Review

Musculoskeletal colour/power Doppler in sports medicine: image parameters, artefacts, image interpretation and therapy

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ABSTRACT

This review article discusses the aspects of sports medicine where musculoskeletal Doppler ultrasound has valuable contribution in diagnosis and/or treatment of some of the typical musculoskeletal sports injuries. Also, conditions where the Doppler ultrasound has no value are discussed. Some guidelines and recommendations are based on personal experience since no evidence in literature exists. The basic technical background of Doppler ultrasound and typical artefacts will be discussed, in order to understand and interpretate the Doppler result. Recommendations for the Doppler settings are given in relevant sections. Ultrasound guided treatments where the Doppler result is used as a guide are mentioned and discussed.

Introduction

Within the last decade ultrasonography has become an established technique used for musculoskeletal imaging in rheumatology and sports medicine (1-7). Originally, musculoskeletal ultrasound was predominantly a tool for dedicated ultrasound specialists and was primarily used for assessment of soft tissue changes, detection of fluid collections (8, 9), and to guide interventional procedures (5, 10). Nowadays, musculoskeletal ultrasound (US) examinations are performed not only by radiologists and sonographers but also by clinicians (7, 11) as a supplement to their clinical assessment.

Most musculoskeletal US is performed using grey-scale US but newer techniques include the use of Doppler US, which may be used in the detection of hyperaemia (4, 12) that may occur in inflammatory conditions (4, 13). An increasing interest in the use of US in sports medicine – both conventional grey-scale US and colour/power Doppler – has developed in recent years. Whereas grey-scale ultrasound is now more accessible due to a decrease in price and the introduction of high quality portable machines, ultrasound machines with a sensitive Doppler demand more regarding both equipment and technique. Consequently, US machines with a sensitive Doppler are more costly and demand more of the investigator, and many clinicians refrain from buying US equipment with the relative expensive Doppler function.

A substantial improvement in the quality of high frequency ultrasound probes and introduction of three-dimensional ultrasound have contributed to the evolution of musculoskeletal US, which is used as a sensitive diagnostic aid that now challenges modalities such as MRI (6, 14, 15).

In sports medicine, the user of US must be familiar with numerous technical aspects of both grey-scale and Doppler ultrasound. The inexperienced examiner may easily draw misleading conclusions.

This article focuses on Doppler ultrasound: Ultrasound equipment, physical principles of Doppler ultrasound and the different modes (power and colour Doppler), some of the typical Doppler artefacts, and the use of Doppler ultrasound in some of the most common injuries in sports medicine. It is assumed that readers are well-versed in grey-scale US. For novices in the field of ultrasound we recommend further reading (1, 9, 16). The use of contrast agents in musculoskeletal ultrasound is still experimental and therefore not included in this paper.

1. Ultrasound equipment

Ultrasound equipment varies considerably in its near field image quality. A major factor is the probe design combined with different methods of beam focusing and signal processing. There are no easily applied general technical

tests that will inform the purchaser or examiner that a machine is of adequate resolution and performance for musculoskeletal application (9). There is no general test that will test the Doppler sensitivity and function. We can recommend looking for small arteries, e.g. in the wrist or thenar muscles, to see if the Doppler detects these. These vessels have relatively weak Doppler shifts similar to many of those detected in pathologic areas. This will give an impression of the sensitivity.

Most equipment can be used in a broad variety of clinical settings, and many functions may not be relevant for the musculoskeletal specialists.

We recommend the use of 'high-end' machines, *i.e.* ultrasound machines in the high end of the spectrum, regarding both overall quality and cost. These machines provide better resolution and have a more sensitive Doppler. When a machine has been acquired, the examiner with the assistance of the ultrasound company should develop Doppler setups for musculoskeletal use. With these in place, only the Doppler focus zone must be adjusted during examinations in order to monitor activity precisely.

Transducers

In musculoskeletal US, linear array transducers are preferred. They produce a rectangular image in which the parallel grey-scale scan lines are vertical. High frequency transducers ensure high image resolution on the expense of image penetration, and are suited for examination of superficial structures. Examination of deeper structures is traditionally performed by decreasing the US frequency, thereby increasing penetration at the expense of resolution (the image appears coarser). On newer high-end equipment impressive depth penetration may be obtained with high frequencies (14 MHz) with so-called coded signals. An example is hip scans where a 14 MHz transducer with coded signals is used.

The choice of transducer usually represents a compromise between resolution and penetration. In musculoskeletal ultrasound, linear array probes with frequencies over 10 MHz are normally preferred to give an optimum resolution (9).

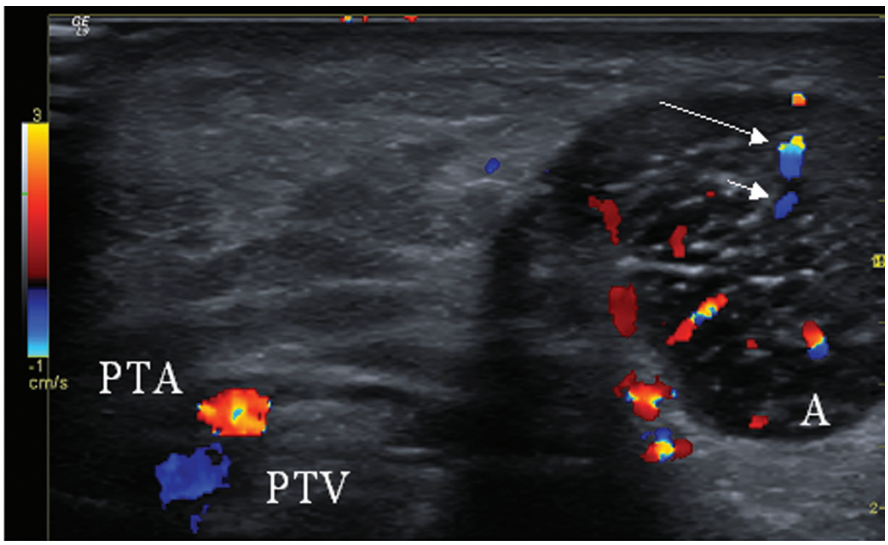

Fig. 1. Understanding relative velocities. A transverse scan on the medial side of the right Achilles tendon showing the Achilles tendon (**A**), the posterior tibial artery (PTA), and posterior tibial vein (PTV). The transducer is tilted slightly cranial in order to improve the Doppler angle to the PTA. The colour bar shows that blood moving downwards in the image is deep blue if slow, and light blue if fast. Likewise, upward movement is deep red if slow, and yellow if fast. If blood moves straight up the signal will aliase if the velocity is above 3 cm/s – straight down at 1 cm/s. Since we do not know the insonation angle to any of the vessels in the image we cannot compare velocities between vessels. The vessel indicated by the long arrow has a lighter hue of blue (indicating higher velocity) than the vessel indicated by the short arrow. However, it may in fact be blood moving at a lower velocity but at a better Doppler angle (closer to 0 degrees insonation). It is correct to compare the relative velocities inside the PTA because the whole vessel is probably insonated at the same angle. It is therefore correct to interpret the yellow in the centre as blood moving at a higher velocity than that closest to the wall (red). Actually, at the very centre of the PTA, the signal is aliasing (showing a blue spot in the centre of the yellow).

2. Doppler ultrasound

The Doppler effect is a change in frequency of sound resulting from motion of a sound source, receiver or reflector. This difference is known as the Doppler shift, named after the Austrian physicist and mathematician Christian Andreas Doppler, who first described the phenomenon in 1843 for light (17).

Colour Doppler

In colour Doppler real time presentation of flow information in colour is superimposed on the grey-scale morphological image (Fig. 1). Positive Doppler shifts (movement toward the transducer) are usually given red hues and negative shifts are given blue hues.

In colour Doppler the Doppler analysis is carried out in multiple cells inside the colour box (18). The mean velocity for each cell is determined and presented as a colour according to a colour-code (18). The colours that arise from the detected Doppler shifts primarily indicate direction of flow and to some degree also velocity (Fig. 1).

A large colour box is demanding on computer power and will cause the frame rate to drop. The machine may try to counteract this (maintaining the highest frame rate) by reducing the grey-scale line density (resolution) and other image improvement functions that take up computing power. The result would be a degraded grey-scale image. It is, however, important to force the machine to give image quality a higher priority than frame rate. In sports medicine, where the region of interest can be kept immobile (as opposed to respiratory movements in the upper abdomen or pulsating heart), a large colour box should be allowed to make the frame rate drop (19).

Power Doppler

With power Doppler it is the summation of the power (amplitude) of all the different Doppler shifts (velocities) within a cell that are displayed instead of the average velocity (20). The power of the signal from each cell reflects the number of erythrocytes moving in that cell.

The power mode does not measure velocity or direction and is without aliasing (see below). When it was introduced, it had markedly higher sensitivity than the existing colour Doppler

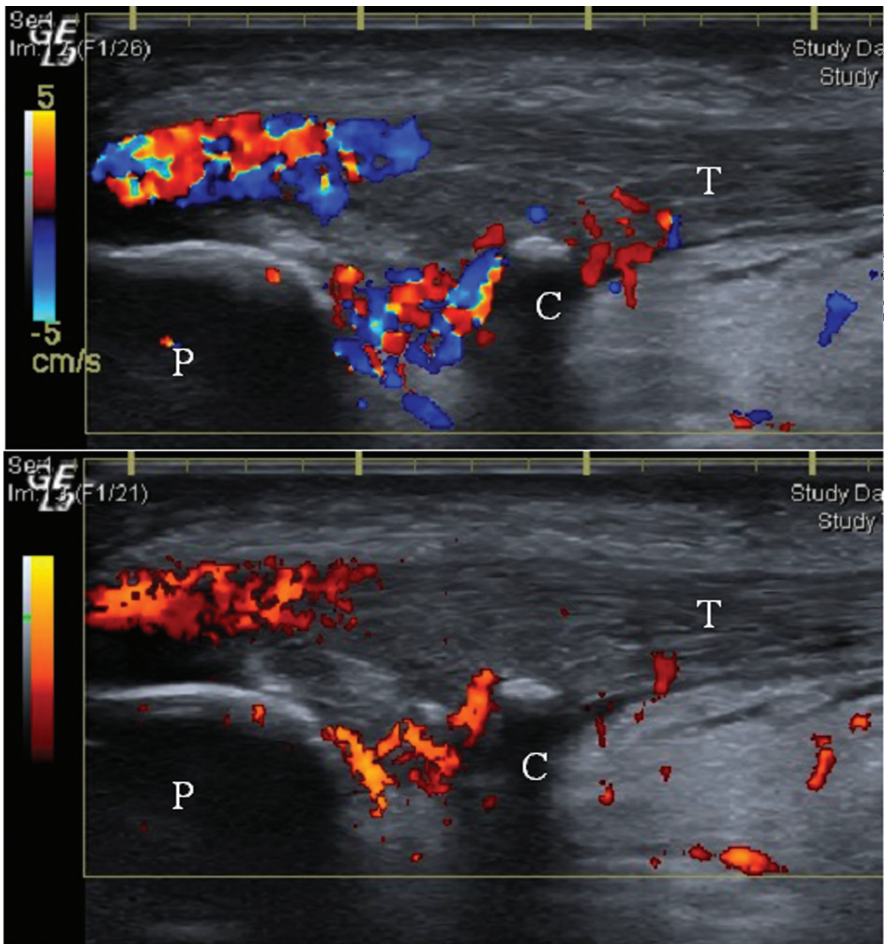

Fig. 2. Colour versus power Doppler in Jumpers knee. A longitudinal scan showing Doppler activity inside the infrapatellar tendon. **P**: patella bone; **T**: tendon; **C**: intratendinous calcification. The top image shows colour Doppler and the bottom power Doppler. The power Doppler gain has been adjusted too high in an attempt to match the sensitivity of colour Doppler. Tiny noise pixels are seen in the bottom of the image. The colour Doppler shows more true flow (higher sensitivity) with less noise and is therefore preferable on this machine.

on the equipment available at that time, being 3-4 times more sensitive (21). The high sensitivity made it nearly angle independent (20, 22).

Power versus colour Doppler

The superior sensitivity of power Doppler made it the Doppler of choice in musculoskeletal ultrasound because it is perfusion (amount of Doppler activity – not mL/s per se), and not direction or velocity that is of interest. However, on present high-end machines, the colour Doppler has become as sensitive as or even more sensitive than power Doppler. Therefore, we recommend that the choice between power and colour Doppler be based on actual comparison (subjective visual assessment of sensitivity) between the two on a given piece of equipment (Fig. 2). The following Doppler parameters and artefacts apply to both colour and power Doppler unless otherwise stated.

Angle

The angle between ultrasound beam and blood direction has major influence on the Doppler signal.

The Doppler angle is especially important in the quantification of the Doppler shift and flow velocity (spectral Doppler). However, in musculoskeletal ultrasound, the spectral Doppler and flow velocity is currently used only in research and will therefore not be mentioned further.

Pulse repetition frequency

Pulse repetition frequency (PRF) is the Doppler sampling frequency of the transducer. The Doppler shift is determined indirectly by comparing the phase of the received sound with the phase of the emitted sound over a number of pulses. The frequency of the emitted pulses (the PRF) determines how high a Doppler shift that can be detected. The maximum Doppler shift that can be obtained is PRF/2, which is called the Nyquist limit, and which is displayed on screen in Hz (20). If the blood velocity is above the Nyquist limit, the machine will misinterpret the velocity and display it as reversed flow, *i.e.* aliasing (see below).

When a high PRF is chosen, it is assumed that the investigator is mostly interested in high velocities, and the machine applies filters that remove low flow (to remove noise). Selecting a high PRF therefore makes the system more insensitive to lower velocities. In sports medicine, it is any flow (low as well as high velocity) that is of interest and therefore the PRF should be set as low as possible.

Aliasing does not occur with power Doppler. However, the sensitivity of power Doppler to low velocity flow is affected by the PRF adjustments in the same manner as colour Doppler.

Filters

Every Doppler instrument has high-pass filters, which eliminate the lowest Doppler shifts that originate from motion of the vessel wall and solid tissue. These unwanted shifts are referred to as clutter or motion artefacts.

The filters – also called wall filters – may, however, eliminate signals from low velocity flow as the filters separate by frequency alone (24, 25). The filters should therefore be kept at their lowest setting for sports medicine in order to detect slow flow (any flow).

In many Doppler systems the PRF and the wall filters are linked controls, which mean that the wall filters linked to a low PRF are lower than the wall filters linked to a higher PRF.

Doppler frequency (transmitted frequency)

The Doppler frequency at which the transducer operates is selectable. Like the grey-scale US frequency, a lower Doppler frequency will allow more

penetration but also a lower resolution colour picture. Higher Doppler frequency gives a more detailed delineation of vessels at the expense of penetration. However, a higher Doppler frequency enhances sensitivity for low flow, which counteracts the influence of penetration. In sports medicine where almost all regions of interest are superficial, the optimal frequency cannot be determined in theory but must be found in practice.

Gain setting

This is the only well described adjustment in the literature (26). The gain is increased until noise pixels dominate the Doppler box. The gain is then decreased until almost all noise has disappeared. The machine then has maximum sensitivity. With this setting, hard surfaces may generate some false Doppler activity, which must be accepted and recognised as such (or else true flow would be removed).

Actually gain should be the last adjustment because many of the other parameters determine sensitivity as well. The adjustment of these parameters will therefore very likely lead to repeated lowering of the gain (26).

3. Doppler artefacts

Some artefacts are induced by errors in scanning technique or instrument set-up and are therefore avoidable; others are unavoidable and need to be understood. The most important causes of artefacts are pressure, tissue strain, incorrect focus, motion, and noise. All the resulting artefacts may lead to misinterpretation of the amount of perfusion. Less important artefacts are blooming, aliasing and mirroring. These artefacts will always be present, must be detected, and accepted.

Pressure

False findings of absence of flow may occur if the examiner presses too hard on the tissue with the transducer, thereby blocking the flow (Fig. 3).

To avoid this, a generous amount of scanning gel should be used, which obviates the need for pressure to obtain good acoustic contact.

Tissue strain

Tissue strain is similar to transducer pressure and is affected by patient positioning. In musculoskeletal Doppler US it is especially the Doppler signal in tendons that will be affected. Even a slight strain on a tendon will elevate the intratendinous pressure and diminish or even remove Doppler activity. The tendon may be strained by patient positioning: Achilles strain by dorsiflexion in the ankle or patella tendon strain by flexion of the knee. Therefore, care must be taken to ensure that there is absolutely no tension on the structures. This requires examination on fully extended and relaxed knees when evaluating the patella tendon for Doppler flow. If a flexed (non-weight-bearing) position is used, the colour Doppler findings will significantly underestimate the flow (27). Similar observations on Doppler flow can be seen in the Achilles tendon (28).

It is also obvious that the same position must be used from examination to examination, since the changes due to patient position may lead to false positive or negative Doppler results.

Focus

The focus cursor in the side of the image indicates where the pulse is the narrowest and the energy most concentrated.

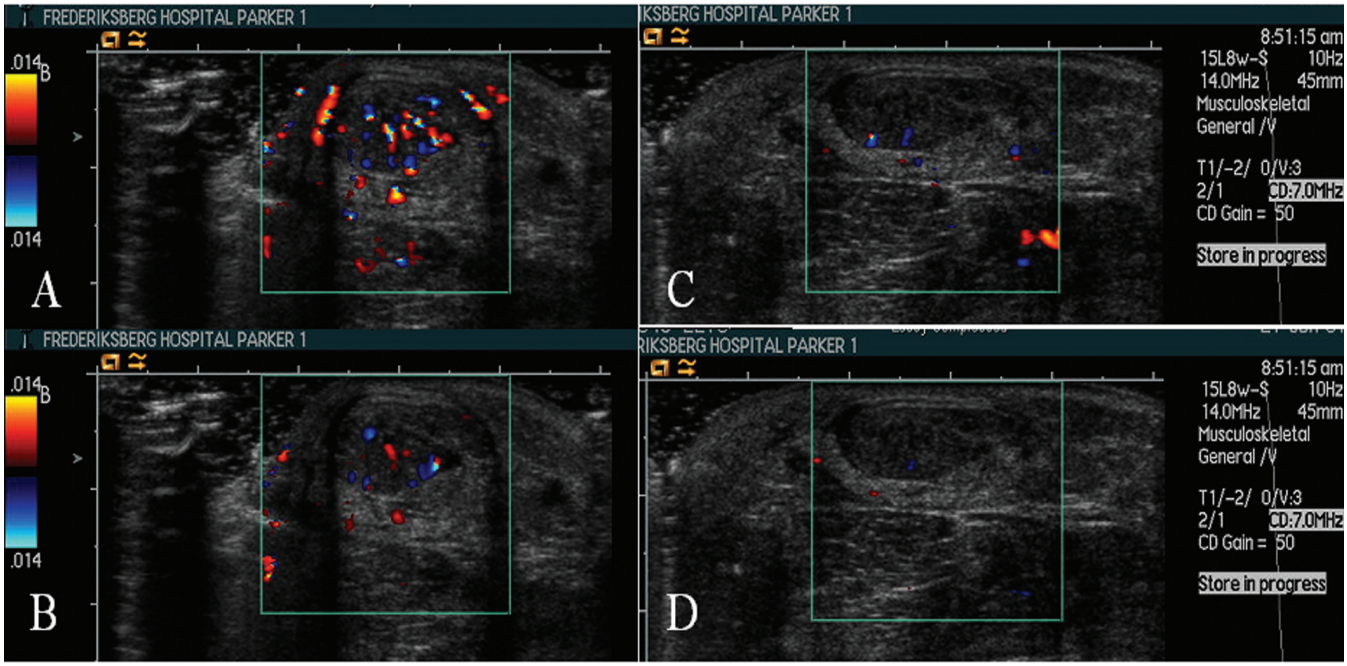

Fig. 3. Pressure artefact in Achilles tendinosis. Image **A** and **B** are transverse images of the Achilles tendon with very light transducer pressure. **A** shows the intratendinous Doppler activity in the systole and **B** in the diastole. Images **C** and **D** are with more transducer pressure, which is demonstrated by a larger skin-transducer contact as well as slight flattening of the tendon. **C** is in the systole and **D** is in the diastole. Note the obvious decrease in intratendinous flow in both systole and diastole when pressure is applied. The decrease would erroneously indicate that the tendon was borderline normal (very little intratendinous systolic flow).

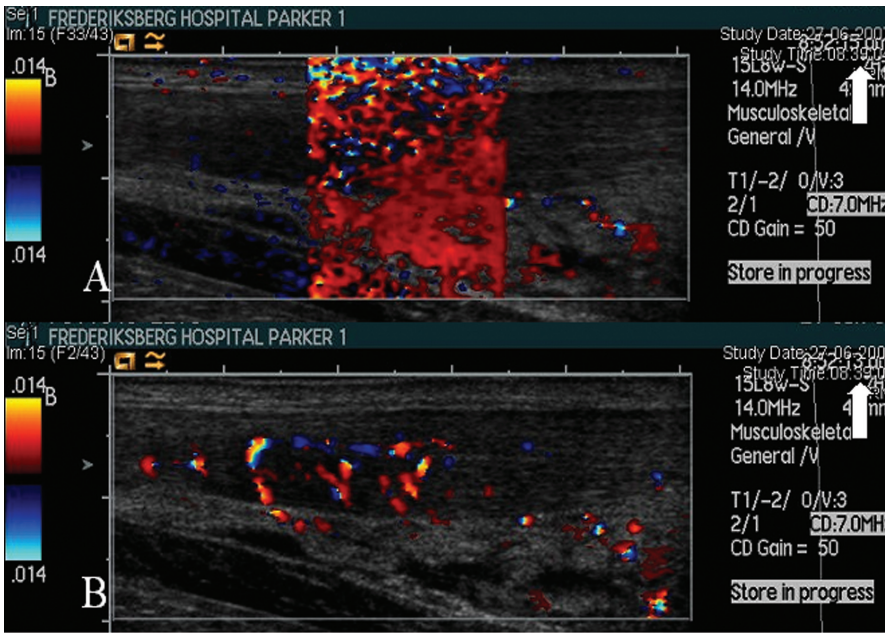

Fig. 4. Motion artefact. Movement of the patient or the examiner during Doppler imaging gives a motion relative to the transducer and produces a Doppler shift, which appears as random short flashes of large confluent areas of colour (**A**). The same examination without the motion artefact is seen in (**B**). The clock (arrows at the top right corner) shows that the two images are from within the same second.

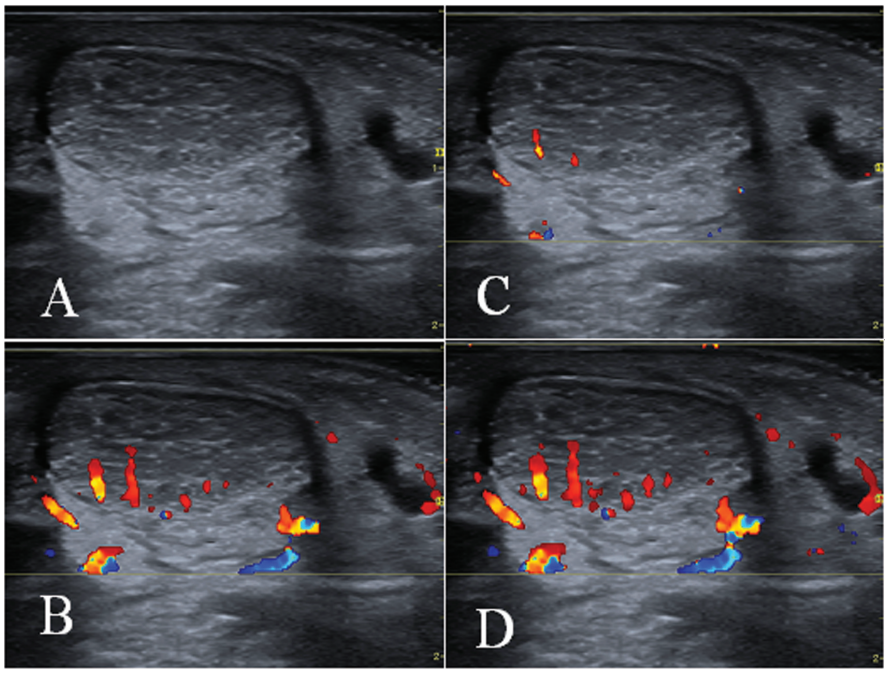

Fig. 5. Blooming artefact in a patient with Achilles tendinosis. Transverse image of the Achilles tendon with medial oriented right showing intratendinous Doppler activity in different gain settings. **A** is the corresponding grey scale image and **B** is the Doppler image with the standard settings we use, allowing blooming as an systemic error. The blooming artefact displays colour outside the vessel making the vessels appear larger than they are because the artefact exceeds the vessel wall. Focussing on the two vessels outside the tendon (white arrows) the blooming inside these vessels can be adjusted by lowering the Doppler gain setting. However, by lowering the gain thereby minimizing the blooming artefacts the weakest signals are lost and the smallest vessels disappear in other part of the image (tendon). The change is clinically relevant because the evaluation changes from moderately hyperaemic (**B**) to slightly hyperaemic (**C**).
Blooming can be enhanced by increasing the gain (**D**).

Motion (flash or clutter)

Movement of the patient or slow movement of the tissue or vessel wall caused by arterial pulsation gives a motion relative to the transducer and produces a Doppler shift (29) (Fig. 4). The same effect will be observed if the transducer is moved. The movements produce lower frequency Doppler shifts (25) that appear as random short flashes of confluent areas of colour. One way to avoid these low frequency flash artefacts is by using filters, *e.g.* wall filters. They are high pass filters, meaning that a Doppler shift must be above a certain threshold to be displayed. Such filters also remove information from slow moving blood (25).

Noise

All electrical circuits produce random noise. It is usually seen only when the Doppler gain is increased and may be displayed randomly as red or blue pixels over wide regions of the image (30).

Blooming

The blooming artefact displays colour outside the vessel and it is a function of the energy in the received Doppler signals (30). The vessels appear larger than they are because the artefact exceeds the vessel wall (Fig. 5). Usually it is due to the gain setting that can be adjusted. If the Doppler gain is lowered thereby minimising the blooming artefacts (26), the weakest signals may be lost and the smallest vessels go undetected. To avoid false impressions of development in flow, examinations at follow-up must use the same Doppler setting as the original, even though this may mean acceptance of blooming. The important message is to be aware of the phenomenon.

Aliasing

Aliasing occurs when the Doppler shift of the moving blood is higher than half of the PRF (Nyquist limit). In colour Doppler, it is seen as two opposing colours (red and blue) touching each other without a black line in between. To surmount the problem with aliasing, the PRF may be increased; however, by increasing the PFR the sensitivity to low flow is decreased.

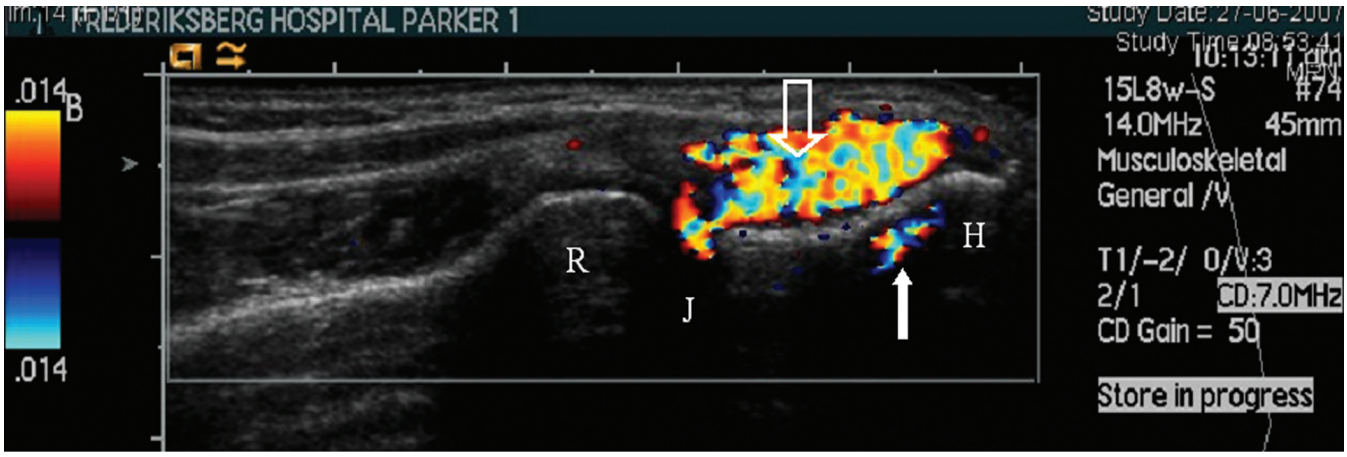

Fig. 6. Mirror artefact in lateral epicondylitis. It is a longitudinal image of the elbow in a patient with lateral epicondylitis. **H**: humerus, **R**: radius; **J**: joint space. The hollow arrow points at the common extensor origin, which is filled with Doppler activity. The solid arrow points at Doppler activity below the bone surface. It is a mirror image of the Doppler activity in the common extensor origin. The mirror is the bone surface.

Mirror

Reflection of the Doppler signal from highly reflective flat surfaces may generate colour Doppler mirror images. Bone is such an example of a highly reflective surface, and a vessel adjacent to a bone surface may be reflected, giving a false signal (a mirror of the vessel) from inside the bone (Fig. 6) (29-31).

4. Standardisation of scanning procedure and Doppler interpretation

To avoid artefacts and intraobserver variation the examiner should try to standardise as much as possible. All patients should be placed in standard positions according to the region of interest. The region should, when possible, be scanned in orthogonal planes and the structures should always be scanned in a relaxed position with generous amounts gel to avoid pressure and tissue strain artefacts (see Fig. 1). To minimise machine related artefacts, we recommend using standardised settings (set-ups) for Doppler ultrasound. Only the focus zone should be adjustable and always placed in the centre of the ROI. A predetermined setting for *e.g.* shoulder tendons, knee tendons and ankle tendons, could be determined and kept the same in all examinations. In this way it is not possible to hide or invent treatment responses due to different settings.

Documentation should be in the form of standardised images, *i.e.* predetermined number and order of images containing anatomical landmarks. The examiner should consider recording the Doppler images with maximum or minimum amount of Doppler activity in the ROI. And finally in the ROI the pulsated Doppler activity can be obtained in either the systole (usually higher amount of Doppler activity) or diastole (usually lower amount of Doppler activity).

In other words, it is necessary to develop a protocol for the examination and documentation. Such protocols are undoubtedly in use in various centres; however, none are currently available in the literature. Some authors recommend that the Doppler US examination should be carried out after (strenuous) exercise (32) in order to see as much flow as possible, whereas others, including us, recommend a period of rest before the examination in order to eliminate a possible (false positive) physiological flow response (33).

In future sport medicine studies, where the Doppler US response will be part of the presented message, we recommend illustrating the entire Doppler US picture including the settings (usually present in the right part of the US image).

Interpretation of Doppler findings

The Doppler findings in a certain patient will depend on the sensitivity and settings of the machine and will vary from machine to machine. Generalisations from literature are difficult since the equipment varies in terms of age (technology), cost (technology, quality), brand (technology, quality), machine settings, and finally the quantification of Doppler findings (classification in grades or actual measurement). Therefore it is important to know your machine and especially to know pathological from normal (*i.e.* normal flow). There seems to be a tendency to call any intratendinous Doppler activity neovascularisation instead of (hyper)aemia, which is what the Doppler actually displays. The term neovascularisation in Doppler ultrasound is based on Doppler findings and biopsies from pathological tendons (mainly Achilles and patella tendons) (34-39). Along with the technological development of ultrasound equipment, the sensitivity of the Doppler has increased. This means that the Doppler tends to visualise smaller vessels with slower flow and therefore possibly also some of the normal physiological flow (33). We have recently demonstrated an intratendinous flow (colour Doppler activity) in the Achilles tendons of non-symptomatic subjects and elite badminton players after strenuous physical activity (33, 40). We regard this flow as a normal physiological response to tendon strain. Further, it has been demonstrated that physical activity provokes increased intratendinous Doppler activity in symptomatic tendons. It is very likely that also this hyperaemia is at least in part physiological. Moreover, the hyperaemia can hardly be a neovascularisation because there has not been sufficient time to develop new vessels (32, 33). Whether Doppler activity in a particular examination is neo-vascularisation or just hyperaemia in already existing vessels is not

Table I. Common sports related conditions and value of Doppler ultrasound.

	Valuable	Not valuable	Debateable
1. Achilles tendinopathy	+		
2. Patella tendinopathy "jumper's Knee"	+		
3. Lateral epicondylitis "tennis elbow"	+		
4. Supraspinatus tendinopathy	+		
5. Bursitis	+		
6. Plantar fasciitis		+	
7. Hip joint pathology		+	
8. Lateral hip pathology			+
9. Groin injuries			+
10. Extremity joint sprains			+
11. Muscle tears		+	
12. Ligament injuries	+		

clear, and therefore the term should be used with caution.

Some authors regard any intratendinous Doppler activity as pathological (34, 41) whereas others report some Doppler activity as being normal (33). In some studies, neovascularisation (hyperaemia) is present in all symptomatic tendons (41, 32), while others report a percentage of 50-88% (43-45). It has been demonstrated that some tendons with neovascularisation (hyperaemia) may not be painful (40). Conversely, pathologic tendons without neovascularisation (hyperaemia) may indeed be painful (45, 46). An association of a high degree of neovascularisation (hyperaemia) with clinical symptoms has been found in some (43, 44) but not all studies (40, 45).

It is important to emphasise that the studies just mentioned all are carried out on different ultrasound machines with different settings. Therefore a substantial variation may be due to difference in the Doppler sensitivity of the machines.

Concerning quantification, the amount of Doppler is usually reported as grades in a semi-quantitative scoring system (*e.g.* grade 0, 1, 2 etc.). A grade 0 is normally no Doppler activity, whereas grade 1 and further are differently defined in the published papers. The thresholds between grades will naturally depend on machine quality and settings. Some machines never detect a Doppler flow of >50% in the region of interest, and therefore demand other thresholds than more sensitive machines. The advantage of semiquantitative scoring systems is that they are well suited for daily clinical work, being very fast with no need for image processing. They are, however, subjective and not necessarily accurate. To overcome this problem, some authors have developed quantitative scoring systems either reporting the number of colour pixels in a ROI as a colour fraction (47, 48) or measuring the length of vessels formed by connecting colour spots (49). However, both these systems demand a time-consuming post-processing and are therefore not at present well suited for clinical practice. The results, however, are more objective than those of the semi-quantitative scoring systems and presumably more accurate. Future development of software for quantification and three-dimensional colour Doppler might solve some of these problems (6). No proper evidence exists so far on this matter.

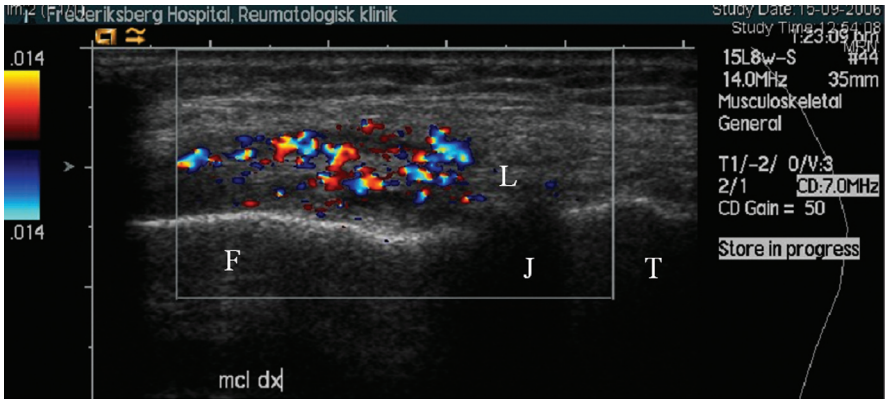

Fig. 7. Partial rupture of the right MCL. Longitudinal images of the proximal origin of the MCL ligament. The ligament is swollen with hypoechoic spot indicating fluid and partial rupture. There is Doppler activity in the ligament indicating hyperaemia and acute injury. **L**: MCL-ligament; **J**: joint line (with meniscus); **F**: femur; **T**: tibia bone.

5. Sports injuries

It is important to emphasise that a thorough grey-scale examination should always be performed prior to the Doppler examination. Recent research with Doppler in sports medicine indicates that the Doppler should now be an integral part of the ultrasound examination in some type of injuries (7). The following is based on published evidence and recommendations from the authors.

Table I gives an overview of some of the most common sports injuries and the value of using Doppler ultrasound. The table is an overview of our opinion on the value of Doppler in different conditions.

Muscle injuries

Both resting and active muscles have intramuscular Doppler flow as a normal appearance (50). A resting muscle has a relatively sparse flow with high resistance, which changes to a more abundant flow with low resistance during exercise. To date, the possible value of Doppler has not been clarified in the diagnosis of muscle injuries.

Doppler ultrasound can, when relevant, be used to distinguish an intramuscular vessel from a fluid collection. Small ruptures will in theory produce a Doppler response due to the inflammatory response, but the problem is to distinguish already existing flow from that caused by inflammation. With the present

knowledge, muscle injuries should primarily be diagnosed with grey-scale US. Finally, somewhat ill-defined disease entities, *e.g.* muscle problems in the lateral elbow region, may not be associated with Doppler *at all*. (51).

Ligamentous disease and synovitis
Ligamentous injuries often coexist with a sprain, and therefore a joint affection with a following synovitis in the adjacent joint. This is common in the ankle where a ruptured ligament can lead to instability and tendinopathy with resulting synovial proliferation and synovitis.
Acute dislocation of the patella has been described with a concomitant fluid collection around the medial collateral ligament (51). In our experience, MCL ruptures (partial and total) can be diagnosed with fibre rupture, fluid collections and Doppler activity in and around the rupture site (Fig. 7). This hyperaemia indicates inflammation and is seen in acute cases compared to the chronic injuries. The hypervascularisation seen in synovitis and/ or tenosynovitis, especially in RA patients, is perfectly visualised with colour Doppler (4, 13, 15, 47, 52).However, in sports injuries the Doppler flow is usually no or sparse despite fluid in the joint and tendon sheet. At present, we recommend evaluating the ligaments with grey-scale US and adding the Doppler function in the evaluation of synovitis and/ or tenosynovitis.

Injuries in tendon structures
Recent research in sports medicine and Doppler ultrasound has mainly focussed on tendinopathies and the presence of intratendinous colour Doppler, which seems to reveal hyperaemia (neovascularisation) as part of the pathology (34, 53-56). Intratendinous colour Doppler activity has been shown to correspond closely to the patient's pain. In patients with jumper's knee it has been reported that the greater the amount of colour Doppler activity present, the greater the pain (56). We agree with the possible correlation on Doppler activity and pain, but in certain subgroups we have observed intratendinous Doppler activity without co-existing pain (33, 40, 57). In these studies we observed intratendinous Doppler activity without co-existing pain but we believe there is a theoretical explanation for this. The Doppler activity in elite badminton players (40) may be a result of high training load and constant remodelling in the tendons. The observed Doppler activity in patients with chronic Achilles tendinosis after an electro-coagulation (57) may be due to the procedure, and the symptom relief due to a denervation of the painful area. Finally, the Doppler activity in non-symptomatic, non-trained subjects (33) after a strenuous run may be due to remodelling of the tendon and high sensitivity of the ultrasound machine. This Doppler activity may be distinguished from chronic tendinosis by the disappearance of the Doppler signals in the resting tendon. However, in all examinations with a highly sensitive Doppler some Doppler activity may be detected; therefore, we advise examiners to be aware of possible physiological flow.
The suggested neovessels are accompanied by pain fibres (58), growth factors, accumulation of glycosaminoglycans (GAGS) and the peptide glutamate (39), and these factors are believed to be the cause of the patients' symptoms.
Tendinopathy should be diagnosed with both grey-scale US and Doppler US. The grey-scale US will reveal the structural changes, whereas the Doppler will reveal intratendinous flow in patients with tendinopathy and ruptures. Colour Doppler has found its place in diagnosing tendinopathies such as Achilles tendinopathy (34), patellar tendinopathy (jumper's knee) (48), lateral epicondylits (tennis elbow) (51), supraspinatus tendinopathy (54), and bursitis (59). All in all, based on Doppler alone it is not possible to distinguish between acute and chronic tendinopathy – the clinical findings and patient history need to be taken into account. However, based on Doppler alone it is possible to distinguish between active and non-active disease – presence or absence of pathological Doppler acitivity.
In our experience, colour Doppler may also be used to establish the diagnosis of calcific tendonitis. The presence of a calcification inside a tendon is not rare especially near the insertion. It is the accompanying hyperaemia immediately around the calcification(s) that indicate calcific tendonitis. There has been one report of the use of colour Doppler in the quantification of treatment response in calcific tendonitis of the rotator cuff (60).
However, in plantar fasciitis (heel spur) and pathology in the hip joint, the Doppler energy cannot penetrate the overlying superficial structures (skin, fat and muscle) and therefore the Doppler may not be used as a sign of tendinopathy or enthesopathy. However, one study reports the positive use of power Doppler in patients with plantar fasciitis (61). This study even uses an older machine. In our experience, neither the power nor colour Doppler on new high-end machines can be used in plantar fasciitis because lack of Doppler activity does not indicate absence of disease and because presence of Doppler activity is extremely rare.
In the lateral hip and the groin, the Doppler may have a diagnostic relevance. However, due to the relatively deep position of the structures (insertion of the gluteal muscles in the lateral hip and the insertion and origin of the psoas major and the rectus femoris, respectively); the Doppler findings are again not a common sign; this is especially so in obese individuals.

Bone injuries
When the clinician has a suspicion of a fracture, ultrasound is not the modality of choice. Conventional x-ray is preferred. However, very small avulsions and rib fractures may be detected as cortical breaks with or without Doppler activity in the near surroundings (*e.g.* an avulsion of the phalanx), and US may therefore be used in these circumstances (9). In stress fractures the modality of choice is bone scintigraphy or MRI, while US may be used, often to reveal a defect in the cortex with surrounding Doppler activity as a sign of early periosteal oedema (65).

6. Doppler guided therapies
Our interest has been concentrated towards ultrasound guided therapy directed at the hyperaemia (neovascularisation) in patients with chronic tendinosis. Different groups have suggested different techniques with the same

Table II. Level of evidence in varying published methods of tendon treatments where the aim is to target and reduce the Doppler activity.

	Achilles	Patella	Shoulder	Elbow
1. Sclerosing therapy	1b	1b	4	4*
2. Coagulation therapy	4			
3. Intratendinous steroid injection	4			
4. Dry needle and autologous blood injections		4		4*~

* lateral epicondylitis; ~ medial epicondylitis.
Level of evidence for evidence-based medicine: Level 1b: Individual RCT.
Level 4: cases-series and poor quality cohort and case-control studies.
Reference: Oxford centre for evidence-based medicine (May 2001) (67).
http:/www.cebm.net/index.aspx?o=1025.

purpose, *i.e.* to target the hyperaemia and eventually diminish or remove it. These techniques include sclerosing therapy (63), coagulation therapy (57), dry needling and autologous blood injections (64-66), and intratendinous steroid injections (67). All treatments have shown promising short-term results with some good long-term results from the sclerosing therapy of the Achilles and patella tendon. Table II is an overview of where these methods have been used and the level of evidence.

The primary aim of most studies was to remove the Doppler activity; nevertheless, there is not always a correlation between the presence of US Doppler and pain after treatment (57, 68). An obvious explanation could be varying efficacy of the different methods of treatment. However, another explanation may be different Doppler settings and scanning set-ups. As shown above, both the settings and the scanning set-up can reproduce a highly variable Doppler response in the same patient.

There seems to be a consensus of using ultrasound for guidance of various injections in the musculoskeletal system (2), but only few articles mention the hyperaemia as the primary target of the needle. This might be due to the relatively new focus on the Doppler changes as part of the pathology in tendinopathy. Since the exact aetiology and pathogenetic significance of these vessels are still unknown, more research is needed to fully understand the meaning of reducing the vascular supply to the ultrasonograpically pathological site of the tendon.

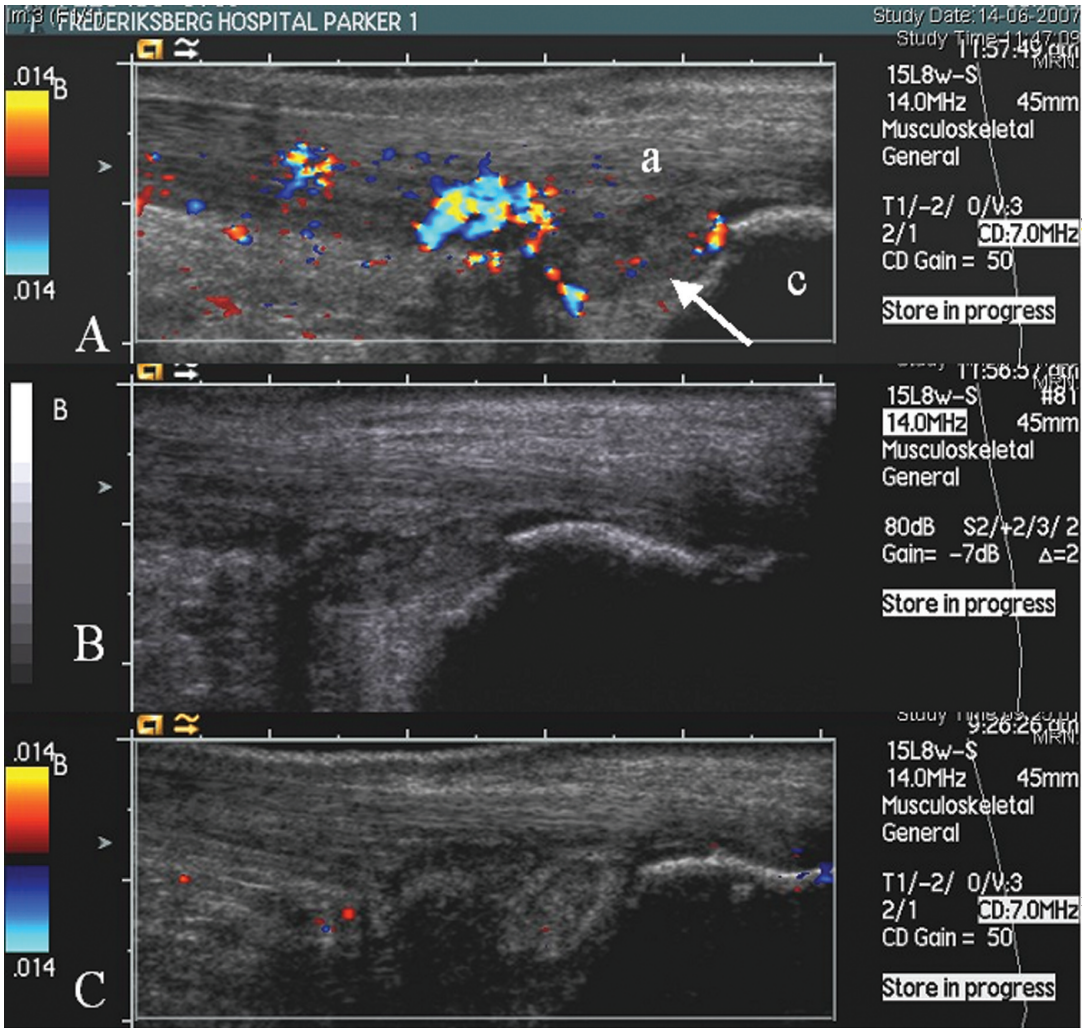

Fig. 8. Doppler response to a steroid injection. A longitudinal image of an Achilles tendon in a patient with both pre-insertional tendinopathy and bursitis. The top image illustrates the Doppler response (A) in both the bursa (white arrow) and the overlying Achilles tendon (a). (B) is the corresponding grey-scale image. The patient received an ultrasound guided injection of steroid in the bursa and experienced a total pain relief at the 14 days follow up examination where the intratendinous Doppler activity was gone (C).

The Doppler is a sensitive tool for showing response to a steroid injection. Following an injection of steroid, it seems that the Doppler is the first variable to respond to the treatment along with the patient's symptoms (Fig. 8). The grey-scale findings evolve more slowly and may normalise later in the case of successful treatment. In such instances, the Doppler is recommended for visualisation of the immediate response: without the Doppler, the patient may still be classified as ultrasonographically unchanged.

7. Conclusion

Doppler ultrasound examination on good, modern equipment is a valuable tool in the hands of the properly trained professional. The Doppler techniques along with a standard grey-scale ultrasound examination should be the first line test for patients with some of the most common ligament and especially tendon injuries. In muscle injuries, the Doppler technique is not preferable. However, neither grey-scale nor Doppler ultrasound should be judged alone, as the most effective and informative examination will usually be a combination of methods.

Knowledge of the many Doppler artefacts in the image gives the examiner a better understanding of the images and probably also a more critical approach. The discussed artefacts will occur in all areas of musculoskeletal US.

8. Perspective

In theory, the Doppler function may be influenced by intrinsic and extrinsic factors. The examiner must have all possible factors in mind when evaluating the examination. Moreover, individual differences in the structures and Doppler responses amongst elite athletes and recreational athletes must be investigated. So far, no prognostic value of colour or power Doppler have been found in patients with patella and Achilles tendinosis (46). However, we believe that with further standardisation, high-end equipment and development of investigator independent three-dimensional US a prognostic value of Doppler will be found.

We recommend that future authors when writing the method section mention something about the Doppler settings and how they tried to standardise the scanning set-up. This information gives the reader a clearer picture of how to interpret the Doppler image; it also makes the Doppler result more reliable.

The current problem in reporting the findings in a scoring system may be solved with the fast technological development of ultrasound equipment. New machines may calculate the Doppler activity in the entire scanned region (*i.e.* three-dimensionally) and present it in real-time. Accordingly, some of the subjectivity may disappear; however, ultrasound will always be operator-dependent to a certain degree, and that is the major disadvantage of this modality.

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