

## TENDINOPATHY: IS IMAGING TELLING US THE ENTIRE STORY?

Sean I. Docking<sup>1,2</sup>(BHSc Hons), Chin C. Ooi<sup>3,4,5</sup> (MMedUS, BAppSc) and David Connell<sup>4,5</sup> (MBBS, MMed)

<sup>1</sup>Monash Tendon Research group (MONSTERS), Monash University, Victoria, Australia

<sup>2</sup>Australian Centre of Research into Injury in Sport and its Prevention (ACRISP), Federation University, Victoria, Australia

<sup>3</sup>Department of Diagnostic Radiology, Singapore General Hospital, Singapore

<sup>4</sup>Department of Medical Imaging and Radiation Sciences, Monash University, Victoria, Australia

<sup>5</sup> Imaging at Olympic Park, Victoria, Australia

The authors certify that they have no affiliations with or financial involvement in any organization or entity with a direct financial interest in the subject matter or materials discussed in the article, with the exception of funding by Ultrasound tissue characterisation imaging company to Sean Docking to attend a conference in April 2013. Sean Docking is supported by the Monash University Postgraduate Publication Award for the preparation of this paper.

### **Corresponding author**

Sean Docking

PO Box 527

Frankston, Victoria, 3199

Australia

Email - sean.docking@monash.edu

Ph - +613 9904 4818

Fax - +613 9904 4812

**SYNOPSIS:** Tendinopathy is frequently associated with structural disorganisation within the tendon. As such, the clinical use of ultrasound and magnetic resonance imaging for tendinopathy has been the focus of numerous academic studies and clinical discussions. However, similar to other musculoskeletal conditions (osteoarthritis and intervertebral disc degeneration) there is no direct link between structural disorganisation and clinical symptoms, with findings on imaging potentially creating a confusing clinical picture. While imaging shows the presence and extent of structural changes within the tendon, the clinical interpretation of the images requires context in regards to the features of pain and the aggravating loads. This review will critically evaluate studies that have investigated the accuracy and sensitivity of imaging in the detection of clinical tendinopathy and the methodological issues associated with these studies (subject selection, lack of a robust gold standard, reliance on subjective measures).

The advent of new imaging modalities allowing for the quantification of tendon structure or mechanical properties has allowed new critical insight into tendon pathology. A strength of these novel modalities is the ability to quantify properties of the tendon. Research utilising ultrasound tissue characterisation and sonoelastography will be discussed.

This narrative review will also attempt to synthesis current research whether imaging can predict the onset pain or clinical outcome, the role of monitoring tendon structure during rehabilitation (ie, does tendon structure need to improve to get a positive clinical outcome?), future direction for research and propose the clinical role of imaging in tendinopathy.

**Key words:** magnetic resonance imaging, tendinosis, tendon, ultrasound

The old saying goes ‘a picture is worth a thousand words’. Imaging of tendons with ultrasound and magnetic resonance (MR) imaging have been utilised in the clinical setting to assist in the diagnosis of tendinopathy, monitor the efficacy of treatments, and assess the risk of developing symptoms.<sup>44, 73, 81</sup> However, while imaging shows the presence and extent of structural changes within the tendon, the clinical interpretation of the images requires context in regards to the features of pain (location and distribution) and the aggravating factors (loads that are related to increases in pain). This is due to the limited relationship between structural disorganisation and pain; similar to other musculoskeletal conditions such as osteoarthritis and intervertebral disc degeneration.<sup>81</sup> Clinically, tendon abnormalities on imaging do not confirm that pain and dysfunction is generated by the tendon.<sup>77</sup> Conversely, a relatively normal tendon does not rule out the tendon as the source of pain and dysfunction. In the case of tendons, we may need to make an addition to the old saying where ‘a picture is worth a thousand words *but only as an adjunct to the clinical picture*’. This clinical commentary discusses the imaging features of the pathological tendon, accuracy and sensitivity of ultrasound and MR imaging, new and novel imaging modalities, the role of imaging in the clinical and research setting (prediction of symptoms and monitoring), and future directions.

Tendinopathy is the clinical condition that describes pain and dysfunction of the tendon, which is independent of pathology within the tendon.<sup>53</sup> It is frequently described as localised pain that increases with greater load (ie, single leg hopping is more painful for the Achilles tendon than calf raises).<sup>15, 77</sup> Degenerative changes in structure observed histologically or on imaging, independent of clinical symptoms, is termed tendinosis.<sup>53, 72</sup> These terms have been used interchangeably in the literature, however it is important to clarify that they represent differing aspects of the same condition and highlight the disconnect between structure and pain.

### **Features of normal and pathological tendons on imaging**

Imaging allows for the visualisation of the internal architecture of the tendon. Normal tendon primarily contains type I collagen that is hierarchically arranged into parallel aligned fibrils, fibres, and fascicles.<sup>31, 64, 76, 80</sup> This uniform alignment of fibres can be visualised in normal tendons using ultrasound imaging at the fascicle level (**FIGURE 1**). Water and non-collagenous proteins, such as proteoglycans, are present between the fibres and fascicles, which allow tendon lengthening through interfascicular sliding rather than fibre extension.<sup>82, 92</sup> This relationship between water and collagen results in a strong dipole interaction and little signal being observed on MR imaging in the normal tendon (**FIGURE 2**).<sup>9, 99</sup> Finally, normal tendons are relatively avascular especially when observed with Doppler ultrasound (**FIGURE 3**).<sup>65</sup>

Four main histological changes are observed in tendinosis; the primary change being increases in cell numbers that exhibit an altered more metabolically active phenotype.<sup>10, 47</sup> Rather than flattened tenocytes that are arranged parallel between fibres, increased numbers of rounded, activated tenocytes are interspersed throughout the pathological tendon.<sup>47</sup> While determining changes in cell number and phenotype are beyond the resolution of clinical imaging modalities, the consequence of these active metabolic cells can be detected. A shift in the proteoglycan content, from the small leucine-rich proteoglycans (eg, decorin) to the larger hydrophilic proteoglycans (eg, aggrecan), results in an increase in bound water and tendon thickening.<sup>20, 80</sup> These changes have been described on ultrasound as increases in tendon dimensions and heterogeneous or diffuse changes in echogenicity,<sup>19, 57</sup> as well as, ultrashort echo time MR imaging shown alterations in the hydration state of the tendon.<sup>40</sup> Previous work in asymptomatic patellar tendons suggest that abnormal tenocyte morphology and changes in proteoglycan content are the primary changes in tendinosis.<sup>14</sup>

Fibrillar disorganisation is another feature of tendinosis where fibres are present in a haphazard arrangement, somewhat due to the change from type I collagen to type II and III collagen.<sup>54</sup> The parallel arrangement of normal tendon fibres generates a single ultrasound reflection when the ultrasound probe is perpendicular to the long axis of the tendon. Multiple reflections and shadowing are generated by fibrillar disorganisation and lack of parallel aligned fibres, which is represented by an area of hypoechogenicity on ultrasound (**FIGURE 4**).<sup>73</sup> On MR imaging, the alteration in fibrillar alignment and increased water content results in an increase in intratendinous signal (**FIGURE 5**).<sup>9, 99</sup>

Neovascularisation within the pathological tendon can be imaged with colour and power Doppler ultrasound imaging (**FIGURE 3**).<sup>6, 33</sup> Weinberg et al<sup>98</sup> reported that Doppler flow was only observed in tendons that contained an area of hypoechogenicity and not in abnormally thickened tendons with normal echogenicity. This association between the presence of blood vessels and areas of matrix disorganisation suggest that the infiltration of blood vessels may be opportunistic.<sup>43</sup> The infiltration of blood vessels and accompanying nerves have previously been implicated as a source of pain, with moderate associations reported between Doppler signal and the presence and location of pain<sup>22, 27, 38</sup>; with Doppler signal also being associated with poorer clinical outcomes.<sup>49</sup> However, increased Doppler signal is present in asymptomatic tendons suggesting that blood vessels and accompanying nerves are not the primary source of pain.<sup>18, 38</sup> It is also important to note that the reliability of detecting Doppler signal is poor,<sup>17</sup> with exercise affecting the presence/absence of Doppler signal.<sup>16</sup>

The pathological features outlined above are not the only indication of pathology within the tendon. Partial tears, especially in the rotator cuff of the shoulder, are frequently described. However, there is no consensus on the features of partial tears and a number of studies have reported difficulty in differentiating partial tears from tendinosis.<sup>68, 75</sup> Bony spurs and areas of calcification, frequently near the tendons bony insertion, have previously been described as a 'tombstone of tendon pathology' yet recent investigations have shown that they have little impact on the development of symptoms.<sup>12</sup> Extra-tendinous tissues, such as paratendinous sheath, associated bursa, and fat pad, can also display changes on imaging yet have a different pathogenesis to tendinosis.<sup>73</sup>

Paratendinitis is described as an inflammatory response of the tendon sheath, which clinically can present as crepitus and pain through range of movement. Thickening of the sheath and the presence of fluid surrounding the tendon are frequently observed on ultrasound (**FIGURE 6**), with adhesions of the sheath to the tendon occurring in chronic cases that can be observed on dynamic ultrasound.<sup>67, 101</sup> Imaging can be useful in the diagnosis of paratendinitis as it can be present in conjunction with tendinosis and needs to be considered during rehabilitation (ie, reducing joint movement and friction between the sheath and tendon).

### **Accuracy, sensitivity, and validity of imaging**

There has been considerable debate of the clinical utility of imaging in tendinopathy. There have been numerous studies that have investigated the accuracy (number of correct imaging diagnoses, both abnormal and normal imaging, divided by the total number of cases) and sensitivity (number of correct abnormal imaging diagnoses divided by the total number of symptomatic cases) of a number of imaging modalities in detecting clinical tendinopathy. A central issue with studies that test the accuracy of imaging is the lack of a valid clinical gold standard. The diagnosis of tendinopathy can be complex due to a confusing clinical picture with few clinical diagnostic tests for tendinopathy. As yet, there is no consensus as to what clinical exam is the gold standard in the diagnosis tendinopathy, with pain on palpation, location of pain and pain during certain movements frequently used as the reference test when testing the accuracy of imaging. However, the accuracy and sensitivity of these measures have been variable<sup>42, 74</sup>. Determining the accuracy of imaging is dependent on how valid the gold standard is. With that yet to be ascertained, caution is advised when assessing the accuracy of imaging in detecting clinical tendinopathy.

A number of studies have investigated the accuracy of imaging in diagnosing tendinopathy. These studies have consistently shown that both ultrasound and MR imaging have good-to-excellent

accuracy (ultrasound: 0.63-0.83, MR imaging: 0.68-0.70), with varying sensitivity (ultrasound: 0.68-0.87 and MR imaging: 0.50-0.57) in detecting clinical tendinopathy.<sup>1, 45, 48, 49, 62, 97</sup> But, caution is required when interpreting the results of these studies as asymptomatic participants are frequently included and their inclusion may result in an over-estimation of the accuracy and sensitivity of imaging in detecting clinical tendinopathy. Participant selection in these studies is critical and future studies need to reflect the use of imaging in the clinical setting (ie, use of imaging to differentiate tendinopathy from other pain conditions in the same anatomical region).

Due to ethical issues in collecting tissue from appropriate controls, most studies have compared imaging to a clinical diagnosis as the gold standard,<sup>49</sup> with few studies comparing findings on imaging to surgical or histological findings. A number of studies have reported variable sensitivity values (0.33-1.00) but good-to-excellent accuracy (0.91-0.95) of imaging compared to surgical findings.<sup>46, 61, 88, 96, 100</sup> For example, Adams et al<sup>1</sup> identified subscapularis tears on MR imaging in 16 patients that were confirmed by arthroscopy, yet 28 patients with subscapularis tears identified arthroscopically had normal MR imaging. Similar findings have been reported for the Achilles tendon where ultrasound diagnosis correlated with surgical findings in approximately 80% of cases,<sup>3, 68</sup> with ultrasound imaging being limited in its ability to differentiate between partial Achilles rupture and local degenerative lesions.<sup>68</sup> Caution is advised extrapolating the accuracy and sensitivity findings of these studies to the diagnosis of tendinopathy as the majority of studies investigated the ability to identify partial tears due to this condition frequently requiring surgery. Shalabi et al<sup>85</sup> found that intratendinous signal observed on dynamic contrast-enhanced MR imaging correlated with the severity of histopathological changes. Histopathological comparison to ultrasound has shown that areas of hypoechogenicity contained significant tendon pathology, with areas adjacent subjectively described as 'normoechoic' also exhibiting pathological changes yet to a lesser extent.<sup>61</sup>

### **Which imaging modality is the gold standard?**

Radiographs and computed tomography scanning have been used to image tendons,<sup>7, 59, 89</sup> however ultrasound and MR imaging are the preferred imaging modalities. MR imaging has excellent soft tissue contrast detail and multi-planar imaging capabilities with excellent reproducibility.<sup>5</sup> However, MR imaging is costly and of limited availability. Advances in ultrasound transducer technology and improvement in the sensitivity of Doppler imaging have increased the utility of ultrasound. However, it is somewhat user-dependent as slight changes in the ultrasound transducer tilt generate imaging artefacts that are similar to those seen with tendon pathology.<sup>73</sup> Ultrasound imaging can focus on an area of pain or clinical suspicion of pathology, whereas MR imaging provides a global assessment of the region of concern.

Few studies have directly compared MR and ultrasound imaging. Westacott et al<sup>100</sup> performed a systematic review and reported that the sensitivity of MR imaging for detecting gluteal tendon tears ranged from 0.33 to 1.00, whereas specificity was consistently high (0.92-1.00). In contrast, ultrasound was found to be a highly sensitive technique (0.79-1.00), suggesting that ultrasound may be used as first-line imaging modality for evaluating gluteal tendon tears. Similarly, previous investigations have reported that ultrasound demonstrates higher sensitivity but lower specificity compared to MR imaging in detecting clinically symptomatic rotator cuff tendinopathy.<sup>99</sup> However, MR imaging has been reported to be superior in the evaluation of various degenerative changes in the Achilles tendon.<sup>61, 63</sup>

There is value in both MR and ultrasound imaging, with the imaging modality to be used being based on patient presentation. MR imaging may be suitable where differential diagnosis is required (eg, visualisation of patellofemoral joint chondral changes mimicking aspects of patellar tendon pain). However, due to the superior spatial resolution of ultrasound in the visualisation of fibrillar alignment and vascularity,<sup>73</sup> ultrasound may better image the internal architecture of the tendon. Ultrasound's ability to provide a dynamic image during active and passive movements may provide further information, especially in differential diagnosis (eg, fat pad or sheath adhesion to the tendon, sciatic nerve tethering to the proximal hamstring tendon).

### **New imaging modalities**

Conventional imaging modalities are criticised for their reliance on subjective interpretation of images. Research has been limited to classifying the tendon as abnormal or normal or using a subjective grading score based on a myriad of pathological features and their severity. Objective quantification of tendon structure has been limited to measurements relating to tendon dimensions (antero-posterior diameter or cross-sectional area) and the percentage cross-sectional area of the hypoechoic lesion. Tendon research may be improved with new imaging techniques that address these limitations and begin to provide information of the mechanical properties of the tendon.

#### *Ultrasound Tissue Characterisation (UTC)*

The aligned fibrillar structure of tendon results in a homogenous echotexture on ultrasound imaging, where the stability in echotexture can be quantified.<sup>4, 60</sup> Ultrasound tissue characterisation (UTC) captures contiguous transverse ultrasound images over the length of the tendon and semi-quantifies the stability of the echotexture over the length of the tendon into 4 echotypes (see van Schie et al<sup>94</sup> for further explanation of the 4 echo-types). Research performed on equine histopathological samples found that UTC echo-types were able to distinguish between different

tissue types (normal, granulation, and fibrotic tissue) where basic grey level statistics could not.<sup>93, 95</sup> The ability to capture a 3-dimensional ultrasound image of the tendon, which standardises parameters that affect the repeatability of conventional ultrasound (ie, tilt transducer angle, depth, and gain settings), and semi-quantification of tendon structure attempts to address the limitations of conventional ultrasound imaging.

While UTC echo-types have not been compared to tendon biopsies in humans due to ethical considerations, the structure of equine and human tendons are similar.<sup>69</sup> Van Schie et al<sup>94</sup> scanned a cross-section of individuals with and without Achilles tendon pain and reported that the percentage of intact and aligned tendon bundles (echo-type I) were reduced in the symptomatic tendon with increases in echo-types that represent disorganised structure (echo-type III and IV). The ability to semi-quantify the structural integrity of the tendon has allowed for classification of the tendon pathology based on a continuum of tendon pathology (**FIGURE 7**), treatment efficacy to be investigated,<sup>21, 23, 24</sup> detection of subtle changes in response to load,<sup>29, 79</sup> and demonstration that the asymptomatic Achilles tendon is structurally compromised in individuals with unilateral tendon pain.<sup>30</sup>

### *Sonoelastography*

Ultrasound elastography is a technique that evaluates the mechanical properties of tissues. Tendon pathology alters mechanical properties, and ultrasound elastography may be of value in improving the diagnostic capability of conventional ultrasound. Ultrasound elastography is based on the principle that tissue displacement in response to external compression produces “strain” within the tissue.<sup>50</sup> Strain is defined as the change in length (displacement) of a tissue relative to its original length in response to the compressive force. Stiffer tissues have lower strain values while softer tissues have higher strain values. A visual strain map overlaid on the conventional B-mode image provides a visual representation of the relative stiffness of tissues (**FIGURE 8**).<sup>25, 26, 66, 91</sup>

Ooi et al<sup>66</sup> imaged 120 patients with Achilles tendinopathy and 120 gender- and age-matched controls. The authors found that combining findings from B-mode ultrasound and ultrasound elastography improved diagnostic sensitivity (0.96), specificity (0.95), and accuracy (0.98), with better clinical correlation ( $k=0.9$ ,  $P<.001$ ) when compared to B-mode and colour Doppler US (sensitivity 0.67, specificity 0.94, accuracy 0.83).<sup>66</sup> Adding ultrasound elastography to conventional ultrasound may improve the association with clinical symptoms. Sonoelastography has previously been used to monitor the Achilles tendon post-rupture,<sup>91</sup> investigate tissue displacement patterns under varying loading conditions,<sup>87</sup> and has been compared to histological specimens.<sup>51</sup>



Future studies are needed to investigate its potential role and applications in management and prevention of tendinopathy.

### **Can imaging predict the onset of pain or clinical outcome?**

A feature and criticism of the use of imaging in individuals with tendinopathy is the poor correlation with the presence of pain and pain severity. Abnormal imaging has been reported in various tendons in as many as 59% of asymptomatic individuals.<sup>8, 13, 34, 37, 41, 48, 52</sup> This reflects the complex nature, and our limited understanding, of tendon pain. Tendon pain is not solely driven by local tissue changes, yet there is likely to be an interaction between the local tissue and the peripheral and central nervous system.<sup>77</sup>

Despite the poor relationship between pathological changes and pain, local tissue changes and the use of imaging in visualising these changes may be important as a prognostic tool. Fredberg et al<sup>35</sup> followed 54 asymptomatic Danish elite soccer players for development of Achilles tendon pain over 12 months. The authors reported that players with substantial imaging changes (thickening and hypoechoic region greater than 2mm in the transverse planes) at baseline had a 3-fold increase in the relative risk of developing symptoms (95% CI, 1.6-4.9). Similarly, Malliaras and Cook<sup>56</sup> reported that abnormal ultrasound imaging of the patellar tendon increased the relative risk of developing pain 15-fold in volleyball players (95% CI, 1.9-111.4). Conversely, Giombini et al<sup>37</sup> who investigated the Achilles, patellar, and quadriceps tendons in 37 asymptomatic elite fencers reported that hypoechoic region predicted future symptoms only in the patellar tendon, not the quadriceps or Achilles tendons.

Sonoelastography has been utilised to investigate the development of Achilles tendon pain in elite Australian football players. Structural and mechanical property changes of the Achilles tendon such as intratendinous delaminations, hypoechoic region, neovascularization, as well as soft tendon properties were present in 52.4% of asymptomatic elite Australian football players (Ooi et al, unpublished data). Increased mid Achilles tendon thickness and cross-sectional area, intratendinous delaminations, and soft tendon texture were significant predictors for future symptoms. This suggests that conventional ultrasound supplemented with ultrasound elastography may identify Australian football players at risk of developing Achilles tendon injuries.

Structural disorganisation observed on imaging should be considered as part of the risk factor profile for tendinopathy similar to that of load, anthropometric factors, and genetics, rather than solely as a diagnostic feature. There is a significant association between polymorphisms within the gene that encodes type V collagen, COL5A1, and the presence of Achilles tendon pain.<sup>83</sup> Collins<sup>11</sup>

states that gene variances are not predictive, but rather increase the risk and susceptibility of developing the injury, similar to the increased risk of developing lung cancer in those with a history of smoking. Men who have smoked cigarettes for up to 20 years have an odds ratio of 7.4 (95% CI, 5.5-9.8) for developing lung cancer.<sup>70</sup> Based on previous cross-sectional studies, abnormal Achilles tendons have odds ratio ranging from 3.9 (95% CI, 1.5-10.2)<sup>49</sup> to 16.2 (95% CI, 6.0-43.3)<sup>52</sup> for the presence of tendon pain. While imaging and the presence of structural abnormalities should never be the sole or predominant tests in the prediction of future tendinopathy, local tissue structure may be a risk factor for the development of symptoms.

### **Monitoring of tendon structure – What can we expect from the tendon?**

When assessing the efficacy of treatments, outcome measures that assess pain and function (VISA-A for the Achilles tendon<sup>78</sup>), return to activity, and structure on imaging have been used. But, as mentioned earlier, assessment of tendon structure has been limited to subjective grading or measurements of tendon dimensions.

Recent studies that have semi-quantified aspects of tendon structure have provided information on how tendons respond structurally to various treatments. Shalabi et al<sup>86</sup> reported a significant decrease in Achilles tendon volume and intratendinous signal following a 3 month eccentric loading program. While improvements in tendon structure were observed, tendon volume and intratendinous signal did not return to normal. Similarly, long-term follow-up (mean of 4.2 years) of the same cohort reported no significant difference in tendon volume compared to baseline measures, despite improvements in pain and function.<sup>36</sup> Furthermore, previous research has found that Achilles tendon structure on UTC is no different after a 16-week eccentric loading program despite improvements in the VISA-A score.<sup>23</sup> The findings of these studies suggest improvements in the tendon are not necessary to facilitate clinical improvement after an eccentric exercise program. A systematic review by Drew et al<sup>32</sup> reported that improvements in pain and function with eccentric exercise were not mediated by changes in tendon structure. In this context, while improvement in, or normalisation of, tendon structure is a positive result, it is not necessary for improvement in pain and function, suggesting that the pathological tendon may have adapted to become, and remain, load tolerant.

While some interventions aim to regenerate and remodel structure within the tendon (eg, platelet-rich plasma, stem cells, autologous tenocyte implantation) this may not be a necessary goal. Pathological Achilles and patellar tendons demonstrate an increased mean cross-sectional area of aligned fibrillar structure compared to structurally normal tendons.<sup>28</sup> Therefore, it appears that the

pathological tendon maintains sufficient amounts of aligned fibrillar structure by increasing tendon dimensions (anteriorposterior diameter and total mean cross-sectional area) in parallel with the mean cross-sectional area of disorganisation (ie, the more disorganisation the bigger the tendon). The increase in tendon dimensions may be a mechanism by which the pathological tendon maintains sufficient mean cross-sectional area aligned fibrillar structure to still tolerate load. Interventions such as eccentric exercise may not be efficacious in remodelling the area of pathology, rather these loading protocols may cause adaptation and increase the loading capacity of the surrounding aligned fibrillar structure.

In the context of previous research, stability in tendon structure accompanied by improvements in pain and function can be considered a positive outcome. Interestingly, progression of rotator cuff tears was found to be related to an increase risk of symptom manifestation compared to those that remained stable over time.<sup>55</sup> Future research is needed to investigate whether tendons that remain stable, in terms of extent of pathology, have a better clinical outcome to those that worsen over time.

### **Future directions for research**

Load is a critical factor in the development of tendinopathy, and numerous investigators are using imaging to improve our understanding of how tendons respond to load. Grigg et al<sup>39</sup> reported an acute response in the Achilles tendon where anteriorposterior diameter reduced immediately after eccentric exercise and was restored after 24 hours. UTC has been used to detect a short-term temporal response in the Achilles tendon<sup>79</sup> and superficial digital flexor tendon of the horse<sup>29</sup> where a loss of aligned fibrillar structure was observed 48hrs post-maximal load, which returned to baseline at 3-4 days. This is consistent with other studies that have reported a short term response in hydration level using off-resonance saturation MR imaging,<sup>90</sup> tendon volume and intratendinous signal on MR imaging,<sup>84</sup> and microvascular volume using real-time harmonic contrast-enhance ultrasound<sup>71</sup> in response to load. Of interest, these studies reported an altered response in tendinopathic tendons.<sup>39, 71, 79</sup>

These new and novel imaging modalities may provide insight in how tendons respond to load. There is overwhelming evidence that structural disorganisation predates the development of symptoms and tendon rupture.<sup>48, 58</sup> These new imaging modalities may help to define loading parameters that result in structural disorganisation and identify the point where tendon load exceeds the tendon capacity.

### **Proposed clinical role of imaging in tendinopathy**

In answering the question we posed in the title, imaging is not telling us the entire picture in tendinopathy. The role of imaging in the clinical setting may be somewhat limited as it does not directly relate to symptoms. Imaging allows for the visualisation of structure, it does not represent the entire clinical picture and should not be used as the sole diagnostic criteria in determining whether the clinical presentation is generated by the tendon. While imaging may not tell us the entire picture, just like pain on palpation gives us little information on muscular strength and endurance, it provides important information around structure. While not discussed as part of this review, imaging may be useful in differential diagnosis (eg, detection of an invaginated plantaris tendon,<sup>2</sup> paratenonitis) where treatment may need to be altered to address the specific condition.

As has been consistently stated throughout this narrative review, imaging needs to be placed in the context of the overall clinical picture and, despite the risk of potential bias, this may be enhanced by the clinician performing the imaging themselves (specifically ultrasound). However, caution is advised with the potential for imaging in the clinician's hands to confuse the clinical picture and lead to poor outcomes due to technical insufficiencies. As stated above, ultrasound is highly user-dependent with specifically trained musculoskeletal radiologists able to produce high quality images that may provide more clinically relevant information than in the hands of a clinician with less experience in imaging. The converse to this discussion would be that in an attempt to improve the clinical utility of imaging, the radiologist may need to concern themselves further with the unique clinical presentation of tendinopathy. There is definitely scope for the specialised musculoskeletal radiologist with a special interest in tendon imaging to take their own detailed history beyond the referral note. Whether it is the clinician having a role in imaging or the radiologist taking detailed clinical history themselves, there is a need for the sharing of skills and clear dialogue between the two fields to enhance the clinical utility of imaging.

In testing the efficacy of treatments or monitoring the improvement of clinical symptoms using imaging, a potential shift away from focusing on improving tendon structure may be needed. As clinical improvements have been shown not to be mediated by structural changes, stability in tendon structure may be a positive outcome in the clinical context of reduced pain and dysfunction. Currently, we are limited by conventional imaging modalities reliance on subjective interpretation. The development of new imaging techniques that utilise more quantifiable parameters, such as UTC or sonoelastography, will hopefully enhance our ability to diagnosis, predict the development of symptoms, and monitor the efficacy of treatments.

## **Acknowledgements**

Sean Docking is supported by the Australian Centre for Research into Sports Injury and its Prevention, which is one of the International Research Centres for Prevention of Injury and Protection of Athlete Health supported by the International Olympic Committee.

1. Adams, CR, JD Schoolfield, and SS Burkhart, Accuracy of preoperative magnetic resonance imaging in predicting a subscapularis tendon tear based on arthroscopy. *Arthroscopy*, 2010;26(11):1427-33.
2. Alfredson, H, Midportion Achilles tendinosis and the plantaris tendon. *Br Journal Sports Med*, 2011;45(13):1023-5.
3. Astrom, M, CF Gentz, P Nilsson, A Rausing, S Sjoberg, and N Westlin, Imaging in chronic achilles tendinopathy: a comparison of ultrasonography, magnetic resonance imaging and surgical findings in 27 histologically verified cases. *Skeletal Radiol*, 1996;25(7):615-20.
4. Bashford, GR, N Tomsen, S Arya, JM Burnfield, and K Kulig, Tendinopathy discrimination by use of spatial frequency parameters in ultrasound B-mode images. *IEEE Trans Med Imaging*, 2008;27(5):608-15.
5. Bleakney, RR and LM White, Imaging of the Achilles tendon. *Foot Ankle Clin*, 2005;10(2):239-54.
6. Boesen, MI, A Boesen, MJ Koenig, H Bliddal, and S Torp-Pedersen, Ultrasonographic investigation of the Achilles tendon in elite badminton players using color Doppler. *Am J Sports Med*, 2006;34(12):2013-21.
7. Bolton, NR, KE Smith, TK Pilgram, MJ Mueller, and KT Bae, Computed tomography to visualize and quantify the plantar aponeurosis and flexor hallucis longus tendon in the diabetic foot. *Clin Biomech (Bristol, Avon)*, 2005;20(5):540-6.
8. Brasseur, JL, O Lucidarme, M Tardieu et al., Ultrasonographic rotator-cuff changes in veteran tennis players: the effect of hand dominance and comparison with clinical findings. *Eur Radiol*, 2004;14(5):857-64.
9. Calleja, M and DA Connell, The Achilles tendon. *Semin Musculoskelet Radiol*, 2010;14(3):307-22.
10. Clegg, PD, S Strassburg, and RK Smith, Cell phenotypic variation in normal and damaged tendons. *Int J Exp Pathol*, 2007;88(4):227-35.
11. Collins, M, Genetic risk factors for soft-tissue injuries 101: a practical summary to help clinicians understand the role of genetics and 'personalised medicine'. *Br Journal Sports Med*, 2010;44(13):915-7.
12. Comin, J, JL Cook, P Malliaras et al., The prevalence and clinical significance of sonographic tendon abnormalities in asymptomatic ballet dancers: a 24-month longitudinal study. *Br J Sports Med*, 2013;47(2):89-92.
13. Cook, J, K Khan, P Harcourt et al., Patellar tendon ultrasonography in asymptomatic active athletes reveals hypoechoic regions: a study of 320 tendons. Victorian Institute of Sport Tendon Study Group. *Clin J Sport Med*, 1998;8(2):73-7.
14. Cook, JL, JA Feller, SF Bonar, and KM Khan, Abnormal tenocyte morphology is more prevalent than collagen disruption in asymptomatic athletes' patellar tendons. *J Orthop Res*, 2004;22(2):334-8.
15. Cook, JL, KM Khan, and C Purdam, Achilles tendinopathy. *Manual Therapy*, 2002;7(3):121-30.
16. Cook, JL, ZS Kiss, R Ptasznik, and P Malliaras, Is vascularity more evident after exercise? Implications for tendon imaging. *AJR Am J Roentgenol*, 2005;185(5):1138-40.
17. Cook, JL, P Malliaras, J De Luca, R Ptasznik, and M Morris, Vascularity and pain in the patellar tendon of adult jumping athletes: a 5 month longitudinal study. *Br J Sports Med*, 2005;39(7):458-61; discussion 458-61.
18. Cook, JL, P Malliaras, J De Luca, R Ptasznik, ME Morris, and P Goldie, Neovascularization and pain in abnormal patellar tendons of active jumping athletes. *Clin J Sport Med*, 2004;14(5):296-9.
19. Cook, JL and CR Purdam, Is tendon pathology a continuum? A pathology model to explain the clinical presentation of load-induced tendinopathy. *Br J Sports Med*, 2009;43(6):409-16.

20. Corps, AN, AH Robinson, T Movin, ML Costa, BL Hazleman, and GP Riley, Increased expression of aggrecan and biglycan mRNA in Achilles tendinopathy. *Rheumatology (Oxford)*, 2006;45(3):291-4.
21. de Jonge, S, RJ de Vos, A Weir et al., One-year follow-up of platelet-rich plasma treatment in chronic Achilles tendinopathy: a double-blind randomized placebo-controlled trial. *Am J Sports Med*, 2011;39(8):1623-9.
22. De Jonge, S, JL Warnaaars, RJ De Vos et al., Relationship between neovascularization and clinical severity in Achilles tendinopathy in 556 paired measurements. *Scand J Med Sci Sports*, 2013.
23. de Vos, RJ, MP Heijboer, H Weinans, JA Verhaar, and JT van Schie, Tendon structure's lack of relation to clinical outcome after eccentric exercises in chronic midportion Achilles tendinopathy. *J Sport Rehabil*, 2012;21(1):34-43.
24. de Vos, RJ, A Weir, JL Tol, JA Verhaar, H Weinans, and HT van Schie, No effects of PRP on ultrasonographic tendon structure and neovascularisation in chronic midportion Achilles tendinopathy. *Br J Sports Med*, 2011;45(5):387-92.
25. De Zordo, T, R Chhem, V Smekal et al., Real-time sonoelastography: findings in patients with symptomatic achilles tendons and comparison to healthy volunteers. *Ultraschall Med*, 2010;31(4):394-400.
26. De Zordo, T, C Fink, GM Feuchtner, V Smekal, M Reindl, and AS Klauser, Real-time sonoelastography findings in healthy Achilles tendons. *Am J Roentgenol*, 2009;193(2):W134-8.
27. Divani, K, O Chan, N Padhiar et al., Site of maximum neovascularisation correlates with the site of pain in recalcitrant mid-tendon Achilles tendinopathy. *Man Ther*, 2010;15(5):463-8.
28. Docking, S and J Cook, Tendon size increases in parallel with tendon disorganisation: Evidence of tendon remodelling to maintain adequate levels of aligned fibres. *Br J Sports Med*, 2014;48(Suppl 2).
29. Docking, SI, J Daffy, HT van Schie, and JL Cook, Tendon structure changes after maximal exercise in the Thoroughbred horse: use of ultrasound tissue characterisation to detect in vivo tendon response. *Vet J*, 2012;194(3):338-42.
30. Docking, SI, SD Rosengarten, J Daffy, and J Cook, Structural integrity is decreased in both Achilles tendons in people with unilateral Achilles tendinopathy. *J Sci Med Sport*, 2014.
31. Dowling, BA, AJ Dart, DR Hodgson, and RK Smith, Superficial digital flexor tendonitis in the horse. *Equine Vet J*, 2000;32(5):369-78.
32. Drew, BT, TO Smith, C Littlewood, and B Sturrock, Do structural changes (eg, collagen/matrix) explain the response to therapeutic exercises in tendinopathy: a systematic review. *Br J Sports Med*, 2014;48(12):966-72.
33. du Toit, C, M Stieler, R Saunders, L Bisset, and B Vicenzino, Diagnostic accuracy of power Doppler ultrasound in patients with chronic tennis elbow. *Br J Sports Med*, 2008;42(11):872-6.
34. Fredberg, U and L Bolvig, Significance of ultrasonographically detected asymptomatic tendinosis in the patellar and achilles tendons of elite soccer players: a longitudinal study. *Am J Sports Med*, 2002;30(4):488-91.
35. Fredberg, U, L Bolvig, and NT Andersen, Prophylactic training in asymptomatic soccer players with ultrasonographic abnormalities in Achilles and patellar tendons: the Danish Super League Study. *Am J Sports Med*, 2008;36(3):451-60.
36. Gardin, A, T Movin, L Svensson, and A Shalabi, The long-term clinical and MRI results following eccentric calf muscle training in chronic Achilles tendinosis. *Skeletal Radiol*, 2010;39(5):435-42.
37. Giombini, A, S Dragoni, A Di Cesare, M Di Cesare, A Del Buono, and N Maffulli, Asymptomatic Achilles, patellar, and quadriceps tendinopathy: A longitudinal clinical and ultrasonographic study in elite fencers. *Scand J Med Sci Sports*, 2011.

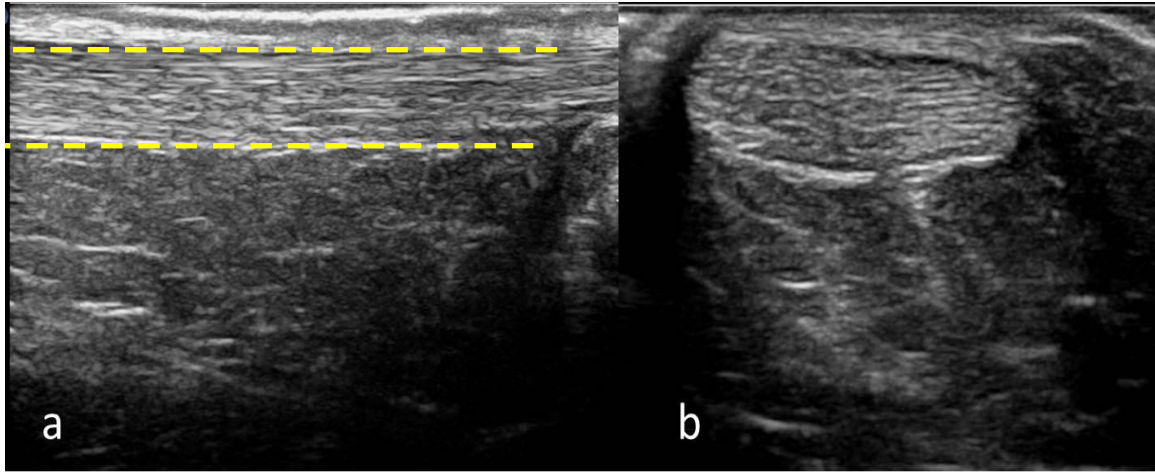
38. Gisslen, K and H Alfredson, Neovascularisation and pain in jumper's knee: a prospective clinical and sonographic study in elite junior volleyball players. *Br J Sports Med*, 2005;39(7):423-8; discussion 423-8.
39. Grigg, NL, SC Wearing, and JE Smeathers, Achilles tendinopathy has an aberrant strain response to eccentric exercise. *Med Sci Sports Exerc*, 2012;44(1):12-7.
40. Grosse, U, R Syha, P Martirosian et al., Ultrashort echo time MR imaging with off-resonance saturation for characterization of pathologically altered Achilles tendons at 3 T. *Magn Reson Med*, 2013;70(1):184-92.
41. Hirschmuller, A, V Frey, L Konstantinidis et al., Prognostic value of Achilles tendon Doppler sonography in asymptomatic runners. *Med Sci Sports and Exerc*, 2012;44(2):199-205.
42. Hutchison, AM, R Evans, O Bodger et al., What is the best clinical test for Achilles tendinopathy? *Foot Ankle Surg*, 2013;19(2):112-7.
43. Ingber, DE, Control of capillary growth and differentiation by extracellular matrix. Use of a tensegrity (tensional integrity) mechanism for signal processing. *Chest*, 1991;99(3 Suppl):34S-40S.
44. Kainberger, F, F Mittermaier, G Seidl, E Parth, and R Weinstabl, Imaging of tendons--adaptation, degeneration, rupture. *Eur J Radiol*, 1997;25(3):209-22.
45. Kainberger, FM, A Engel, P Barton, P Huebsch, A Neuhold, and E Salomonowitz, Injury of the Achilles tendon: diagnosis with sonography. *AJR Am J Roentgenol*, 1990;155(5):1031-6.
46. Kalebo, P, C Allenmark, L Peterson, and L Sward, Diagnostic value of ultrasonography in partial ruptures of the Achilles tendon. *Am J Sports Med*, 1992;20(4):378-81.
47. Khan, KM, JL Cook, F Bonar, P Harcourt, and M Astrom, Histopathology of common tendinopathies. Update and implications for clinical management. *Sports Med*, 1999;27(6):393-408.
48. Khan, KM, JL Cook, ZS Kiss et al., Patellar tendon ultrasonography and jumper's knee in female basketball players: a longitudinal study. *Clin J Sport Med*, 1997;7(3):199-206.
49. Khan, KM, BB Forster, J Robinson et al., Are ultrasound and magnetic resonance imaging of value in assessment of Achilles tendon disorders? A two year prospective study. *Br J Sports Med*, 2003;37(2):149-53.
50. Klauser, AS, R Faschingbauer, and WR Jaschke, Is sonoelastography of value in assessing tendons? *Semin Musculoskelet Radiol*, 2010;14(3):323-33.
51. Klauser, AS, H Miyamoto, M Tamegger et al., Achilles tendon assessed with sonoelastography: histologic agreement. *Radiology*, 2013;267(3):837-42.
52. Leung, JL and JF Griffith, Sonography of chronic Achilles tendinopathy: a case-control study. *J Clin Ultrasound*, 2008;36(1):27-32.
53. Maffulli, N, KM Khan, and G Puddu, Overuse tendon conditions: time to change a confusing terminology. *Arthroscopy*, 1998;14(8):840-3.
54. Maffulli, N, UG Longo, F Franceschi, C Rabitti, and V Denaro, Movin and Bonar scores assess the same characteristics of tendon histology. *Clin Orthop Relat Res*, 2008;466(7):1605-11.
55. Mall, NA, HM Kim, JD Keener et al., Symptomatic progression of asymptomatic rotator cuff tears: a prospective study of clinical and sonographic variables. *J Bone Joint Surg Am*, 2010;92(16):2623-33.
56. Malliaras, P and J Cook, Patellar tendons with normal imaging and pain: change in imaging and pain status over a volleyball season. *Clin J Sport Med*, 2006;16(5):388-91.
57. Malliaras, P, C Purdam, N Maffulli, and JL Cook, Temporal sequence of gray-scale ultrasound changes and their relationship with neovascularity and pain in the patellar tendon. *Br J Sports Med*, 2010;44(13):944-7.
58. Malliaras, P, C Voss, G Garau, P Richards, and N Maffulli, Achilles tendon shape and echogenicity on ultrasound among active badminton players. *Scand J Med Sci Sports*, 2012;22(2):149-55.



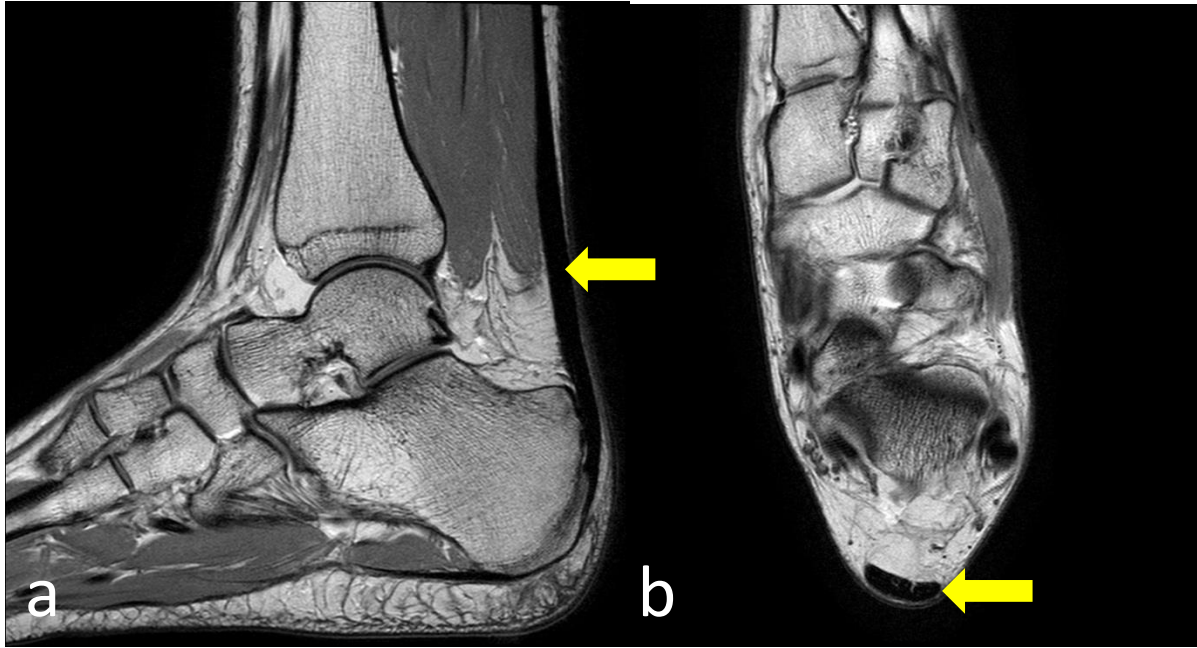
59. Mallinson, PI, C Stevens, C Reisinger, S Nicolaou, PL Munk, and H Ouellette, Achilles tendinopathy and partial tear diagnosis using dual-energy computed tomography collagen material decomposition application. *J Comput Assist Tomogr*, 2013;37(3):475-7.
60. Meghroufel, A, G Cloutier, N Crevier-Denoix, and JA de Guise, Tissue characterization of equine tendons with clinical B-scan images using a shock filter thinning algorithm. *IEEE Trans Med Imaging*, 2011;30(3):597-605.
61. Movin, T, M Kristoffersen-Wiberg, A Shalabi, A Gad, P Aspelin, and C Rolf, Intratendinous alterations as imaged by ultrasound and contrast medium-enhanced magnetic resonance in chronic achillobodynia. *Foot Ankle Int*, 1998;19(5):311-7.
62. Nehrer, S, M Breitenseher, W Brodner et al., Clinical and sonographic evaluation of the risk of rupture in the Achilles tendon. *Arch Orthop Trauma Surg*, 1997;116(1-2):14-8.
63. Neuhold, A, M Stiskal, F Kainberger, and B Schwaighofer, Degenerative Achilles tendon disease: assessment by magnetic resonance and ultrasonography. *Eur J Radiol*, 1992;14(3):213-20.
64. O'Brien, M, Structure and metabolism of tendons. *Scand J Med Sci Sports*, 1997;7(2):55-61.
65. Ohberg, L, R Lorentzon, and H Alfredson, Neovascularisation in Achilles tendons with painful tendinosis but not in normal tendons: an ultrasonographic investigation. *Knee Surg Sports Traumatol Arthrosc*, 2001;9(4):233-8.
66. Ooi, C, M Schneider, P Malliaras, M Chadwick, and D Connell. Diagnostic performance of sonoelastography in confirming clinically diagnosed achilles tendinopathy: Comparison with B-mode ultrasound and color doppler imaging. 2014 Combined Scientific Meeting - Imaging and Radiation in Personalised Medicine. Melbourne, Australia: 2014.
67. Paavola, M and TA Jarvinen, Paratendinopathy. *Foot Ankle Clin*, 2005;10(2):279-92.
68. Paavola, M, T Paakkala, P Kannus, and M Jarvinen, Ultrasonography in the differential diagnosis of Achilles tendon injuries and related disorders. A comparison between pre-operative ultrasonography and surgical findings. *Acta Radiologica*, 1998;39(6):612-9.
69. Patterson-Kane, JC and T Rich, Achilles tendon injuries in elite athletes: lessons in pathophysiology from their equine counterparts. *ILAR J*, 2014;55(1):86-99.
70. Pesch, B, B Kendzia, P Gustavsson et al., Cigarette smoking and lung cancer--relative risk estimates for the major histological types from a pooled analysis of case-control studies. *Int J Cancer*, 2012;131(5):1210-9.
71. Pingel, J, A Harrison, L Simonsen, C Suetta, J Bulow, and H Langberg, The microvascular volume of the Achilles tendon is increased in patients with tendinopathy at rest and after a 1-hour treadmill run. *Am J Sports Med*, 2013;41(10):2400-8.
72. Puddu, G, E Ippolito, and F Postacchini, A classification of Achilles tendon disease. *Am J Sports Med*, 1976;4(4):145-50.
73. Rasmussen, OS, Sonography of tendons. *Scand J Med Sci Sports*, 2000;10(6):360-4.
74. Reiman, M, C Burgi, E Strube et al., The utility of clinical measures for the diagnosis of achilles tendon injuries: a systematic review with meta-analysis. *J Athl Train*, 2014;49(6):820-9.
75. Reinus, WR, KL Shady, SA Mirowitz, and WG Totty, MR diagnosis of rotator cuff tears of the shoulder: value of using T2-weighted fat-saturated images. *AJR American Journal of Roentgenol*, 1995;164(6):1451-5.
76. Riley, GP, RL Harrall, CR Constant, MD Chard, TE Cawston, and BL Hazleman, Tendon degeneration and chronic shoulder pain: changes in the collagen composition of the human rotator cuff tendons in rotator cuff tendinitis. *Ann Rheum Dis*, 1994;53(6):359-66.
77. Rio, E, L Moseley, C Purdam et al., The pain of tendinopathy: physiological or pathophysiological? *Sports Med*, 2014;44(1):9-23.
78. Robinson, JM, JL Cook, C Purdam et al., The VISA-A questionnaire: a valid and reliable index of the clinical severity of Achilles tendinopathy. *Br J Sports Med*, 2001;35(5):335-41.

79. Rosengarten, SD, JL Cook, AL Bryant, JT Cordy, J Daffy, and SI Docking, Australian football players' Achilles tendons respond to game loads within 2 days: an ultrasound tissue characterisation (UTC) study. *Br J Sports Med*, 2014.
80. Samiric, T, J Parkinson, MZ Ilic, J Cook, JA Feller, and CJ Handley, Changes in the composition of the extracellular matrix in patellar tendinopathy. *Matrix Biol*, 2009;28(4):230-6.
81. Scott, A, S Docking, B Vicenzino et al., Sports and exercise-related tendinopathies: a review of selected topical issues by participants of the second International Scientific Tendinopathy Symposium (ISTS) Vancouver 2012. *Br J Sports Med*, 2013;47(9):536-44.
82. Screen, HRC, JC Shelton, VH Chhaya, MV Kayser, DL Bader, and DA Lee, The influence of noncollagenous matrix components on the micromechanical environment of tendon fascicles. *Ann Biomed Eng*, 2005;33(8):1090-9.
83. September, AV, J Cook, CJ Handley, L van der Merwe, MP Schwellnus, and M Collins, Variants within the COL5A1 gene are associated with Achilles tendinopathy in two populations. *Br J Sports Med*, 2009;43(5):357-65.
84. Shalabi, A, M Kristoffersen-Wiberg, P Aspelin, and T Movin, Immediate Achilles tendon response after strength training evaluated by MRI. *Med Sci Sports Exerc*, 2004;36(11):1841-6.
85. Shalabi, A, M Kristoffersen-Wiberg, N Papadogiannakis, P Aspelin, and T Movin, Dynamic contrast-enhanced mr imaging and histopathology in chronic achilles tendinosis. A longitudinal MR study of 15 patients. *Acta Radiol*, 2002;43(2):198-206.
86. Shalabi, A, M Kristoffersen-Wilberg, L Svensson, P Aspelin, and T Movin, Eccentric training of the gastrocnemius-soleus complex in chronic Achilles tendinopathy results in decreased tendon volume and intratendinous signal as evaluated by MRI. *Am J Sports Med*, 2004;32(5):1286-96.
87. Slane, LC and DG Thelen, Non-uniform displacements within the Achilles tendon observed during passive and eccentric loading. *J Biomech*, 2014;47(12):2831-5.
88. Smith, TO, T Back, AP Toms, and CB Hing, Diagnostic accuracy of ultrasound for rotator cuff tears in adults: a systematic review and meta-analysis. *Clin Radiol*, 2011;66(11):1036-48.
89. Sundararajan, PP and TS Wilde, Radiographic, clinical, and magnetic resonance imaging analysis of insertional Achilles tendinopathy. *J Foot Ankle Surg*, 2014;53(2):147-51.
90. Syha, R, F Springer, G Grozinger et al., Short-term exercise-induced changes in hydration state of healthy achilles tendons can be visualized by effects of off-resonant radiofrequency saturation in a three-dimensional ultrashort echo time MRI sequence applied at 3 tesla. *J Magn Reson Imaging*, 2013.
91. Tan, S, S Kudas, AS Ozcan et al., Real-time sonoelastography of the Achilles tendon: pattern description in healthy subjects and patients with surgically repaired complete ruptures. *Skeletal Radiol*, 2012;41(9):1067-72.
92. Thorpe, CT, HL Birch, PD Clegg, and HR Screen, The role of the non-collagenous matrix in tendon function. *Int J Exp Pathol*, 2013;94(4):248-59.
93. van Schie, HT, EM Bakker, AM Jonker, and PR van Weeren, Ultrasonographic tissue characterization of equine superficial digital flexor tendons by means of gray level statistics. *Am J Vet Res*, 2000;61(2):210-9.
94. van Schie, HT, RJ de Vos, S de Jonge et al., Ultrasonographic tissue characterisation of human Achilles tendons: quantification of tendon structure through a novel non-invasive approach. *Br J Sports Med*, 2010;44(16):1153-9.
95. van Schie, HTM, EM Bakker, AM Jonker, and PR van Weeren, Computerized ultrasonographic tissue characterization of equine superficial digital flexor tendons by means of stability quantification of echo patterns in contiguous transverse ultrasonographic images. *Am J Vet Res*, 2003;64(3):366-75.

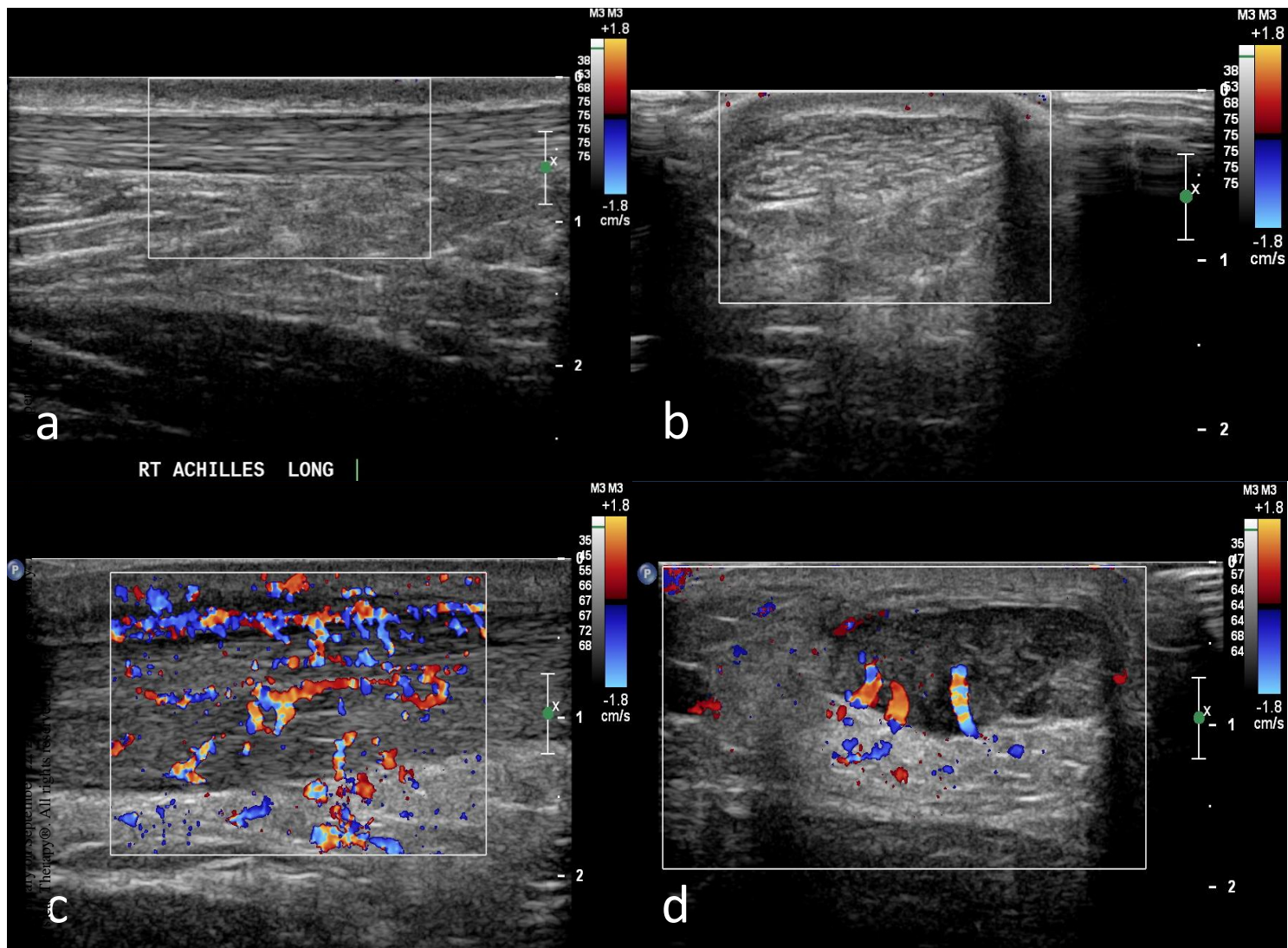
96. Vlychou, M, Z Dailiana, A Fotiadou, M Papanagiotou, IV Fezoulidis, and K Malizos, Symptomatic partial rotator cuff tears: diagnostic performance of ultrasound and magnetic resonance imaging with surgical correlation. *Acta Radiol*, 2009;50(1):101-5.
97. Warden, SJ, ZS Kiss, FA Malara, ABT Ooi, JL Cook, and KM Crossley, Comparative accuracy of magnetic resonance imaging and ultrasonography in confirming clinically diagnosed patellar tendinopathy. *Am J Sports Med*, 2007;35(3):427-36.
98. Weinberg, EP, MJ Adams, and GM Hollenberg, Color Doppler sonography of patellar tendinosis. *AJR Am J Roentgenol*, 1998;171(3):743-4.
99. Weinreb, JH, C Sheth, J Apostolakos et al., Tendon structure, disease, and imaging. *Muscle Ligaments Tendons J*, 2014;4(1):66-73.
100. Westacott, DJ, JI Minns, and P Foguet, The diagnostic accuracy of magnetic resonance imaging and ultrasonography in gluteal tendon tears--a systematic review. *Hip Int*, 2011;21(6):637-45.
101. Wijesekera, NT, JD Calder, and JC Lee, Imaging in the assessment and management of Achilles tendinopathy and paratendinitis. *Semin Musculoskelet Radiol*, 2011;15(1):89-100.



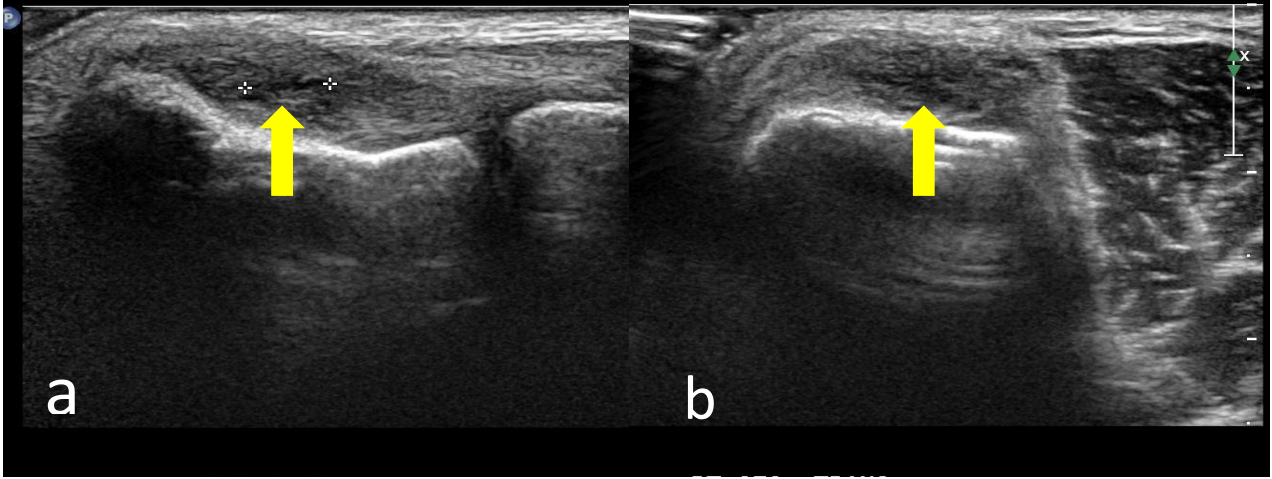
**FIGURE 1.** Ultrasound of a healthy Achilles tendon. **(a)** Longitudinal and **(b)** transverse ultrasound images of the mid Achilles tendon. The normal tendon texture appears homogeneous with parallel echogenic lines reflecting the internal fibrillar structure of the tendon. The dashed yellow lines represent the superficial and deep borders of the tendon.



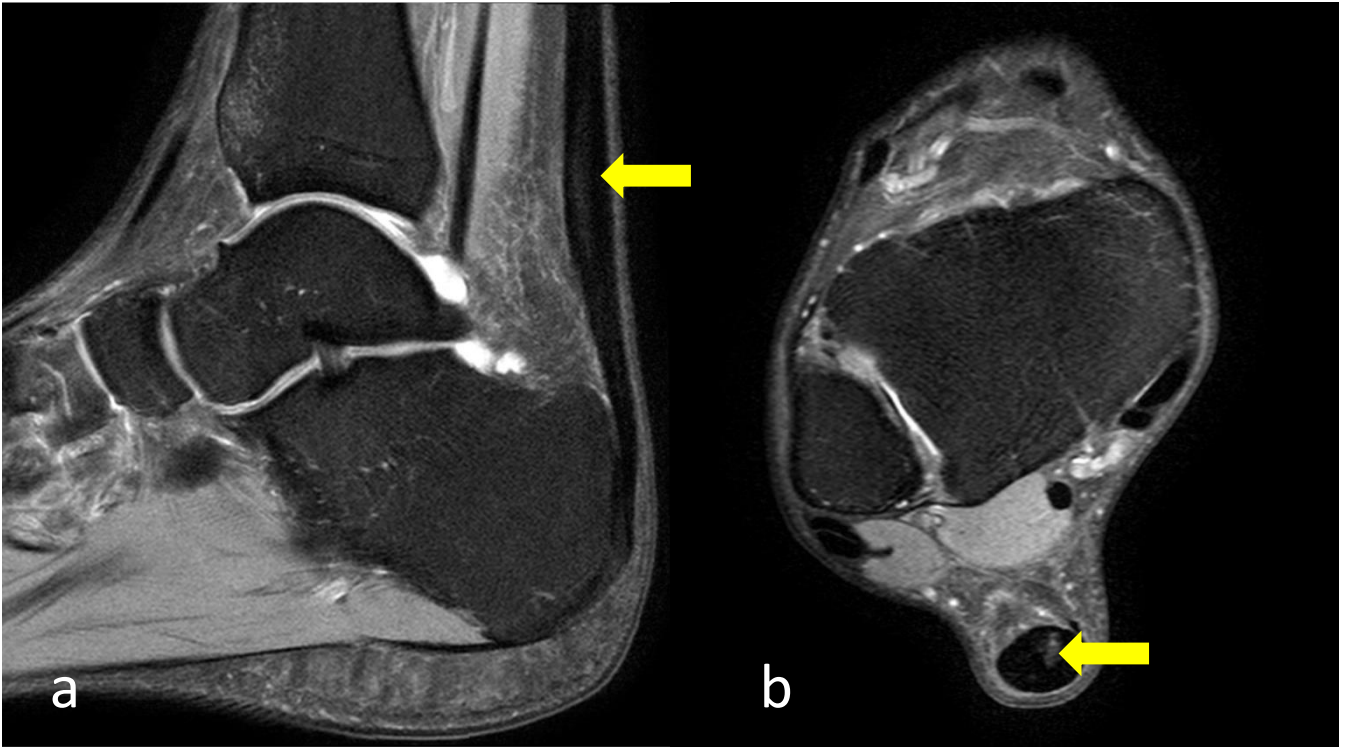
**FIGURE 2.** Magnetic resonance (MR) imaging of the normal Achilles tendon. (a) Sagittal and (b) axial proton-density weighted sequence MR image showing a normal Achilles tendon (arrow) with uniform thickness and predominantly low signal intensity.



**FIGURE 3.** Ultrasound image of the Achilles tendon with colour Doppler. Longitudinal (a) and transverse (b) image of a normal, asymptomatic Achilles tendon, showing normal tendon echotexture with no Doppler signal. Longitudinal (c) and transverse (d) image of a symptomatic Achilles tendon showing significant thickening of the tendon and the presence of hypoechoic changes. Significant Doppler signal is also apparent within the tendon.

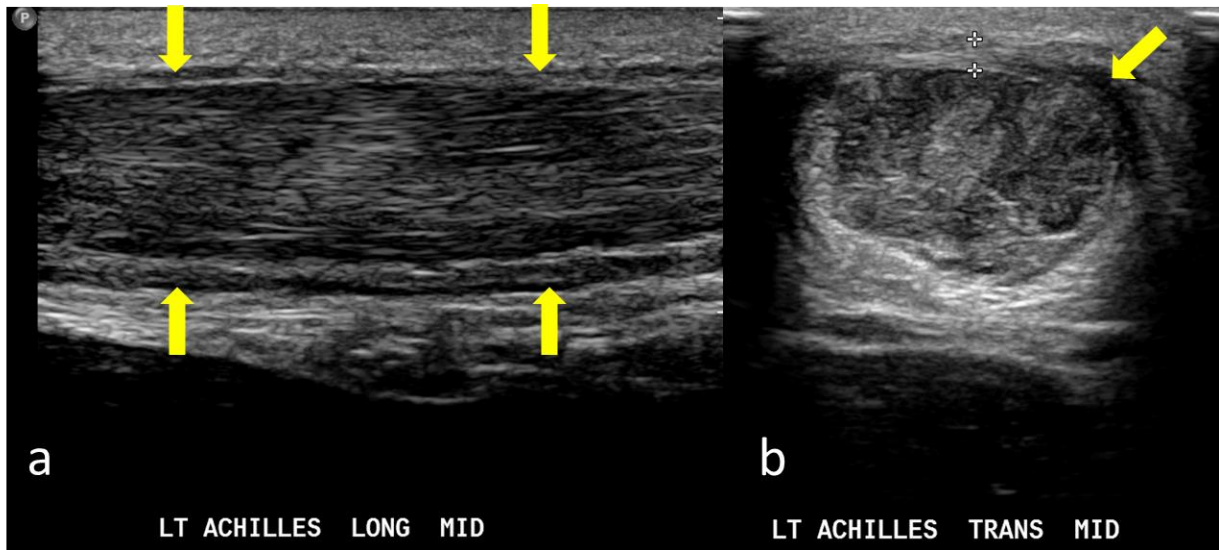


**FIGURE 4.** Ultrasound image of a pathological common extensor tendon of the elbow. Longitudinal (a) and transverse (b) images reveal a focal intratendinous hypoechoic lesion (yellow arrow)

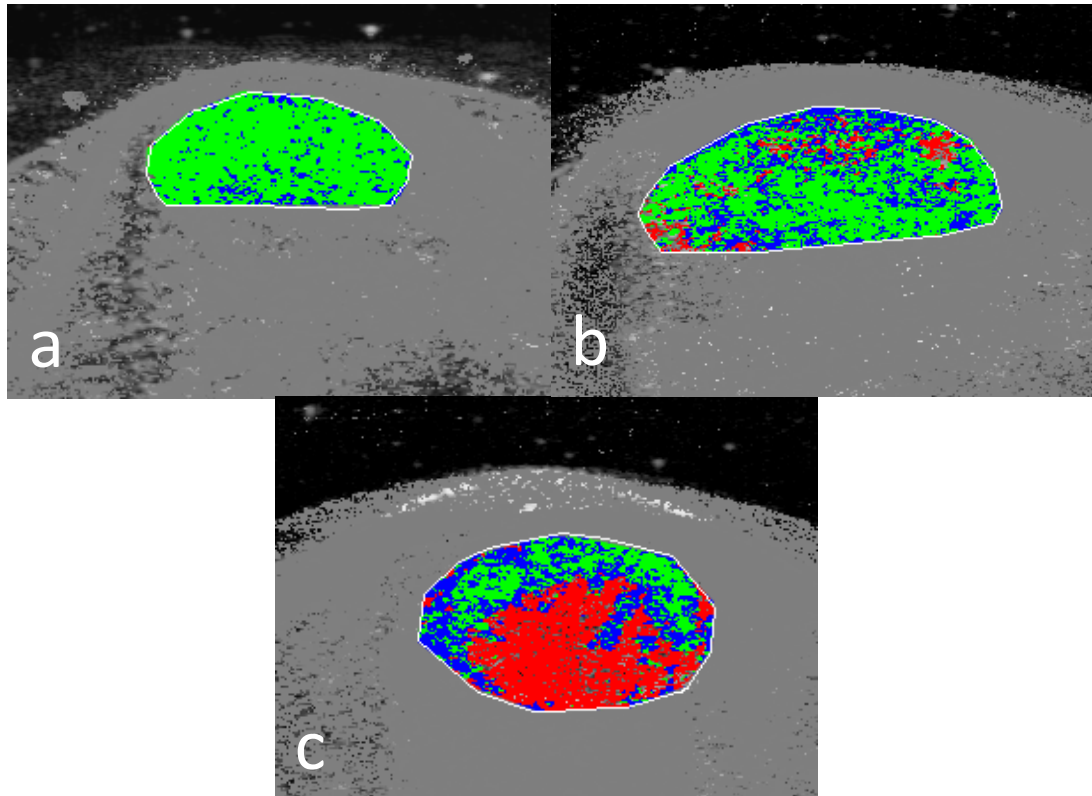


**FIGURE 5.** Magnetic resonance (MR) imaging of an abnormal Achilles tendon. Longitudinal (a) and transverse (b) image reveal increased signal intensity (yellow arrow) within the midsubstance of the tendon.

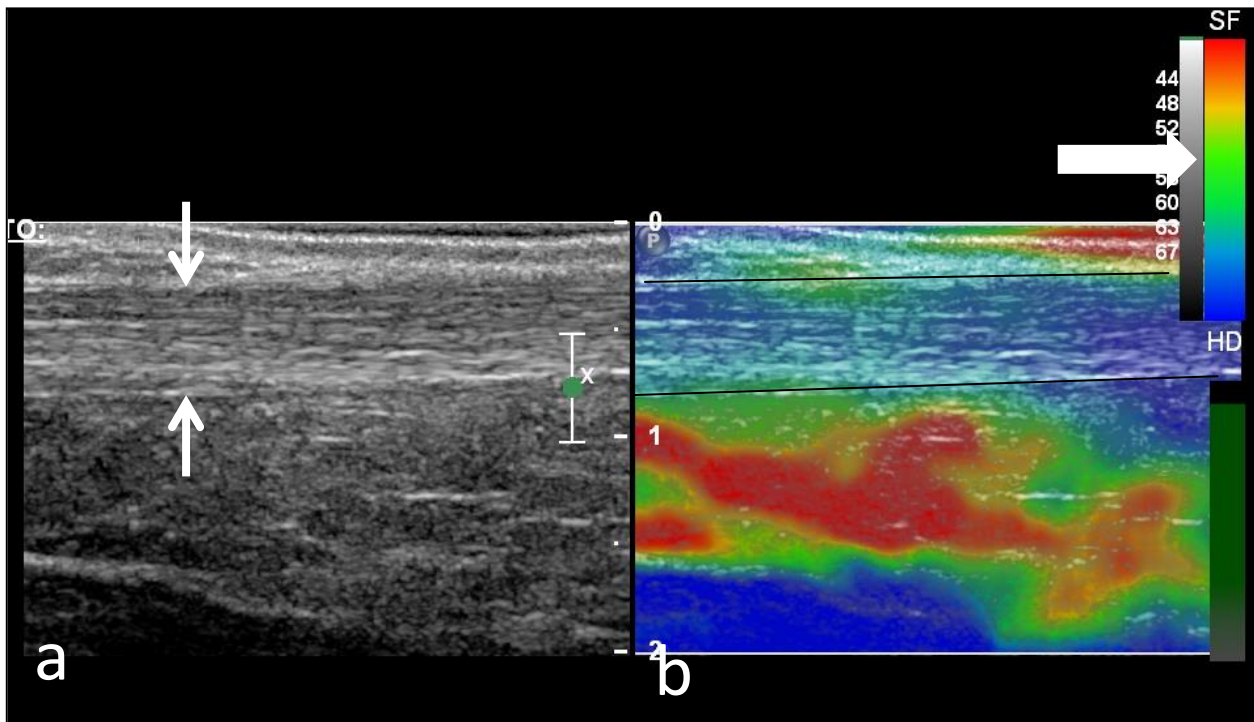




**FIGURE 6.** Paratenonitis. Longitudinal (a) and transverse (b) ultrasound images of the Achilles tendon showing thickened and edematous paratenon (arrows) surrounding the tendon. Background of thickened, hypoechoic and heterogeneous Achilles tendon.



**FIGURE 7.** Ultrasound tissue characterization (UTC) of the Achilles tendon midsubstance. **(a)** Normal Achilles tendon characterised by a high proportion of echo-type I (green pixels) representing aligned tendon bundles. **(b)** Reactive tendinopathy due to tendon thickening and the presence of diffuse speckling of echo-type II (blue pixels) and echo-type III (red pixels). **(c)** Degenerative tendinopathy indicated by significant focal area of echo-type III (red pixels).



**FIGURE 8.** Dual mode display of B-mode ultrasound (**a**) and sonoelastogram (**b**) of a 25 year-old male. (**a**) Longitudinal B-mode ultrasound displays the normal homogeneous, linear fibrillar echo pattern of the mid Achilles tendon (arrows). (**b**) Corresponding sonoelastogram shows blue-coloured Achilles tendon (between lines, b) overlaid on the conventional B-mode image which represents normal, stiff tendon structure. Elastography colour map bar is shown on the right upper corner of the image (arrow).