focusing	The correct focus point positioning is extremely important to improve the amplitude of the echoes produced in the focal area.
Mirror	In rheumatology, mirror artefact is sometimes generated by the bone surface that creates mirror images below the bone profile.
Motion	Any kind of movement (patient, probe, vessels) generates a Doppler shift, thus causing the appearance of false signal. To avoid them, both patients and operator should be comfortably positioned to remain stationary even during a long examination.
Pressure	The use of abundant amount of acoustic gel is extremely important to give good acoustic adherence between the probe and the skin of the patient. This avoids the tendency to apply too much pressure thereby creating flow blockage and the generation of false negatives.
Random noise	Depends on the noise caused by the electric circuits and appears, when the gain is too high, as a random colour signal in the Doppler image.
Reverberation	The appearance of false colour foci may sometimes occur when a superficial vessel is imaged lower in the image either as a simple or a complex reverberation. It sometimes simulates the presence of Doppler signal within a joint.

Quantification methods

Essential requirement for US short-term monitoring is a reliable quantification method for assessing abnormal soft tissue vascularisation (23-28).

In the last decade, several different approaches have been developed in chronic inflammatory arthritis (mostly for assessing synovitis, only a few for enthesitis), including: presence/absence of signal at single or multiple anatomic sites, semiquantitative evaluation of PD and/or CD Doppler signal, colour pixel or voxel count, spectral Doppler evaluation, contrast enhanced, three-dimensional (3D) blood vessel count.

The detection of presence/absence of PD signal may appear more reproducible if compared with semiquantitative methods but there is evidence that its presence may also be detected in small joints of healthy subjects and this is especially true for the wrist (25). Which anatomic sites (joints or entheses) to examine and which acoustic windows to use, have not yet been established. In recent literature, it is possible to find some proposals by Naredo *et al*. (27), de Miguel *et al*. (14) and D'Agostino *et al*. (28).

Semiquantitative evaluation of colour signal is the most commonly used method in clinical practice and it has also been used in several clinical studies to define increased vascularisation. A nominal scale (0-3) of the intra-articular PD signal intensity is used as follows: grade 0, no Doppler signal or no flow; grade 1, single vessel signal or mild flow; grade 2, confluent signals or moderate flow; grade 3, more than 50% of the area of the synovial membrane with signal, or severe flow.

There is a number of dedicated software which allows the quantification of colour pixels and voxels, respectively in 2D and 3D images (8, 10, 11, 15, 20, 21). There is evidence that the results

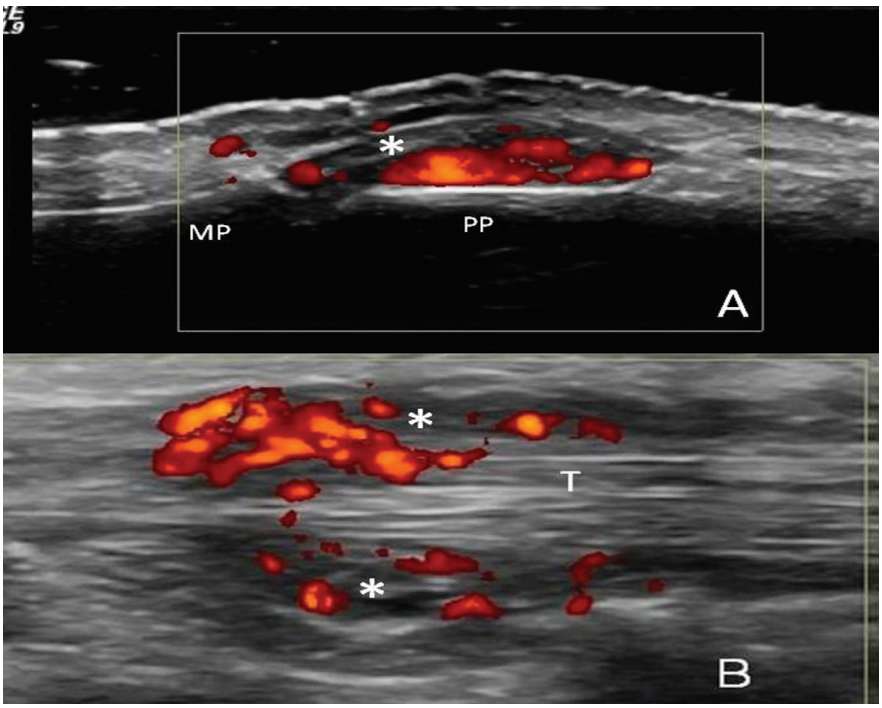

Fig. 1. Rheumatoid arthritis. Longitudinal dorsal scan of the proximal interphalangeal joint (**A**), showing the presence of power Doppler signal in the joint. (**B**) longitudinal dorsal scan of the IV compartment of the extensor tendons at the wrist. Hyper-perfusion of the synovial tissue is demonstrated. The asterisk indicates synovial proliferation. **T** = extensor tendon; **PP** = proximal phalanx; **MP** = middle phalanx. Images taken using a Logiq 9 (General Electric Medical Systems, Milwaukee, WI) equipped with a 14 MHz linear probe.
For further ultrasound images, go to www.clinexprheumatol.org/ultrasound

obtained using such a method correlate with synovial inflammation (11).

Analysis of Doppler curves and evaluation of resistance index (RI) is another quantitative method applicable for synovial flow assessment. Low RI correlates with hypervascularisation of the tissues indicating a low vessel resistance, conversely high RI correlates with sparse perfusion and high vessel resistance.

Contrast agents have been used with the aim of increasing the sensitivity of Doppler in the detection of tissue hyperemia in different rheumatic diseases (8, 11). However, they are not used in clinical practice because of their invasiveness and high cost. Several quantification methods have been used including delineation of the area under the curve for a specific amount of time, computerised quantification of colour pixel at the peak of contrast phase and evaluation of steepness of the time-intensity curve after bolus injection (8, 11).

Acquisition and misinterpretation of Doppler US

A correct acquisition of PD signal needs: neutral patient position and minimal probe compression to avoid underestimation (29). Both patient and probe should maintain a stationary position during the acquisition to avoid flash artefacts. Multiplanar scanning technique is required to identify maximal expression of PD signal. Table I lists a set of parameters and corresponding values which allow the achievement of the best setting of the US equipment. The decision to use PD instead of CD depends on the specific US equipment since some US systems are more sensitive to CD than PD, and vice versa. The CD and/or PD acquisition process using a volumetric probe reduces acquisition time, requires no particular skills, is not operator-dependent and allows for a comprehensive storage of colour signal. The 3D data set differs from conventional 2D sonographic images because it can be interpreted offline by a reader who may not be the operator who acquired the images.

For a correct interpretation of Doppler images it is mandatory for the operator to have an extensive knowledge of artefacts (Table II).

Doppler US and other imaging techniques

The detection of soft tissue inflammation can be obtained by various imaging techniques including Doppler techniques, magnetic resonance imaging (MRI), triphasic scintigraphy and arthroscopy (30). The choice of the most appropriate imaging technique is never absolute and usually depends on several factors, including the suspected abnormality, the examiner's experience, the availability of the techniques, and their specific advantages, limitations and contraindications.

MRI provides an accurate assessment of synovitis and its validity has been the object of several investigations (31, 32). Its main disadvantages include the need to use contrast medium to distinguish synovial tissue from synovial fluid, the low availability, the high cost, and the long waiting list.

CD or PD US allows for a rapid and sensitive multi-site examination which can be clinically oriented or based on a pre-defined scanning protocol (*i.e.,* the 28-joint count for assessing disease activity). Its sensitivity relies on the specific US equipment and is very high at the level of superficial soft tissue and small joints (*i.e.,* metacarpophalangeal joints), but it is substantially lower in the assessment of deep structures (*i.e.,* sacroiliac joints).

Scintigraphy is also indicated when multifocal processes have to be assessed and when high sensitivity is required. However, its main disadvantages include radiation hazards, relatively higher costs and lower specificity.

Arthroscopy allows direct visualisation of the synovial tissue and it has been used as a gold standard in studies comparing imaging modalities to assess intra-articular blood perfusion. Its main limitation is the extent of invasiveness (33-35).

Conclusion

PD US is a sensitive and reliable method for longitudinal assessment of disease activity in patients with chronic arthritis. Several investigations have indicated its role in monitoring therapy even after few weeks of baseline examination. More recently, evidence has

begun to emerge on the positive correlation between PD US findings and radiographic outcome in patients with early rheumatoid arthritis. Thus, we believe that the "era" of PD US in daily clinical practice and multicentric studies is just around the corner.

Links

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

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