Journal of Orthopaedic Translation (2018) 15, 9—20

Available online at www.sciencedirect.com

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journal homepage: http://ees.elsevier.com/jot

REVIEW ARTICLE

Ultrasound elastography and ultrasound tissue characterisation for tendon evaluation

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Received 10 February 2018; received in revised form 4 June 2018; accepted 7 June 2018
Available online 4 July 2018

KEYWORDS
Elastography;
Strain elastography;
Shear wave elastography;
Ultrasound;
Ultrasound tissue characterisation

Abstract Ultrasound elastography (UE) and ultrasound tissue characterisation (UTC) are two newer modes of ultrasound (US) which have begun to attract scientific interests as ways to improve tendon characterisation. These modes of US show early promise in improved diagnostic accuracy, prediction of at-risk tendons and prognostication capability beyond conventional grey-scale US. Here, we provide a review of the literature on UE and UTC for Achilles, patellar and rotator cuff tendons.

The translational potential of this article: The present literature indicates that UE and UTC could potentially increase the clinician's ability to accurately diagnose the extent of tendon pathology, including preclinical injury.

Introduction

Tendinopathy poses a large socioeconomic burden as one of the most common musculoskeletal injuries [1,2]. Tendinopathies comprise the majority of upper-limb musculoskeletal disorders in the work place, resulting in high economic costs [1]. For example, absenteeism from work in the United Kingdom in 2012 due to lateral

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https://doi.org/10.1016/j.jot.2018.06.003

epicondylitis/tennis elbow alone was estimated to result in £27 million in lost productivity [2]. Today, grey-scale sonography is widely used for evaluation of suspected tendon injury [3]. In many tendons, such as the Achilles tendon, the diagnostic accuracy and sensitivity using grey-scale ultrasound (US) have been shown to be more than 90% for each [4]. Structural details gained through US (e.g., tendinopathy vs. a moderate-sized tear) have allowed the trained clinician to characterise and prognosticate injuries beyond the information gained from history and physical examinations alone. Recently, ultrasound elastography (UE) and ultrasound tissue characterisation (UTC) have been applied to tendons with the potential of increasing the diagnostic capability of US.

UE was first introduced in 1991 by Dr Jonathan Ophir with his work on foam blocks and bacon slabs [5]. Based largely on the work done by Hans Oestriecher, who had studied the physics of vibration in soft tissue, UE is able to measure the stiffness of biological tissues [5—7]. UE has been historically used in the assessment of internal organ pathology, and more recently, its clinical application to tendon tissue has been a growing area of interest.

Computerised UTC was first developed by van Schie et al for the assessment of equine tendon integrity and later applied to the Achilles tendon [8,9]. The technology evaluates tendon integrity based on a custom-designed algorithm that quantifies the three-dimensional stability of echo patterns [8,9].

In the present article, we aim to provide a comprehensive review of these newer diagnostic US methods in their clinical application to tendon tissue, including their technical strengths and limitations.

UE technology and tendon-specific basic knowledge

The two most common forms of UE are strain elastography (SE) and shear wave elastography (SWE). Both forms of UE assess the stiffness of the material, which is measured by Young's modulus. The basic premise of UE is that an external force or stress is applied to a tissue, which induces certain strain on the deformed structure. Young's modulus can be calculated by the following equation:

$$E = \sigma / \varepsilon$$

where E is the Young's modulus measured in pascals (Pa), σ is the force externally applied ("stress" measured in Pa), and ε is the strain, which is a unitless measure of relative tissue elongation [10,11].

Physics of SE and SWE

SE technology was the first form of UE developed by Ophir et al in the early 1990s [5]. The operator exerts an external force by means of repetitive compressions using the US probe. The inability to accurately measure the applied force limits the ability to calculate Young's modulus [10,11]. Instead, analysis of the deformed tissue is displayed as a strain map, commonly referred to as an elastogram, which allows for a qualitative assessment of tissue stiffness (Figure 1) [10]. Most elastograms help to differentiate among three levels of stiffness—hard, medium and soft tissue—as compared to a nearby reference image point, typically subcutaneous fat, by means of a colour scale [12]. In contrast to SE, SWE involves a force created by a US pulse to form shear waves with measurable velocity, which allows for the calculation of Young's modulus [10,11,13]. In SWE, Young's modulus can be estimated based on the adjusted formula:

$$E \cong 3\rho v_{sw}^2$$

where E represents Young's modulus (kPa), ρ is the density of the tissue (believed to be constant at 1000 kg/m^3 with the assumption that tissue is purely elastic and isotropic), and v_{sw} is the shear wave velocity (SWV) (m/s) [10,11,13].

Comparing SE and SWE: advantages and limitations

The advantage of SE is that it tends to be more readily available in mobile cart-based systems as the hardware can be compact. The largest limitation to SE is that the technology generates a qualitative outcome without generating an actual stiffness value.

The most significant advantage of SWE is that it can quantify the stiffness of the tissue. The "stress" is generated by a US pulse as opposed to human pressure, which allows for quantification of tissue stiffness with Young's modulus [10]. Limitations of SWE include the following: (1) the necessity of a depth of about 0.4 cm for shear waves to be generated [13]; (2) structures deeper than 9 cm from the surface of the skin are not assessed properly due to US pulse attenuation [14]; and (3) inaccurate assessment of fluid filled structures as shear waves are not generated within fluids [15]. A potential limitation shared by both

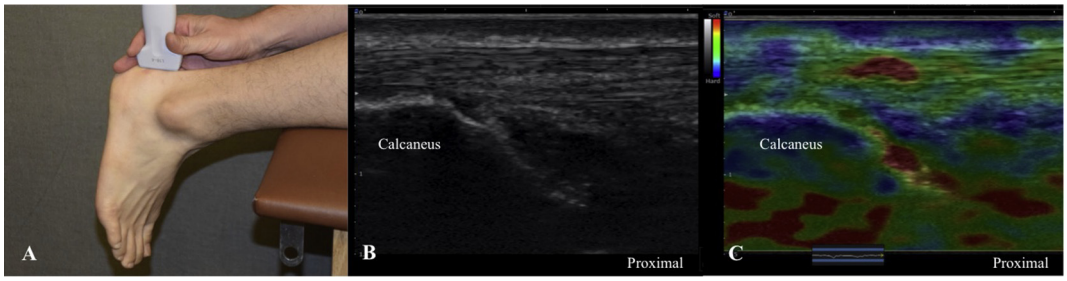

Figure 1 (A) Ultrasound probe placement over the distal Achilles tendon in long axis; (B) corresponding grey-scale image; (C) elastogram image.