Sonoelastography in the evaluation of painful Achilles tendon in amateur athletes

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Abstract

Objectives

The purpose of our paper was to evaluate by sonoelastography the Achilles tendon of asymptomatic volunteers and of patients referring for chronic overuse-associated pain, also comparing these findings with those obtained with B-mode ultrasound (US).

Patients and methods

This study had local Ethics Committee approval; all patients gave their written informed consent. Twelve patients (9 men, 3 women, median age 52.5 years, range 38–64 years) referred for unilateral Achilles tendon pain associated with amateur sporting activities and 18 healthy controls (11 men, 7 women, median age 54 years, range 27–64 years) were studied. US/sonoelastography were performed with a Logos EUB8500 system (Hitachi Ltd., Tokyo, Japan) equipped with a 10-6 MHz high-resolution broadband linear array, on 12 symptomatic tendons and 36 controls. The probe was positioned at the calcaneal enthesis, retrocalcaneal bursa, myotendineus juction, and in three different areas of the tendon body. The elastogram colour range was translated to a numeric score and the differences of tendon resilience were compared by the Kruskall-Wallis test.

Results

On US, symptomatic tendons showed increased tendon thickness (12/12 tendons vs. 8/36 controls, $p<0.0001$), interruption (5/12 vs. 0/36, $p=0.0004$), and fragmentation (5/12 vs. 0/36, $p=0.0004$). Disappearance of fibrillar echotexture was comparable in the two groups. Symptomatic tendons were harder, showing a prevalence of blue to green colour ($p<0.0001$). Loss of elasticity was associated with both fragmentation ($p=0.0089$) and loss of fibrillar texture ($p=0.0019$), and was inversely correlated with tendon thickness ($p<0.0001$). Sonoelastography showed no difference between symptomatic and control tendons at the enthesis and myotendineus junction.

Conclusions

Sonoelastography shows increased stiffness in symptomatic enlarged Achilles tendons in comparison to normal ones.

Key words

Sonoelastography, Achilles tendon, ultrasound

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Introduction

Sonoelastography is a recently developed non-invasive ultrasound (US) technique that allows *in vivo* assessment of the mechanical properties of tissues. In 1999, Ophir *et al*. described the basic principles of applying ultrasonographic techniques in order to obtain information about the resiliency properties of tissues (1). Konofagou *et al*. in 2004 pointed out the state-of-the art and the future possibilities of the clinical use of sonoelastography (2).Transient elastography has been used in the assessment of neuromuscular diseases, in particular to investigate the stiffness of muscles during isometric contraction (3).

Sonoelastography measures the changes of the "native" (*i.e*. unfiltered) ultrasonographic signal before and after application of a mechanic stimulation (4, 5). A conventional B-mode image is obtained using less than 15% of the information contained in the native signal, whereas sonoelastography also reveals raw data that do not concur to the creation of B-mode images.This technique requires induced tissue deformation in order to assess return elasticity. The most common stimulus adopted to elicit structural deformation is gradual manual compression. An alternative technique is "transient elastography", where mechanical compression is obtained by the emission of low radiofrequency impulses (6). The elastogram is visualised as a colour image superimposed on the B-mode image. The scale varies from red (soft tissue) to blue (hard tissue), with yellow and green as intermediate grades (5). Up to now, this technique has been mainly used to investigate prostatic tumors (7), breast masses (8, 9), liver diseases (10), thyroid nodules (11), skin ulcers (12), and lymph nodes (13). The postulate, in these cases, is that tumor is harder that normal tissues, and that malignant masses are harder than benign ones. To the best of our knowledge, sonoelastography has been applied to the musculoskeletal system only to evaluate muscle elasticity (14), anecdotal shoulder bursitis in polymyalgia rheumatica (15), and, more recently, lateral epicondilitis (16) and normal anatomy of the Achilles tendon (17). However, the role of sonoelastography in the evaluation of pathologic conditions of the Achilles tendon has never been established.

Conventional B-mode ultrasound examination is a common imaging method for normal and diseased tendons (18). Unfortunately, it does not provide information about the resiliency of tendons and its modification after injuries. Investigating the mechanical properties of tendons could be useful for lesions that produce only a transient biomechanical effect or permanent damages undetectable with US. The purpose of our paper was to use sonoelastography in the evaluation of the Achilles tendon of asymptomatic volunteers and of patients referring for chronic overuse-associated pain, also comparing these findings with those obtained by B-mode US.

Patients and methods

Twelve patients (9 men and 3 women, median age 52.5 years, range 38–64 years) referred for unilateral Achilles tendon pain due to overuse associated with amateur sporting activities and 18 healthy controls (11 men and 7 women, median age 54 years, range 27–64 years) were evaluated in this prospective study. Both patients and controls did not report any previous comorbidities or treatments potentially harmful to their tendons. The study protocol was approved by the Institutional Review Board. All patients signed a written informed consent for inclusion in this study before the examination. US, which included also sonoelastography evaluation, was performed on the 12 symptomatic tendons and 36 control tendons with an US system (Logos EUB8500 – Hitachi Ltd., Tokyo, Japan) equipped with a 10-6 MHz electronic high-resolution broadband linear array. The same examiner with 20-year experience in US, blinded to the patients' complaints, evaluated all the tendons. US and sonoelastographic images were recorded, and evaluated at the time of examination and after six months by two independent readers (one was the radiologist who performed the original scans and the other was a radiologist with four years of experience in musculoskeletal ultrasound). Conventional US of the tendon was performed according to the "Musculoskeletal Ultra-

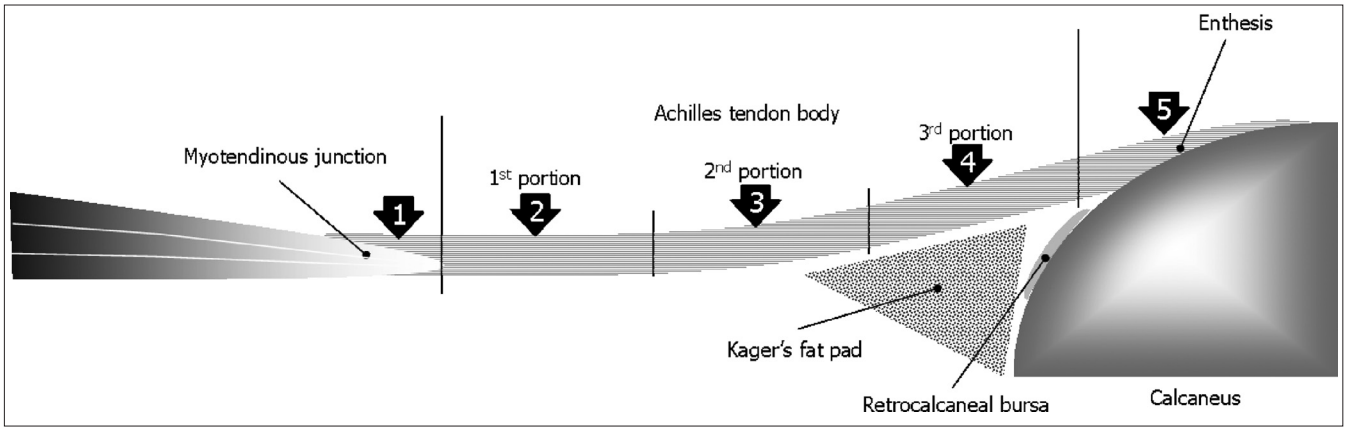

Fig. 1. The scheme shows an Achilles tendon as it was subdivided for the purposes of our study. Black arrows indicate the position of the probe in the assessment of the tendon. 1=myotendinous junction; 2=1st portion of the tendon; 3=2nd portion of the tendon; 4=3rd portion of the tendon; 5=calcaneal enthesis.

sound Technical Guidelines" proposed by the European Society of Skeletal Radiology, which method includes both transverse and longitudinal planes. All patients were scanned in a prone posture with the foot hanging free in a neutral position at the end of the examination table (19). A special adapter was applied to the probe, in order to optimise distribution of pressure. Such mechanic stimulation was applied by the operator directly on the probe, acting perpendicularly to the scanned area, in order to produce a deformation of the tissues. To allow reproducibility of the amount of pressure applied, a feed-back of it was provided by a specific numeric scale displayed on the monitor of the US equipment. A high-quality elastogram is obtained with a light contact that does not distort the underlying tissues. The array was positioned at the calcaneal enthesis and above the retrocalcaneal bursa. In order to cover its whole length, the tendon body was ideally divided into three equal parts – starting from the myotendinous junction up to the calcaneal insertion – and then assessed with the probe (Fig. 1). For comparison purposes, magnetic resonance imaging (MRI) of the Achilles tendon was also obtained in 5 patients. All MRI examinations were performed by using 1.5-T MRI system (Signa Excite, GE Healthcare, Milwaukee, Wis, USA) and the following sequence was used: sagittal T2-weighted fast spin-echo imaging with fat saturation (repetition time 2740 msec, echo time 83,8 msec; 3-mm section thickness, 140 x 140 mm field of view, matrix size 256 x 256; two signals acquired, train echo length 7).

Changes in tendon structure and echotexture were evaluated using B-mode US and classified as thickening (maximum anteroposterior diameter greater than 6 mm measured on the longitudinal scan), interruption (changes affecting groups of normal fibrils, that were interrupted by focal hypoechoic inhomogeneous areas), fragmentation (short interruptions repeated at regular intervals in each fibril, as in a dashed line) and disappearance of fibrillar echotexture, according to Martinoli *et al*. (20). The elastogram obtained was displayed as a coloured mask that was superimposed on the conventional B-mode image (Fig. 2). The colour range varied from blue (very rigid tissues, such as bone) to red (resilient tissues) and was translated to a numeric score (1=blue, 2=light blue, 3=green, 4=yellow, 5=red).

Statistical analysis

The differences of tendon resilience between the two groups of patients were compared statistically by the Kruskall Wallis test. Frequencies were compared by the Chi square test. Intrareader and interreader agreement was compared by Cohen's κ. A *p*-value of <0.05 was considered statistically significant. The MedCalc® statistical software version 9.2.0.1 was used.

Results

On grey scale US, symptomatic tendons showed a variety of basic changes in fibrillar pattern including increased tendon thickness (12/12 tendons vs. 8/36 in controls, $p<0.0001$), interruption (5/12 *vs*. 0/36, $p=0.0004$), fragmentation (5/12 *vs*. 0/36, $p=0.0004$), and disappearance of fibrillar echotexture (5/12 *vs*. 8/36, ns). The first three types of lesion occurred in limited portions of the tendon body, always coexisted with normal areas, and were variably represented in the same tendon. Disappearance of fibrillar echotexture extended to large portions of the affected tendon. Of the eight controls with disappearance of the fibrillar echotexture, three showed also an increased tendon thickness. No tendon interruption or fragmentation was found in controls. Median tendon thickness was 7.6 mm (range 6.6–9 mm) in patients and 5.8 mm in controls (range 5.3–7.2 mm) ($p<0.0001$). No Achilles tendon calcifications were found both in patients and controls. For the most experienced reader, the intra-observer agreement was excellent for increased tendon thickness (κ=0.912), disappearance of fibrillar echotexture (κ=0.938), fragmentation (κ=0.899), and interruption (κ=0.986). For the less experienced reader, the intra-observer agreement was excellent for increased tendon thickness (κ=0.901), disappearance of fibrillar echotexture (κ=0.908), fragmentation (κ=0.911), and interruption (κ=0.923). Inter-reader agreement was excellent for increased tendon thickness (κ=1) and disappearance of fibrillar echotexture (κ=0.946), fair for fragmentation (κ=0.625), and poor for interruption (κ=0.231).

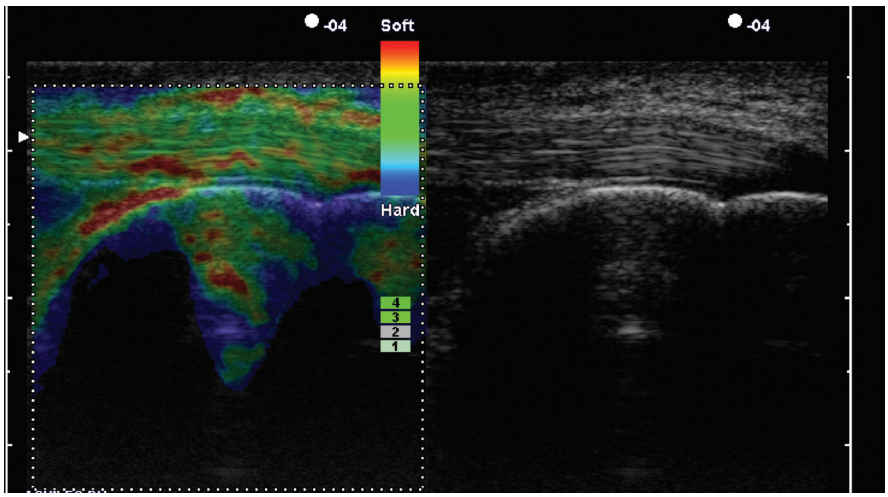

Fig. 2. Conventional B-mode US (right) and superimposed sonoelastogram (left) of a normal Achilles tendon.

Table I. Differences in mean colour between patients and controls in the different Achilles tendon locations studied by sonoelastography (see Fig. 1 for the exact probe location).

	Myotendineus junction	1st portion	2nd portion	3rd portion	1+2+3	Main color	Calcaneal insertion
Patients	3	1.17± 0.4	2.17± 0.4	3.16 ± 0.4	8.6 ± 2.4	1.3 ± 0.78	3 ± 0
Controls	3	2.7 ± 0.6	3.7 ± 0.6	4.7 ± 0.6	11 ± 1.7	2.9 ± 0.58	2.97 ± 1.2
p-value	ns	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	ns

By sonoelastography, no statistically significant difference was observed between symptomatic and control tendons at the myotendineus junction, at enthesis, and at the retrocalcaneal bursa (Table I). However, symptomatic tendons bodies were significantly less elastic than control ones, showing a prevalence of blue, light blue, and green (Fig. 3). The mean value of elasticity, *i.e.* the sum of the colours of the three different tendon locations was 8.6±2.4 (range 6 to 11) in the group of symptomatic patients compared to 11±1.7 (range 6 to 12) in the control group ($p<0.0001$). This difference persisted when the data were analysed at the three different tendon locations (Table I). The mean predominant colour corresponded to a figure of 1.3±0.78 in the group of patients compared to 2.9±0.58 in the control group ($p<0.0001$). Tendon thickness and tendon colour were inversely correlated ($p<0.0001$), indicating that with progressive increase in thickness the tendon became less elastic. The presence of tendon interruptions was not associated with a specific sonoelastographic pattern (Table II). By contrast, inelastic tendons, indicated by low colour values, were seen in both fragmentation ($p=0.0089$) and loss of fibrillar texture ($p=0.0019$) (see Table II). Intra-reader agreement for the determination of the prevailing colour of the tendon was excellent ($\kappa=1$) for both the most and the less experienced readers, while inter-reader agreement was good ($\kappa=0.897$).

On MRI imaging, all tendons (5/5) were found to be thickened with intratendineous signal alterations (Fig. 3).

Discussion

The estimation of tissue hardness is a very ancient diagnostic tool in medicine. Its earliest and most common form, palpation, was practiced by Egyptian physicians as early as 2600 BC. The relationship of tissue elasticity and hardness to palpability follows the basic principle that, to be palpable, the object must differ in consistency from the surrounding tissue. In 400 BC, Hippocrates used to say that "such swellings that are soft, free from pain, and yield to the finger, … are less dangerous than the others … then, painful, hard, and large swellings indicate danger of rapid death; but those that are soft, free of pain, and yield when pressed with the finger are more chronic" (21). The physics of palpation has been recently discussed by Hall (22). The fingers displace tissue downwards, and the pressure receptors on the skin of the fingers are used to sense the local stress values at various levels. The stress is higher on finger receptors palpating a superficial "hard" lesion, and lower on receptors examining the softer surrounding tissues (4). The purpose of sonoelastography is to reproduce this physical examination procedure with higher accuracy.

Arising from the fusion of both muscle bellies of the gastrocnemius and the deeper soleus muscle, the Achilles tendon, about 12 to 15 cm long, is the largest in the human body (18). The use of US in Achilles tendon diagnostics is a consolidated procedure, which is reliable in assessing both small tears and complete ruptures (18, 23, 24). We decided to perform our sonoelastography study on the Achilles tendon because it is the most efficient model for a US study, thanks to its superficial location and large size. In addition, Achilles tendon is prone to damage more frequently than tendons in other parts of the body, a consideration that makes it an ideal site to assess changes in the structure of tendons (25).

From a histological point of view, adult tendons are composed of large-diameter type I collagen fibrils. These are 150 nm in diameter, tightly packed with type III collagen and surrounded by an aqueous gel-like matter containing proteoglycans and elastic fibers (26). The actin and myosin bundles are arranged helically. In healthy tendons, 95% of the collagen is type I (27). In degenerated and aging tendons, type III collagen is prevalent. As a result, the tendon is less elastic and more prone to rupture in older individuals (28). Our sonoelastographic findings are consistent with these data. In our hands, sonoelastography showed increased stiffness in symptomatic Achilles tendons in comparison to normal ones. Likewise, conventional US findings were strictly consistent with sonoelastography, since thick-

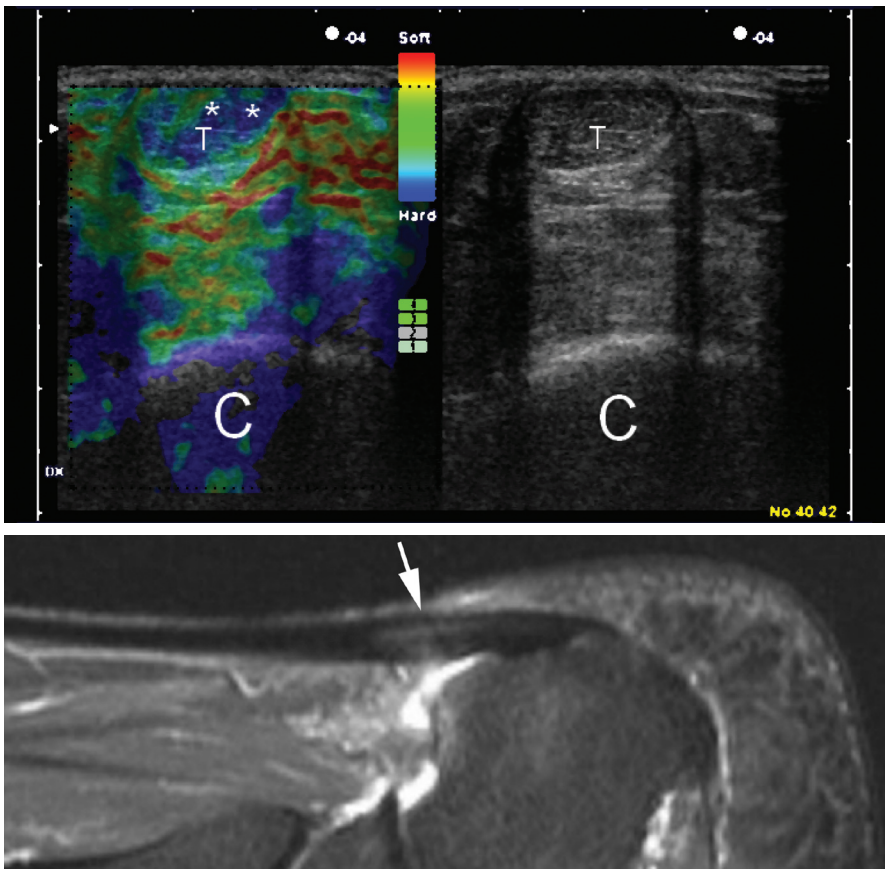

Fig. 3. Sonoelastography and B-mode US (a), and MR (b) of a patient's tendon (T). Note the areas of increased tendon stiffness that appears blue (asterisks), corresponding to the anatomical lesions on US (increased tendon thickness and interruption) and MR (increased tendon thickness and increased signal in the tendon body, arrow). C=calcaneus.

Table II. Median tendon colour by sonoelastography according to the presence or not of relevant lesions by conventional US.

Type of lesion	Median tendon colour value (range)	*p*-value
Interruption present	11 (6-11)	0.153
Interruption absent	12 (6-12)	
Fragmentation present	6 (6-11)	0.0089
Fragmentation absent	12 (6-12)	
Loss of fibrillar structure present	9 (6-12)	0.0019
Loss of fibrillar structure absent	12 (6-12)	

ened and degenerate tendons detected at US were significantly less elastic at sonoelastography. Achilles tendons of patients and controls behaved in the same way at the myotendineus junction and at the enthesis. This last finding is easily understandable because this area is attached to the bone, which is a hard structure.

In clinical practice, we are more likely to consider a single segment of the tendon rather than to make a sum of the colours of all locations. Thus, it is definitely more important to focus on the value of the mean predominant colour in each segment of the tendon. In our series, we demonstrated that affected tendons have a value that is 32% lower than controls. In other words, mostly-blue tendons (elasticity value = 1.3) were found in symptomatic tendons while green tendons (elasticity value = 2.9) were found in controls.

In patients where MR imaging was performed, this imaging technique showed an excellent correlation with grey scale US and sonoelastography.

One limitation of our study may be represented by the use of a 10-6 MHz probe in the evaluation of the Achilles tendon. A 13-6 MHz probe would be more appropriate, but in our system, which was one of the earliest sonoelastography equipments, it was not available. A limitation of sonoelastography is that each tissue is not associated with a given value of intrinsic elasticity, for the colour it exhibits during the scan is related to the other tissues imaged at the same time. In other words, a healthy Achilles tendon could appear yellow or green if scanned together with the calcaneal bone. This point emphasises the need for a precise choice of the area to be analysed for comparison and follow-up studies. Furthermore, since compression is performed manually by the operator, assessment should be performed always by the same sonographer, as occurred in our study, in order to avoid the risk of operator-associated variations. However, this issue has already been addressed by Itoh *et al*. (29) who described as a level of pressure that maintains contact with the skin and permits imaging conditions for which the association between pressure and strain is proportional.

In conclusion, symptomatic, degenerated tendons are less elastic than asymptomatic ones, a feature that can be assessed by sonoelastography. Our findings support the view that US could become the most widely used method for clinical elasticity estimation and imaging, since it is quick and easy to use and only moderately expensive (4). Future applications of this technique could include detection of tendon degeneration even before the damage is clearly assessable with conventional US, evaluation of abnormal tendon elasticity in healthy, first class athletes in order to predict decrease of athletic performance (28), and prediction of tendon rupture. This information cannot be derived from our study, however, because of the absence of a follow up.

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