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ORIGINAL PAPER

Power Doppler in musculoskeletal ultrasound: uses, pitfalls and principles to overcome its shortcomings

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Abstract
Power Doppler (PD) is used widely in musculoskeletal ultrasound, especially in the assessment of structures for evidence of inflammation and in evaluating soft tissue neoplasms. We reinforce and delineate the three cardinal principles of optimising PD assessment in order to avoid false positive or false negative results; namely (1) Optimal gain settings (2) Adequate transducer pressure, and (3) Proper patient/anatomical structure-of-interest positioning with complete tissue relaxation.

Keywords Power doppler · Doppler · Principles

Introduction

Power Doppler (PD) is used widely in musculoskeletal ultrasound, especially in the assessment of structures for evidence of inflammation and soft tissue neoplasms. It is favoured over colour Doppler (CD) due to its increased sensitivity to weak flow and its ability to detect flow in all directions. In this paper, we describe the differences and advantages of using PD rather than CD and the uses of PD in musculoskeletal ultrasound. We reinforce and delineate the three principles of optimising PD assessment in order to avoid false negative results.

How does PD work in comparison to CD?

In both CD and PD, the frequency of the ultrasound pulse reflected from moving red blood cells differs to the transmitted frequency, which is known as the Doppler shift. CD measures the mean Doppler frequency shift and hence demonstrates the overall speed and direction of the flow. The colour indicates the direction of flow, with red conventionally used to indicate flow towards and blue flow away from the transducer. The shade of red or blue is used to demonstrate velocity. This is calculated using a standard formula which includes an insonation angle. The insonation angle is the angle between the direction of the ultrasound beam and the direction of the flow. If the insonation angle is 90° i.e. the beam is perpendicular to flow, no flow will be demonstrated. The greatest degree of flow will be detected when the transducer is positioned with the flow directly towards or away from it (insonation angle of 0°).

PD on the other hand measures the total amplitude (or power) of the Doppler frequency shift and is independent of the angle at which the probe is held relative to the blood flow. The amplitude is dependent on the density of erythrocytes in the sample volume and on the attenuation of the intervening tissue. In PD, large amplitude signals are given a brighter shade than smaller amplitude signals.

Advantages and disadvantages of Power Doppler

A major advantage of PD is in its ability to demonstrate flow in any direction, and will even demonstrate continuous flow in a looped vessel [1]. For this reason Power Doppler displays of vessels are likened to conventional angiography [2]. This is in contrast to CD which will not demonstrate flow which is perpendicular to the ultrasound beam [3].

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Furthermore, because PD evaluates the total number of Doppler shifts of the moving cell, regardless of direction and speed, it is very sensitive in detecting slow flow. This makes it very useful when assessing inflammation of various tissues in musculoskeletal radiology [4]. However, it does mean that PD gives no indication of the speed tor direction of flow making it difficult to determine arterial vs venous flow or to analyse reversal of flow. This is important in the assessment of vascular stenosis and in evaluating porto-systemic shunting but has limited ramifications in musculoskeletal radiology [5].

It is also important to note that the velocity measurements by Colour Doppler are not completely accurate. Unless a manual angle correction has been input into the ultrasound machine, the assumption is that the flow is directly towards the ultrasound beam. If this is not the case then the colours seen on the screen will not match accurately to the reference velocity colour bar [3]. Furthermore, most of the musculoskeletal inflammation, tendinopathies and enthesitis demonstrate very sluggish vascularity (very low flow rate) and therefore, accurate calibration of the ultrasound machine for PD is mandatory. Proper PD calibration is absolutely vital to ascertain the magnitude of both systemic (from inflammation or neoplasms) or random (due to noise) contribution improving diagnostic quality by minimising artefacts [19].

In PD, the greater the density of cells, the greater the number of erythrocytes in a given volume and therefore the stronger the reflection. The vascular flow dynamics in a standard blood vessel mean that the red blood cells tend to clump together in rouleaux formations within the central lumen of the vessel. Higher shearing forces, more laminar flow and more individual cells are seen at the periphery. The rouleaux formations are more reflective than the sum of the individual cells meaning there is an increased amplitude signal coming from the centre of a vessel compared to the periphery. This creates good edge definition in PD imaging of a vessel and less artefact outside the vessel [1].

Uses of PD in musculoskeletal radiology

Uses of Power Doppler in musculoskeletal radiology are widely documented and relate mostly to the assessment of inflammation and neovascularity in tissues. PD can be used to differentiate between synovial inflammation from complex effusion by demonstrating vascularity in the pannus [6]. Synovial inflammation demonstrated by PD has been shown to correlate well with histopathological [7] and MRI findings [8, 9]. A role for PD has also been demonstrated in the follow up of inflammatory arthropathies as it reliably demonstrates response to immunomodulatory therapies [10–12]. It has also been shown to have a predictive value in disease progression and radiological outcome in inflammatory arthropathy [13]. PD can be used to demonstrate vascularity in enthesitis, which correlates with clinical scoring systems. PD is useful in tendinopathies for evaluation of inflammation and neovascularity adding valuable information to the structural changes seen on conventional ultrasound. Temporal assessment of enthesis organ for changes on conventional ultrasound; for example, morphologic enthesis abnormality (hypoechogenicity and/or thickening), entheseal calcific deposits, cortical changes (osseous erosions and/or proliferation), bursitis, when used with PD changes (intraenthesis PD and perienthesis PD) can provide valuable evaluation of disease activity and overall response to treatment helping biotherapy titration. Hence, PD helps in the decisions regarding the treatment pathway [14, 15].

Soft tissue neoplasms, both benign and malignant, are common occurrence in the clinical practice. Due to their superficial location of soft tissue neoplasms, high-resolution ultrasound by means of its multiparametric capability (grey-scale evaluation, colour Doppler, power Doppler, spectral wave analysis and elastography) can provide vital clues about potential malignant potential of the lesion (Fig. 1) [21]. When used in conjunction with colour Doppler and spectral wave analysis, power Doppler permit reproducible visualisation of abnormal vascular architecture (combination of occlusions, stenosis, vascular loops, trifurcations, and shunts) and enable differentiation between benign and malignant tumours [22]. It is typically followed by an MRI ascertaining tumour characteristics, relationship with surrounding anatomical structures and imaging-guided biopsy for histological diagnosis (Fig. 2).

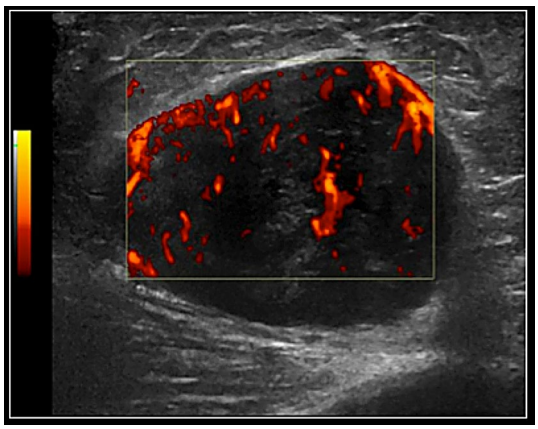

Fig. 1 Utility of power Doppler in evaluation of soft tissue neoplasms: Please note imaging appearance of sinister lesion with multifocal peripheral vascularity

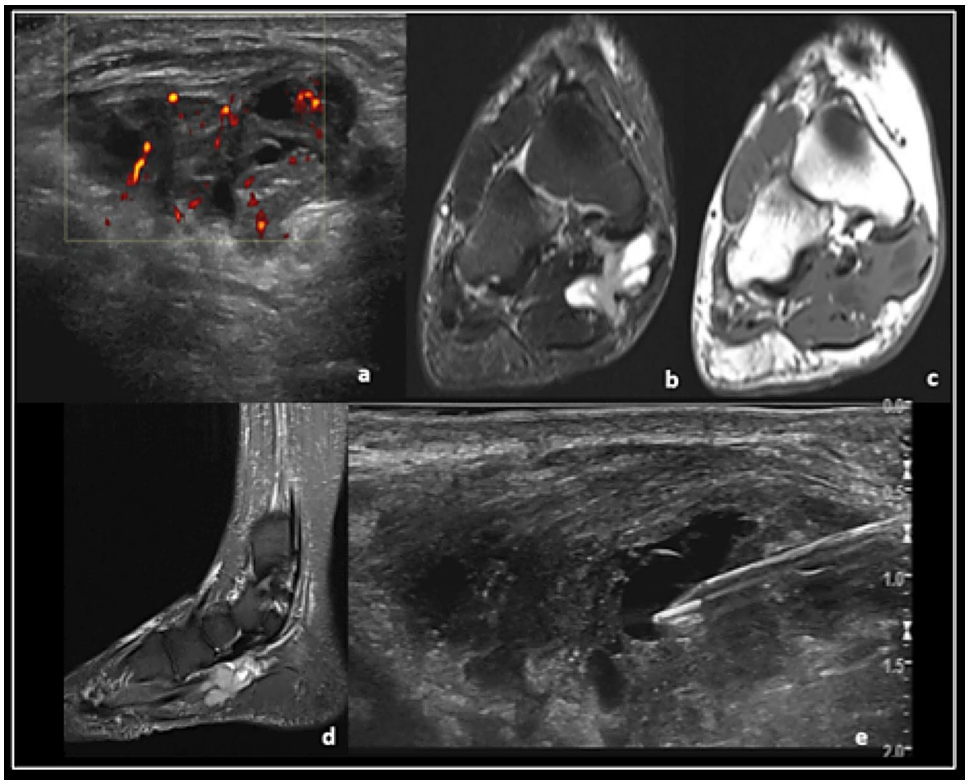

Fig. 2 Synovial sarcoma: Ultrasound (**a**) is typically followed by an MRI to ascertain relationship between the lesion and surrounding anatomical structures (**b**, **c**, **d**). Power Doppler can detect areas of neovascularity improving diagnostic yield of imaging-guided biopsy (**e**)

Principles for optimal use of Power Doppler in musculoskeletal ultrasound

We are reiterating simple but absolute must principles for using PD in evaluation of various musculoskeletal conditions. For optimising PD appropriately, three below mentioned cardinal principles should be followed:

First principle: optimal gain settings

Gain should be set at the appropriate level to detect weak flow but minimise the random noise (Fig. 3). Several methods of setting gain have been described by papers assessing the use of PD. One is the method of Rubin, this suggests adjusting the gain by manual elevation until the colour box is almost uniformly filled with the first indication of colour with only the minimum amount of the next signal beginning to appear [16]. Second method involves setting the gain at a set level, although this is arbitrary and changes between papers [17]. Alternatively, it has been suggested to turn up the gain until random noise is encountered and then lowering it until the noise disappears, thereby setting the gain on the threshold to noise [18].

Second principle: adequate transducer pressure

False negatives can occur if the operator presses too hard on the tissue resulting in compression of the blood vessels (neovascularity) (Fig. 4). This is particularly difficult to prevent in musculoskeletal radiology when many of the imaging surfaces are concave or convex and the temptation is to use pressure to achieve even contact with the transducer. Instead, a gel stand-off can be applied to even out the surface and relieve the pressure off the probe onto the tissues [20]. Similarly, the examiner can use their own fingers to create

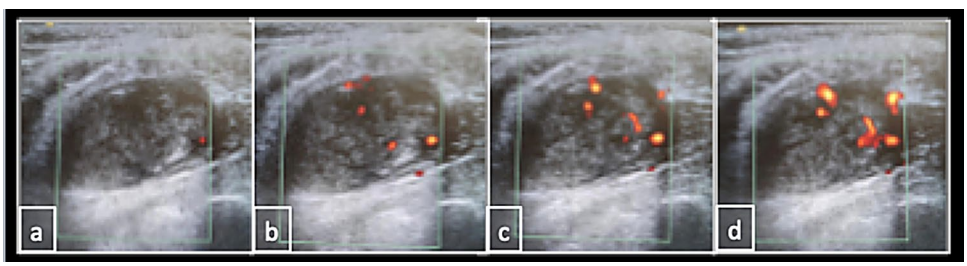

Fig. 3 Proper gain settings: Sequential images showing importance of adequate gain, from **a** to **d**, increase in PD gain (**a**–5db, **b**–3db, **c**–4db, **d**–6db) magnitude showing sinister with varying degree of vascularity on PD

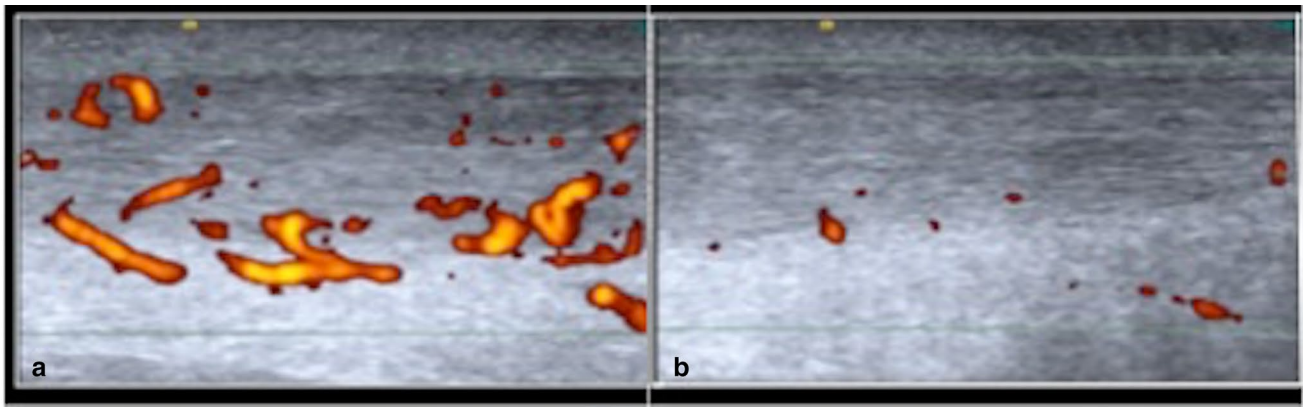

Fig. 4 The difference in the demonstration of Achilles tendon neovascularisation when normal probe pressure is applied (**b**) compared to reduced probe pressure (**a**)

a space between the probe and the surface to decrease the transmitted pressure (Fig. 5).

Third principle: proper patient/structure positioning with complete tissue relaxation

The importance of patient and examiner positioning is well known in general ultrasound in order to prevent tremor and therefore movement artefacts [3]. In PD ultrasound specifically, it is also important to consider the positioning of the structure under evaluation. The structure must be in relaxed state as tissue contraction will result in compression of the vascular structures, in turn leading to false negative results (Figs. 6, 7, 8).

Key points: Power Doppler usage in musculoskeletal radiology

1. Assessing inflammation and neovascularity in tissues which usually demonstrates very low flow rate (inflammatory arthropathy, enthesitis, tendiopathies, soft tissue tumours, slow-flow vascular malformations)
2. Three cardinal principles whilst using power Doppler in musculoskeletal radiology: (1) Standardisation of gain settings, (2) Avoidance of unnecessary probe pressure, and (3) Ensure complete relaxation of the tendon or body part under evaluation

Conclusion

PD is heavily relied upon in musculoskeletal ultrasound in the assessment of vascularity in musculoskeletal inflammations and neoplasms. It has been proven to correlate well with clinical, histopathological and MRI findings. It can also be used to follow-up pathologies and assess response to treatment. It is imperative that cardinal principles described are followed to ensure the best outcome and avoid false positive and negative findings.

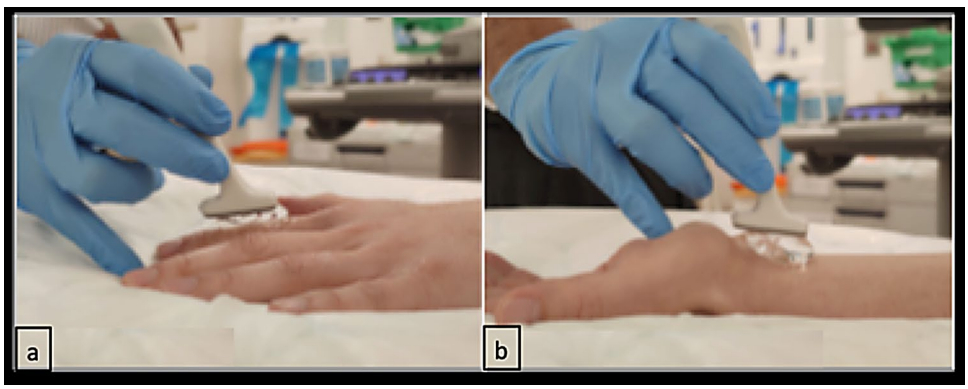

Fig. 5 Gel stand-off: the examiner using own fingers to create a space between the probe and the tissue under sonographic interrogation decreasing the transmitted pressure

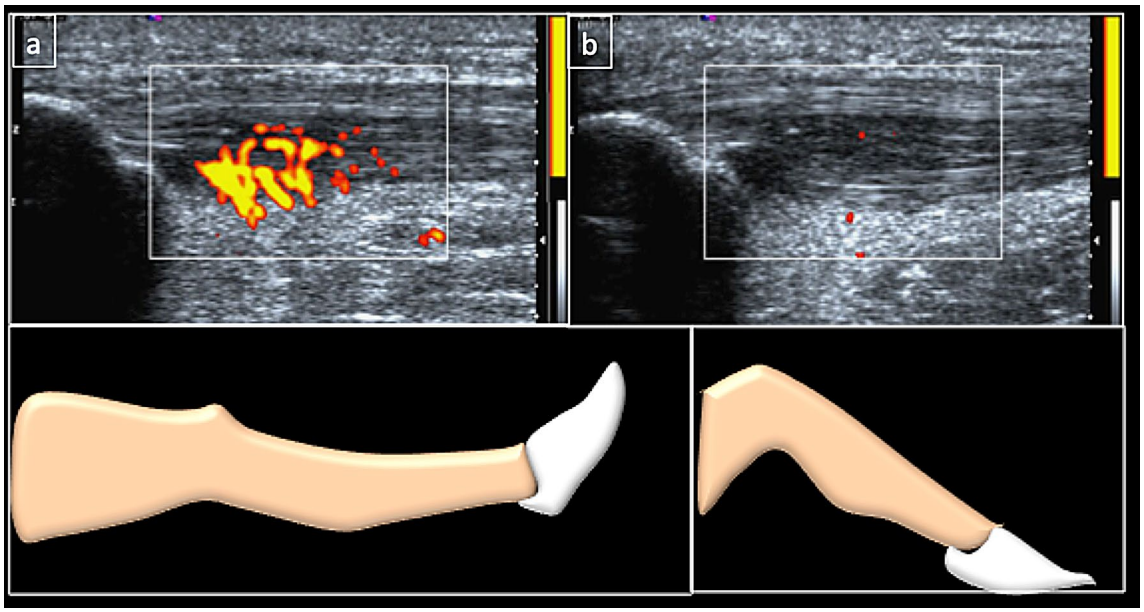

Fig. 6 The difference in the demonstration of patellar tendon neovascularisation with knee relaxed (**a**) compared to knee in flexion (**b**)

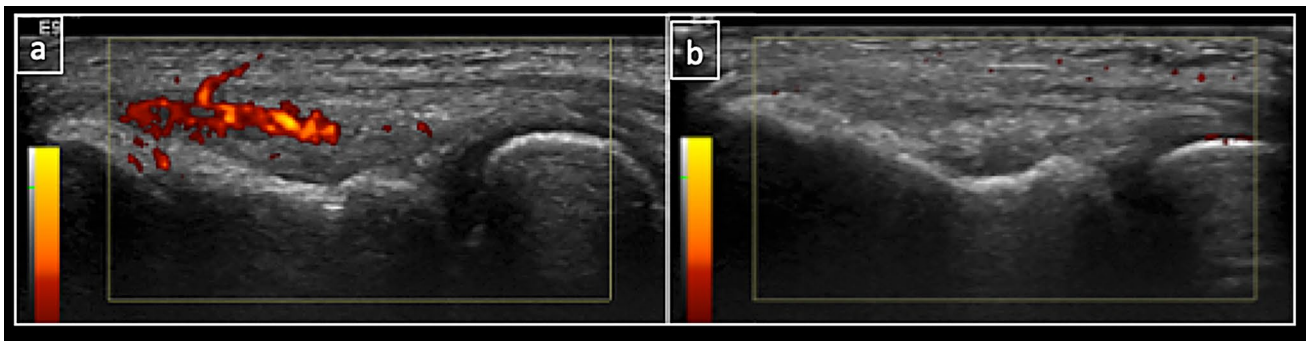

Fig. 7 The difference in the demonstration of common extensor tendon neovascularisation in relaxed (**a**) compared to contracted extensor muscles (**b**)

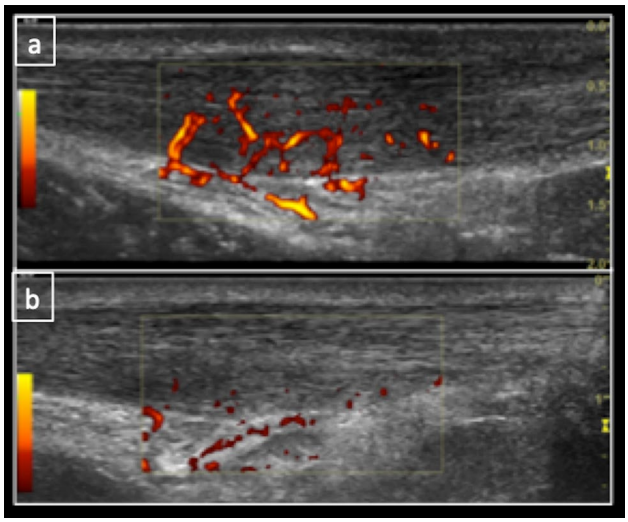

Fig. 8 The difference in the demonstration of achilles neovascularisation in relaxed (**a**) compared to contracted gastrocnemius muscle (**b**)

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This is a pictorial essay/review paper and not a study. All patients had already had ultrasound scans in the department for clinical symptoms and not specifically for this paper.

Informed consent No consent was required.

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