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Evaluation of Normal and Pathological Patellar Tendon by Real- Time Shear Wave Elastography

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Abstract

Tendinopathy covers a range of several tendon conditions, mostly caused by overuse but at least in patellar tendon pathology, increased by obesity, diabetes, inflammatory and autoimmune conditions. Subclinical tendon pathology is difficult to diagnose, as magnetic resonance imaging (MRI) examinations are sometimes inconclusive and non-cost-effective. Elastography is an ultrasound examination method that uses mechanical impulses to produce shear waves in the tissue of interest, than measures the tissue displacement and calculates the shear wave speed or the elastic modulus of the examined tissue. We have used B-mode ultrasonography and share wave elastography on 52 patellar tendons from healthy volunteers with or without tendon pathology history, and correlated the data obtained with the clinical parameters of the volunteers, such as age, body mass index (BMI) and sports practice. We have shown that there is no significant correlation between the elastic modulus of the patellar tendon and age, sports practice and BMI. Share wave elastography has proved to be cost- effective for the patellar tendon in healthy volunteers and was able to monitor evolution of one patient with old knee problems treated conservative. It can complete investigation and it can replace B-mode ultrasonography particularly in monitoring the post-surgery evolution.

Keywords: Patellar tendon; Tendinopathy; Share wave elastography; knee pathology

Introduction

By definition, the patellar tendon is a ligament that connects patella to tibial tubercle. It is approximately 30 mm wide by 50 mm long and have a thickness of 5-7 mm [1]. The patellar ligament has the origin in the patellar apex, but it is considered the distal part of the quadriceps tendon, and the insertion on tibial tuberosity, being a part of the extensor mechanism of the knee [2]. The development of patellar tendon pathology is influenced by several risk factors, which may increase the strain of the patellar tendon. The main risk factors that contribute to patellar tendinopathy are weight, body mass index, leg length difference, quadriceps flexibility and strength, hamstring flexibility and vertical jump performance [3].

Patellar tendinopathy usually affects athletes involved in jumping sports, but also in older people, because of degenerative process which results from repetitive micro-damages over time. Tendinopathy is a generic term comprising a whole area of different pathologies, ranging from degenerative to post- traumatic, metabolic or inflammatory conditions of the tendon, such as paratenonitis, bursitis, tendinosis [4-6]. Patellar tendinopathy is a common condition manifested by anterior knee pain. The diagnosis is established by a thorough history and physical examination, but imaging is the gold standard. Most cases are resolved with nonsurgical treatment, like eccentric exercises, cryotherapy, anti-inflammatory drugs, corticosteroid injections, platelet-rich plasma injections or ultrasound-guided sclerosis. Once patients pass the first inflammatory phase and remain symptomatic, surgical treatment becomes a necessary option [5-8].

The evaluation of the elastic properties of a tissue was firstly reported in 1991 by ultrasound image [9], but the development of magnetic resonance imaging (MRI) made this imaging technique the gold standard for the evaluation of soft tissue lesions, particularly tendons and muscles [10]. A new method used to evaluate tissue elasticity based on differences in stiffness between different biological tissues is the ultrasound elastography (USE) [11]. The main advantage of USE consists in an increased sensitivity to detect the modifications of the viscoelastic properties of the tendon, that appear in tendinopathy [12], and can be early detected even before the abnormalities are being visible on conventional B-mode ultrasonography [13]. There are two major techniques used in USE: Compression elastography (CE) and Shear wave elastography (SWE). Comparing to SWE, conventional B-mode ultrasonography has severe limitations in tendon elastography because the transducer must be held in the same position relative to the tendon fibers during compression and it depends on the ability of the examiner [14]. In tendon elastography, the most often used are shear-wave speed measurements. The transducer can capture high frame rate images of the tissues, therefore assessing the shear wave propagation speed very accurately and reducing the variability observed in axial strain elastography [15].

Materials and Methods

This study includes a group of 52 healthy young volunteers without any preexistent tendon pathology. The inclusion criteria were the age of the patients – all subjects were between 19-29 years old, and the absence of previous knee pathology. Body mass index (BMI) and information regarding the activity level of the subjects were recorded. Patellar tendon length and diameter were measured by Q-Box Mode, then mid-tendon longitudinal elastographic valid measurements were performed for each tendon using an Aixplorer system (SuperSonic Imagine Inc., France) with a linear high-resolution transducer 15-4 MHz, subjects at the edge of the bed, with the foot at 90 degrees.

Three valid measurements were performed for each tendon, then an average value of the elastic modulus was obtained, expressed in kPa. The values obtained were statistically processed using the statistical expansion of Microsoft Office software pack, to assess the feasibility of the method in evaluation of the tendon state, at healthy subjects between 19-29 years old. With subjects sitting in the dorsal decubitus, at the edge of the bed with the knee at 90 degrees, 5 values were elastographically measured, starting with the proximal portion and ending at the tibial insertion level. Following the 5 elastographic measurements, the median of the 5 values was calculated, this being practically the elastographic reference value of the analyzed patellar tendon. After calculating the median of the 5 values, an average of the respective value was achieved, both for male and female patients, this being: 273,6862745 kPa.

The elastographic ultrasound images were displayed in parallel with the B-mode ultrasound images, allowing for the region of interest (ROI) selection of the tendon part that undergoes elastographic measurements. In normal patients without history of tendon lesions, the tendon was stiff, with relatively uniform color-coded blue image on the elastogram. Areas of soft tissue, color-coded red, could be identified in another volunteer, with possible diagnostic significance of a preclinical lesion. The person will be performed follow-up by ultrasound imaging coupled with elastography, to perform early diagnosis of a tendinopathy, particularly if the volunteer is a sport practitioner. The elastographic evaluation of the patellar tendon were performed using different ROI than in the images depicted, and yielded values of the elastic modulus ranging between 122 and 498kPa. The study protocol was approved by the institutional board.

Results

The men vs women ratio of the volunteers in this study was 1: 3.63, body weight of 40-65 kg in women and 60-90 kg in men, respectively, with a BMI of 18.71-27.4 and 16.19- 26.74 in men and women, respectively. The mid-tendon area was calculated by the formula $A=\pi D1D2/4$, where D1 represents the antero-posterior diameter, while D2 represents the transversal diameter. The tendon area was calculated along his insertion and ranged in men and women volunteers ~ 273,6862745 kPa. The elastographic ultrasound images were displayed in parallel with the B-mode ultrasound images, allowing for region of interest (ROI) selection of the tendon part that undergoes elastographic measurements. In normal patients, without history of tendon lesions, the tendon was stiff, with relatively uniform blue color-coded image on the elastogram, with values between 165.44 and 178.67 kPa (Figures 1A & 1B). Areas of soft tissues, color-coded red, were identified in another volunteer, with possible signification of preclinical lesion (Figures 2A & 2B). The elastographic evaluation of the patellar tendon was performed using different ROI than in images depicted and yielded values of the elastic modulus ranging between 112.002 and 163kPa.

Discussion

Ultrasound elastography is a recent technology that has a major development in the past two decades [16]. In this study there were analyzed the two major techniques used in musculoskeletal ultrasound (conventional B-mode ultrasonography and shear-wave elastography) in the context of tendon pathology. Ultrasound elastography is a new method used to evaluate the tissue elasticity based on differences in stiffness between different biological tissues. Elastographic imaging of soft tissue is one of the major improvements of the ultrasound investigation, so it can give us important diagnostic and prognostic information, is non-invasive, requires less expensive equipment than MRI, it is equally sensitive and specific, and does not require significant training. SWE can give morphological information and can quantify the absolute elasticity value of soft tissue structures [17]. Shear waves can

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be induced through various methods, such as US push beams (supersonic shear imaging) or by external mechanical vibrations (transient elastography). These waves can be either longitudinal, where the particles oscillate in the direction of wave propagation, or transversal, in which particles oscillate perpendicular to the direction of wave propagation. The transverse wave propagation speed is called the shear-wave velocity(Vs) [16-19]. One of the mechanical properties of tissues, musculoskeletal elasticity, is mostly affected by age, BMI, sex and muscle strength, and some neuromuscular and orthopedic disorders [16]. When is properly performed, this method can be used to evaluate the healing progress of the tendon after surgery or to detect preclinical tendon lesions [17,20]. Because most tendons are formed by different collagen fibers bundles/fascicles and with different insertions/origins, examination of the tendons can be difficult and elastographic images and data could differ significantly, it is necessary to have an exam standardization.

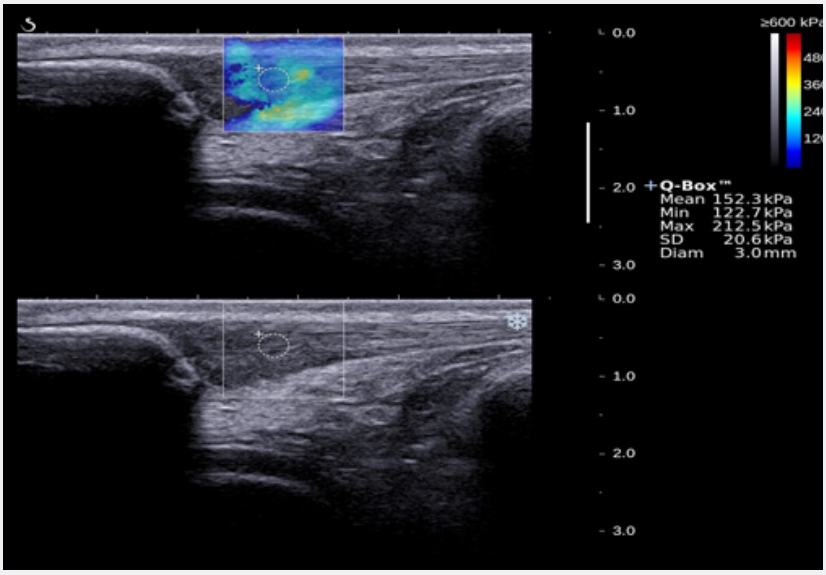

Figure 1A: Illustration of a Two-dimensional SWE (2D-SWE) measurement performed in a normal tendon, using the technology implemented in the Aixplorer system. A color scale map is displayed. Numeric results expressed in kPa are displayed on the right side of the image. The Q-Box displays the mean, minimum, maximum, and standard deviation (SD), along with the diameter of the ROI.

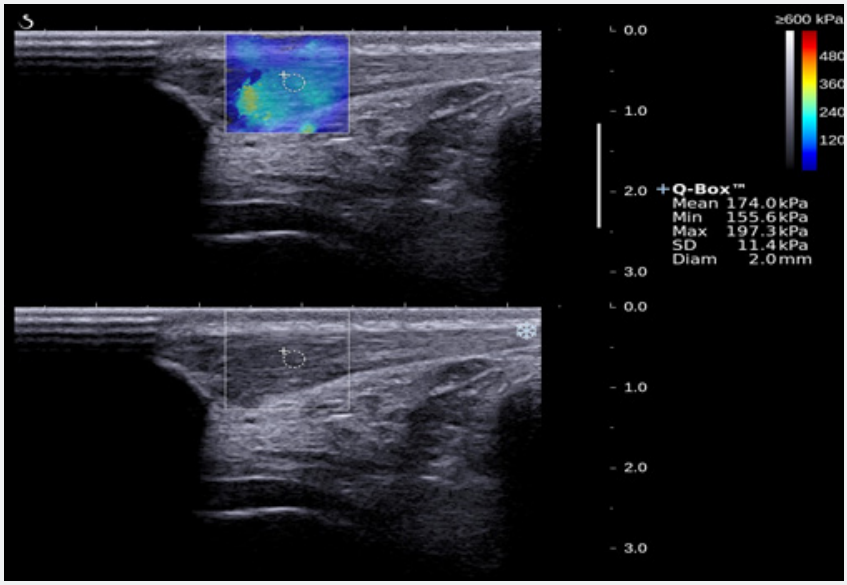

Figure 1B: Illustration of a Two-dimensional SWE (2D-SWE) measurement performed in a normal tendon, using the technology implemented in the Aixplorer system. A color scale map is displayed. Numeric results expressed in kPa are displayed on the right side of the image. The Q-Box displays the mean, minimum, maximum, and standard deviation (SD), along with the diameter of the ROI.

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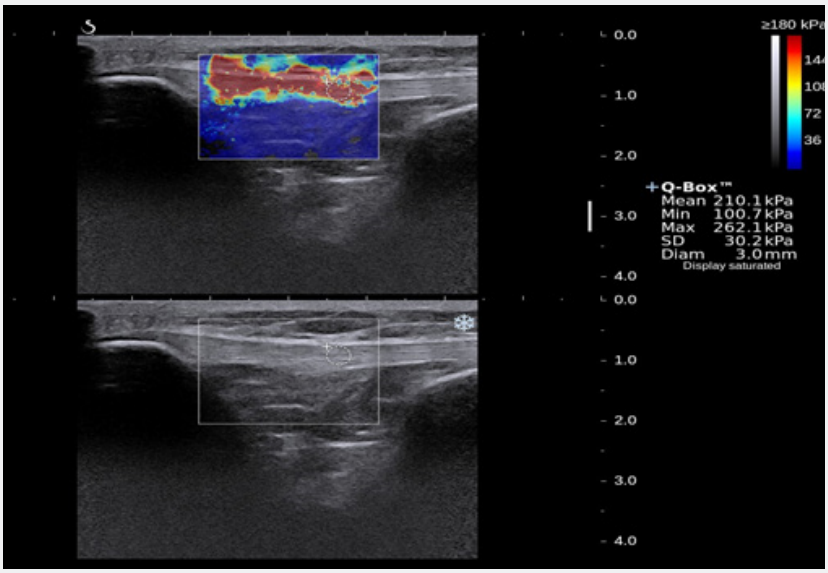

Figure 2A: Illustration of a Two-dimensional SWE (2D-SWE) measurement performed in a patient with patellar tendinopathy, using the technology implemented in the Aixplorer system. A color scale map is displayed. Numeric results expressed in kPa are displayed on the right side of the image. The Q-Box displays the mean, minimum, maximum, and standard deviation (SD), along with the diameter of the ROI.

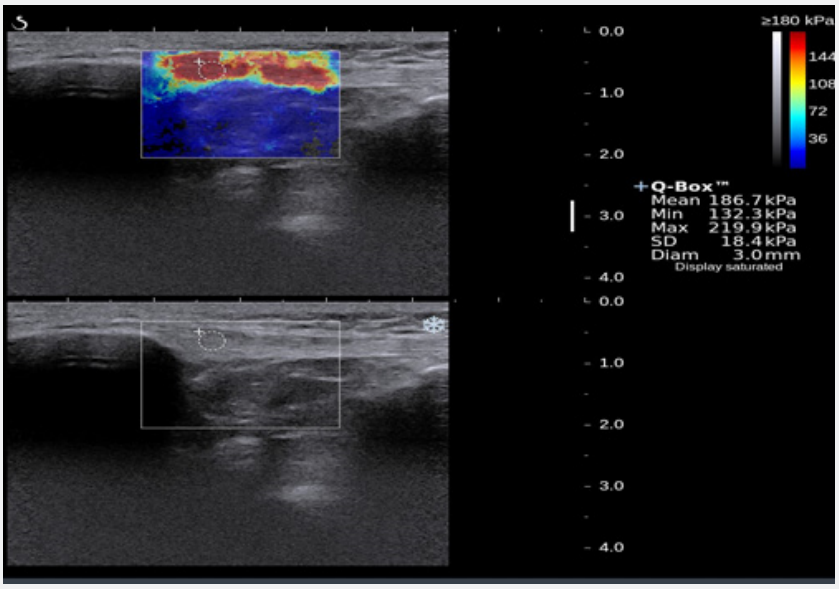

Figure 2B: Illustration of a Two-dimensional SWE (2D-SWE) measurement performed in a patient with patellar tendinopathy, using the technology implemented in the Aixplorer system. A color scale map is displayed. Numeric results expressed in kPa are displayed on the right side of the image. The Q-Box displays the mean, minimum, maximum, and standard deviation (SD), along with the diameter of the ROI.

In our study we have obtained values of the elastic modulus like other published studies, but also with some differences concerning the correlation with age or tendon thickness in symptomatic patients. We questioned pubmed.ncbi.nlm.nih.gov. by the keywords "patellar tendon by real-time shear wave elastography" and found five studies using USE (two using CE and three using SWE), whose results were discrepant concerning elasticity features. Two studies, for example, using SWE, described an increase of Vs (shear-wave velocity) and, therefore, stiffness in patellar tendinopathy; there are important methodological differences that can explain this distinctions, like the regions of the same tendon were assessed and different sizes of ROIs were used. In the article published by Dirrichs et al. [21] measurements of Vs using an ROI of 1 mm in diameter placed at the most rigid area of the tendon were performed; the second study realised by Coombes et al. used a larger ROI and measured Vs at the middle

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and proximal parts of the tendon [22]. In another study, Zhang et al. measured Vs at a proximal part of the tendon; Also, in the research realized by Zhang et al., by using SWE, was evaluated 13 athletes with unilateral patellar tendinopathy and was found a correlation between increased stiffness of painful tendon and the intensity of pain and degree of dysfunction [23]. The conclusion was that the elastic modulus is influenced directly proportional by the size of the ROI (Kot et al. [24,25] and by the assessed tendon portion [26].

Conclusion

Ultrasound elastography is a new method used to evaluate the tissue elasticity based on differences in stiffness between different biological tissues. Elastographic imaging of soft tissue is one of the major improvements of the ultrasound investigation, so it can give us important diagnostic and prognostic information, is non-invasive, requires less expensive equipment than MRI, it is equally sensitive and specific, and does not require significant training. SWE has been proved as a reliable and cost-effective method for the evaluation of patellar tendons in healthy volunteers and can be used to monitor post-surgery evolution of the patients with knee pathology, caution must be taken during image acquisition as the patellar tendon is a highly anisotropic medium and this might alter the results obtained.

Conflicts of Interest

The authors declare no conflict of interest.

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