



Importance of shear-wave elastography in prediction of Achilles tendon rupture

Gordana Ivanac^{1,2} · Domagoj Lemac³ · Vilma Kosovic⁴ · Kristina Bojanic⁵ · Tomislav Cengic⁶ · Ivo Dumic-Cule^{1,2} · Marko Pecina² · Boris Brkljacic^{1,2}

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Abstract

Purpose It was demonstrated that about 6% of patients with a ruptured Achilles tendon experience the rupture of contralateral tendon in the future; the aim of this study was to estimate the risk for rupture of contralateral tendon in patients who underwent surgical reconstruction of ruptured Achilles tendon by using subjective questionnaires and shear-wave elastography.

Methods Twenty-four patients who underwent surgical repair of the ruptured Achilles tendon and twelve age-matched healthy controls were examined with ultrasound SWE. Functional outcomes were assessed with American Orthopedic Foot and Ankle Society (AOFAS) scoring system and subjective rating system which we introduced and validated.

Results The elasticity of injured tendon was markedly decreased (by 42%) compared to the contralateral tendon of the patient, as expected. Both AOFAS score and our novel subjective assessment scale positively correlate with ultrasound SWE values in ruptured Achilles tendons. The elasticity of contralateral Achilles tendons in patients was 23% lower than among healthy individuals.

Conclusion Irrespective of the lack of difference in the subjective feeling assessed by AOFAS, the contralateral tendon in the patients with reconstructed Achilles tendon has significantly lower stiffness than healthy individuals. Therefore, contralateral tendons in patients who suffered from rupture are more prone to future ruptures.

Keywords Achilles tendon · Shear wave elastography · Rupture · Prevention

Introduction

The achilles tendon (AT) is the firmest tendon in the human body. Based on in vitro and in vivo experiments, 100 MPa is considered as point of breaking stress on majority of human tendons. Noteworthy, common tendon experienced peak stress below 30 MPa, whereas AT peak stress is around 70 MPa. Therefore, the safety factor is only 1.5 in AT, in contrast to other tendons where it exceeds 4 [1]. AT is characterized by scarce blood supply, specifically in the area 3–5 cm from calcaneus. Collectively, due to its anatomic position and characteristics, and subsequently applied load, AT is at high risk for rupture.

Rupture of AT presents with typical, well-described symptoms: local pain, retromalleolar haematoma, palpable disruption of continuity on the rupture spot, lameness, disability to stand on leg or toes, and lack of strength during plantar flexion [2]. Ultrasound is considered as a gold standard for visualization and confirmation of AT rupture, due to its availability, reproducibility, low cost, and lack of ionizing radiation.

✉ Ivo Dumic-Cule
ivodc1@gmail.com

¹ Department of Diagnostic and Interventional Radiology, University Hospital Dubrava, Av. Gojka Suska 6, 10000 Zagreb, Croatia

² School of Medicine, University of Zagreb, Salata 3, 10000 Zagreb, Croatia

³ Department of Orthopaedic and Trauma Surgery, University Hospital Dubrava, Av. Gojka Suska 6, 10000 Zagreb, Croatia

⁴ Department of Radiology, General Hospital Dubrovnik, Dubrovnik, Croatia

⁵ Department of Biophysics and Radiology, Faculty of Medicine Osijek, J. J. Strossmayer University of Osijek, 31000 Osijek, Croatia

⁶ Department of Orthopaedic and Trauma Surgery, University Hospital Center “Sisters of Mercy”, Draskoviceva 19, 10000 Zagreb, Croatia

Moreover, it enables dynamic evaluation of the tendon, i.e., visualization of motion of the tendon, which is especially useful for the follow-up during rehabilitation period. Ultrasound shear-wave elastography (SWE) is a tool introduced in the last decade with the ability to quantify the elasticity and stiffness of the tissue and is now routinely used in breast and liver ultrasound [3, 4]. Currently, SWE was utilized to detect quantitative properties of normal and ruptured AT, as well as for monitoring of treatment outcomes [5–8]. SWE was established as a reliable technique for assessment of mechanical properties of AT. Reproducible SWE measures were obtained over a period of five consecutive days and confident agreement between the operators [9]. Additionally, SWE showed ability to distinguish between AT stiffness among healthy athletes and healthy nonathletic individuals [10].

As an addition to B-mode, SWE could be used as a tool for assessment of AT texture and homogeneity. Therefore, we hypothesized that SWE could be used to predict which AT will be at higher risk to future rupture. The theory that individuals who already suffered an AT rupture are more prone to rupture of a contralateral AT was published three decades ago. Single-centre observational study followed 168 patients with AT rupture and detected ten patients (6%) with the rupture of contralateral AT during the follow-up period [11].

Materials and methods

Patients and healthy individuals

This study was conducted in accordance with the Declaration of Helsinki and approved by the Ethical Committee of our institution. Written informed consent was obtained from all subjects. Patients were enrolled between March 2017 and December 2017. A total of 36 subjects were recruited in the study, among which 24 patients who suffered AT rupture and 12 age-matched healthy controls. The causes of rupture in enrolled patients were sports or traumatic injuries. In all patients, the rupture was in the middle third of the tendon.

In both groups, patients with diabetes mellitus, cancer, lung and heart diseases, rheumatoid arthritis, spondyloarthropathy, and hypercholesterolemia were excluded due to the association between these comorbidities and tendon abnormalities [12]. At enrollment, each participant was interviewed, filled validated questionnaire, and was subjected to B-mode ultrasound examination with additional SWE.

Shear-wave elastography and AnSilk software

SWE was performed by Supersonic Aixplorer® system, using linear array transducer (4–15 MHz) in musculoskeletal preset. Imaging protocol was standardized, and all examinations were performed by the same experienced musculoskeletal

radiologist with 20 years of experience in musculoskeletal ultrasound examinations (the first author). The established examination technique was used, without manual compression, with careful electronic focusing of the lesion, and analysis and measurement on B-mode and elastographic image, using always the same preset. Patients were scanned in prone position with foot lying over the edge of examination table, to enable relaxed position and ensure confident and reproducible measurements. AT was first assessed in B-mode, which was followed by SWE. Instead of analyzing specific region of interest on SWE, we analyzed the whole area of elastogram by using in-house developed AnSilk software. By analyzing each pixel captured by SWE, AnSilk enabled uniquely confident assessment of AT stiffness, and avoidance of measurements based on selected region of interest, which will not encompass each part of AT with heterogenous structure.

Subjective questionnaires

Functional outcomes were assessed with American Orthopedic Foot and Ankle Society (AOFAS) scoring system [13]. AOFAS enabled quantification of both functional outcome and subjective feeling of pain and discomfort in AT.

Statistical analysis

Data from B-mode ultrasound, SWE, and AOFAS questionnaire were presented as mean \pm standard deviation (SD) and were analyzed using the non-parametric Mann-Whitney test. Differences were considered statistically significant when a P value < 0.05 was detected.

Results

Upon the rupture, AT lost majority of its stiffness, which was markedly decreased (by 42%, $P < 0.0001$) when compared to contralateral tendon of the patient (Fig. 1a). Accordingly, its overall length was increased for 61% ($P < 0.0001$) in comparison to contralateral tendon and intact tendons of healthy individuals (Fig. 1b). AOFAS questionnaire confirmed deteriorated function of injured tendon, accompanied with feeling of pain (Fig. 1c).

The appearance of tendons on B-mode did not show difference between contralateral intact AT in patients and both tendons of healthy individuals. Additionally, according to the AOFAS questionnaire, both groups reported normal function and lack of pain. Moreover, length of healthy AT was similar as contralateral AT in patients who suffered AT rupture (Fig. 1a). SWE was utilized to reveal exact stiffness of each analyzed tendon. To avoid quantification of only particular region of interest, the whole area of elastogram was analyzed by AnSilk, in-house developed morphometric

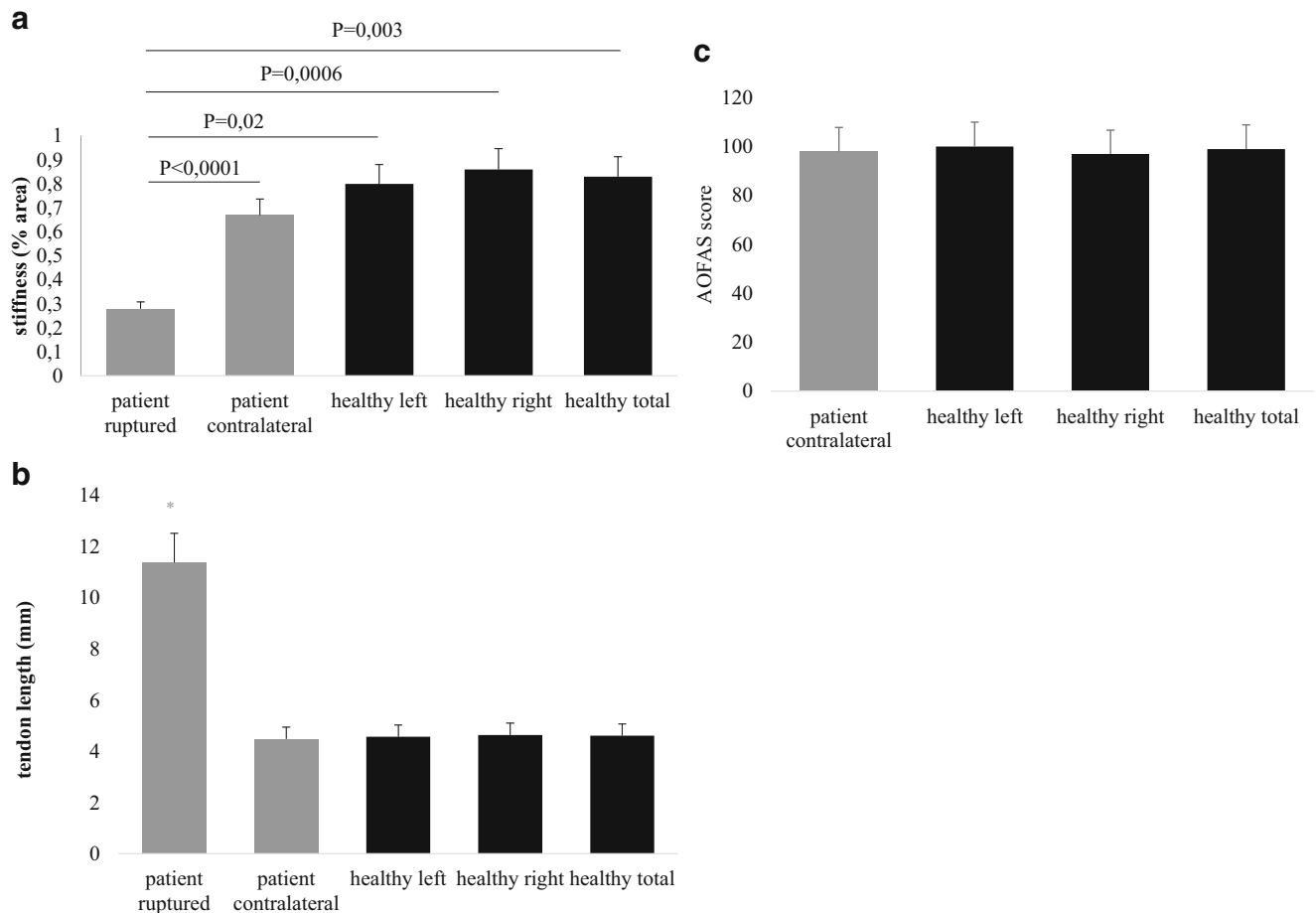


Fig. 1 Achilles tendon parameters measured by B-mode ultrasound (tendon stiffness **a**), shear-wave elastography (tendon length **b**) and subjective feeling measured by AOFAS questionnaire (**c**). * $P < 0.05$ vs patient contralateral and healthy Achilles tendon

software (Fig. 2a, b). Stiffness of contralateral AT in patients with AT rupture was 23% lower than healthy tendon, irrespective of leg dominance ($P < 0.05$) (Fig. 1b). Lower stiffness of contralateral AT, which should be intact and in

physiological range, is visible on each patient enrolled in study as heterogeneity on area of interest on elastogram (Fig. 2a). In contrast, both AT of healthy controls showed homogenous structure (Fig. 2b).

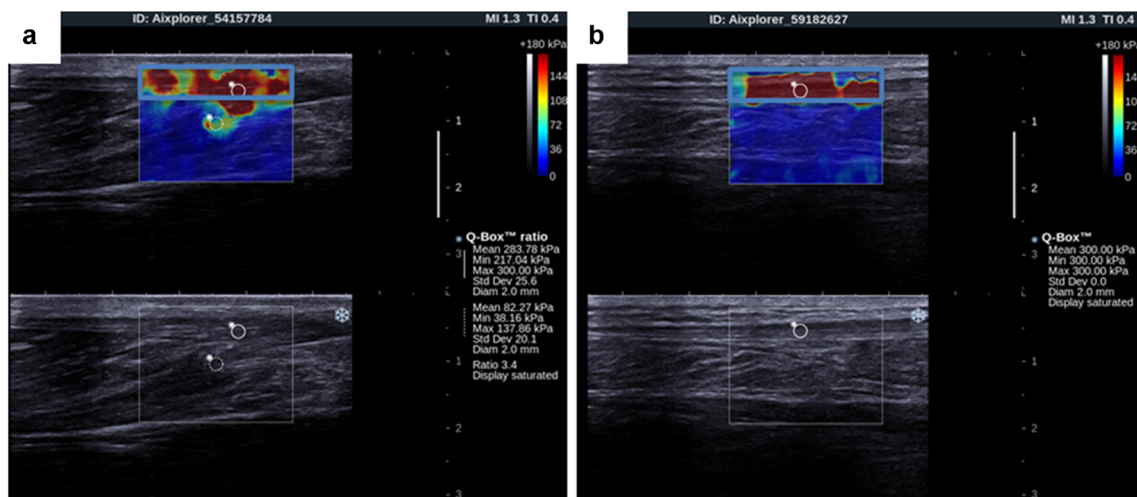


Fig. 2 B-mode ultrasound with SWE elastogram and marked region of interest analyzed by AnSilk—representative examples of contralateral tendon of patient with Achilles tendon rupture (**a**) and healthy individual (**b**)

AOFAS score positively correlated with ultrasound SWE values in healthy and ruptured AT. However, AOFAS underestimated state of contralateral AT of patients. Collectively, irrespective of the lack of difference in the subjective feeling assessed by AOFAS, the contralateral tendon in the patients with reconstructed Achilles tendon has significantly lower elasticity than healthy individuals. Therefore, contralateral tendons in patients who suffered from rupture are more prone to future ruptures.

Discussion

Previously published epidemiologic and clinical studies aimed to connect certain factors with predisposition of AT rupture. Incidence of tendon rupture was higher in Western countries than in Africa and East Asia [14, 15]. Higher incidence of AT rupture was described among individuals with blood group 0 [16]. However, others failed to prove this association [17, 18].

Acute rupture of AT is a common problem in sports medicine and affects both professional and recreational athletes [19, 20]. However, more than 80% of ruptures occur during recreational sports. Nationwide registry-based study was conducted in Sweden for the interval of 11 years and included more than 27,000 patients with acute AT rupture [21]. In the first year, the incidence of rupture was 47.0 per 100,000 person-years for men and 12.0 for women. By the end of the study, there was an increase in incidence of rupture among both genders. Similar retrospective study in Canada showed increased incidence density rate from 18.0 to 29.3 per 100,000 person-years, while peak incidence was in male patients between 40 and 49 years of age [22]. Another retrospective study reported 44.5 years as a mean age for AT rupture [23]. Increase in the rate of AT rupture was registered in the last 20 years, probably mainly due to changes in environmental factors, like increased participation of older individuals in recreational sport activities [14].

Despite extensive studies, no predisposing factors for AT rupture were detected among healthy individuals. Additionally, only 10% of patients who sustain an AT rupture had pre-existing Achilles tendon problems [24]. Due to all currently known facts, there is a great need for a tool that could enable detection of AT with higher risk for rupture. Based on a single observational study, we confirmed that individuals with history of AT rupture have increased risk for rupture of contralateral tendon and suggested SWE as a method of choice for detection of vulnerable AT.

Recent report revealed softer contralateral tendon in patients with acute AT rupture, which is similar as our finding [25]. However, this study was conducted by strain elastography that calculates elastographic value based on compression force of examiner. Compression elastography assessing the strain data

had a low level of reproducibility for measuring the stiffness of the human AT over consecutive days, with coefficient of variation over 53% [26]. SWE was proved as a highly reproducible method for assessing the mechanical properties of AT [9]. Thus, we utilized SWE to provide evidence of significantly softer contralateral tendon in patients with ruptured AT in comparison to healthy individuals. Noteworthy, subjective questionnaire and B-mode ultrasound failed to recognize potentially more vulnerable AT. Confirming our suggestion, SWE was recently shown to be effective in recognition of incipient thickening of AT among patients with familial hypercholesterolemia, presented as a loss of elasticity on elastographic scale [27]. Deposition of lipids in AT could be detected by B-mode ultrasound only in later phase when risk of rupture is increased. SWE was revealed as an appropriate tool for early detection of vulnerable AT and thus could be used as a screening method to predict potential AT rupture among professional and amateur athletes and other individuals with known risk factors.

Data availability All raw data are available in excel tables.

Compliance with ethical standards

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

Ethical approval All procedures were in accordance with the ethical standards of the institutional and research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

Consent to participate All patients in this study signed informed consent prior to enrollment.

Consent for publication Authors provide formal written consent to publish before submission of article.

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