Achilles tendon rupture
Dams, Olivier Christian

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Chapter 4

Substantiating the use of ultrasound tissue characterization in the analysis of tendon structure: a systematic review

Lucas Maciel Rabello, Olivier C. Dams, Inge van den Akker-Scheek, Johannes Zwerver, Seth O’Neill

ABSTRACT

Objective: To determine the role of ultrasound tissue characterization (UTC) in predicting, diagnosing and monitoring tendon structure and/or tendinopathy. In addition, this study aims to provide recommendations for standardized methodology of UTC administration and analysis.

Data source: The PubMed, Embase and Web of Science databases were searched (up to September 2018). All scientific literature concerning the use of UTC in assessing tendons was collected. The initial search resulted in a total of 1972 hits and, after screening by eligibility criteria, 27 articles were included.

Results: In total, 18 investigating the Achilles tendon, 5 the patellar tendon and 4 both Achilles and patellar tendons were included. The methods of UTC administration and analysis differed and were not uniform. The studies showed that the use of UTC to predict Achilles tendinopathy (AT) is inconclusive, but that a higher amount of tendon disorganization increases the risk of developing patellar tendinopathy (PT). In terms of diagnosis, UTC might provide additional information in AT cases. In addition, promising results were found for the use of UTC in both AT and PT in monitoring the effect of load or treatment on tendon structure.

Conclusion: More research regarding the use of UTC in predicting tendon pathology is required. UTC seems useful as an adjunct diagnostic modality because it can be used to differentiate symptomatic from asymptomatic tendons. In addition, UTC is a promising device to be used to monitor changes in tendon structure in response to load or treatment. Moreover, we provide recommendations of a standardized protocol concerning the methods of UTC measurement and analysis.
INTRODUCTION

The Achilles and the patellar tendons are 2 of the strongest tendons in the human body and thus subjected to large and frequent weight-bearing forces [27, 28]. As a result of this loading, these tendons are prone to overuse injuries such as tendinopathy, occurring in both (recreational) athletes [44] and sedentary individuals [18]. The prevalence of Achilles and patellar tendinopathy is estimated at approximately 2.35 and 1.60 per 1000 in the general population,[1] and even higher in competitive athletes [17], and these numbers are expected to rise due to increasing (recreational) sport participation, especially in the middle-aged [25].

Tendinopathy causes significant (functional) impairment and may be career ending for athletes [37]. In addition, tendinopathy is difficult to treat and many patients fail to respond to treatment [28]. It has been proposed that tendinopathy can eventually lead to rupture of the tendon [21, 22, 26], further worsening the prognosis with regard to tendon function and participation in sporting activities.

The diagnosis of tendinopathy is usually clinical, but it can be confirmed with imaging, such as ultrasound (US) or magnetic resonance imaging. However, there seems to be a poor correlation between imaging results and patient-reported symptoms [13, 23]. This makes it difficult for clinicians to monitor treatment and to predict athlete’s (future) risk for tendinopathy. A systematic review by McAuliffe et al. concluded that US may be useful in predicting future tendinopathy [32], though US poses problems such as interoperator variance, variations in transducer positioning and lack of standardization.

Van Schie et al. [42] attempted to address these issues by introducing the imaging modality ultrasound tissue characterization (UTC). UTC is an ultrasonographic imaging modality that consists of a 10-MHz linear array transducer fitted to a tracking device that automatically takes 600 images in transverse plane at intervals of 0.2 mm along the tendon constructing a 3-dimensional block [42]. These recordings can be analyzed by quantification and calculation of the percentage of echo-types of a specific portion of the tendon tissue. These echo-types (I-IV) represent tendon integrity and fibrillar disorganization: (I) highly stable, (II) medium stable, (III) highly variable and (IV) constantly low intensity and variable distribution [42]. This imaging tool is only validated in equine tendon; however, since 2010, the UTC has been widely used in the investigation of humans tendon [41].

UTC can discriminate symptomatic from asymptomatic tendons [42]. However, the role of UTC in diagnosing, predicting and monitoring tendon structure and/or tendinopathy is still relatively unknown. In addition, despite the potential UTC has in quantifying tendon structure, no conclusive guidelines exist for either the scanning of tendons or analyzing of the images. This has led to large variations in scanning and reporting of UTC imaging. There are currently several variations of scanning methods using different patient, ankle/knee and tracker positions, as well as scanning directions that may impact reliability.
and/or validity of reported findings. In addition to the methods of scanning, there are large variations in the methodology employed for the image analysis: the main variations appear to be the window size (number of frames the pixel brightness and stability pattern are based on, variations in this impact the percentage of the different echo-types) and the length of tissue the quantification is based on, entire tendon or small section. Because UTC is not yet standard clinical practice, it is hypothesized that the methods of administration vary and lack uniformity, and this impacts the research conclusions.

This study aims to determine the role of UTC in predicting, diagnosing and (treatment-progress) monitoring tendon structure and/or tendinopathy by systematically reviewing all available literature relating to UTC administration and/or analysis of tendons. In addition, this study aims to provide recommendations for standardized methodology of UTC administration and analysis.
METHODS

This systematic review was conducted according to the PRISMA-Protocol for Systematic reviews [33].

Search strategy and criteria
A systematic electronic search using the databases PubMed, Embase and Web of Science was performed in September 2018. All scientific literature concerning the use of UTC in human tendon (injuries) was collected. Implementation and validation of the search terms and search methods was attained from a medical librarian at the University of Groningen. Search strategy is listed in Table 1.

Study selection
Inclusion criteria were as follows: primary research studies using UTC to assess tendon structure. The exclusion criteria were as follows: reviews, case-studies and animal-studies. There was no language restriction.

Data extraction and analysis
Two reviewers were involved in the study selection process. Two reviewers (LMR and OCD) independently selected the studies by applying the inclusion and exclusion criteria in 3 successive rounds. In the first round, reviewers screened the titles followed by the abstracts selection. In the third round, the full text was screened. In case of disagreement between the two reviewers in any of the rounds, a third opinion (IvdAS) was requested.

Table 1. Search strings by database

<table>
<thead>
<tr>
<th>Database</th>
<th>Search string</th>
</tr>
</thead>
<tbody>
<tr>
<td>Embase</td>
<td>(‘Achilles tendon’/exp OR ‘achilles tendinitis’/exp OR achillodyn*:ab,ti,de OR ((achill* OR patella*) NEAR/3 (tendino* OR tendini* OR tendon* OR rupture OR tear):ti,ab,de) AND (UTC OR echotype* OR (tissue AND characteri*)) OR (ultraso* AND characteri*):ab,ti,de NOT (‘animal’/exp NOT ‘human’/exp)</td>
</tr>
</tbody>
</table>
The following data was extracted from the full texts of the included articles:

1. Study information: author(s), year, design;
2. Subject information: characteristics, tendon, tendinopathy, follow-up;
3. UTC scanning methodology: patient position (prone, supine, sitting or standing), direction of the scan (proximal or distal), window size (9, 17 or 25) and area of the tendon analyzed;
4. UTC’s clinical role in predicting, diagnosing and monitoring tendon structure and/or tendinopathy, UTC results, practical recommendations for UTC application. The following were the definitions used:

Predicting: UTC use prior to or until the development of symptomatic tendinopathy

Diagnosis: UTC use to show structure and pathology; cross-sectional design

Monitoring: UTC use longitudinally to assess tendon structure in response to a stimulus (e.g., treatment and load).
RESULTS

Search results
The applied search yielded 1351 articles (Figure 1). Of these articles, 27 met our inclusion criteria. The methods of UTC administration are presented in Table 2. The other extracted data are presented in Table 3. Eighteen studies performed a scan of the Achilles tendon [4, 10, 11, 16, 19, 20, 30, 31, 36, 40, 42, 43, 46–51], five of the patellar tendon [2, 3, 15, 38, 39] and four studies assessed both [8, 9, 12, 14]. No publications regarding the use of UTC in other tendons were found. Most studies concerned patients with (a history of) Achilles mid-portion tendinopathy.

Figure 1. PRISMA flow diagram
Table 2. Methods of UTC administration

<table>
<thead>
<tr>
<th>Author</th>
<th>Patient position</th>
<th>Direction of the scan</th>
<th>Side</th>
<th>Window size</th>
<th>Region of interest (ROI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Docking et al. [9]</td>
<td>Achilles tendon: prone with their feet off the edge of a plinth in 90 degrees of ankle dorsiflexion&lt;br&gt;Patellar tendon: supine with their knee at ;120 degrees flexion</td>
<td>From proximal to distal</td>
<td>Unilateral or Bilateral</td>
<td>25</td>
<td>Achilles tendon: from the disappearance of the calcaneus to the appearance of the musculotendinous junction&lt;br&gt;Patellar tendon: from the disappearance of the inferior patella pole to 3 cm distally</td>
</tr>
<tr>
<td>Docking et al. [12]</td>
<td>Achilles tendon: prone with their feet off the edge of a plinth in 90 degrees of ankle dorsiflexion&lt;br&gt;Patellar tendon: supine with their knee at ;120 degrees flexion</td>
<td>From proximal to distal</td>
<td>Unilateral</td>
<td>25</td>
<td>Achilles tendon: from the disappearance of the calcaneus to the appearance of the musculotendinous junction&lt;br&gt;Patellar tendon: from the disappearance of the inferior patella pole to 3 cm distally</td>
</tr>
<tr>
<td>de Sá et al. [40]</td>
<td>Prone on an examination bed with their feet placed on a foot and ankle stabilizer to stabilize and position the Achilles tendon</td>
<td>Not described</td>
<td>Bilateral</td>
<td>25</td>
<td>The examiner determined the landmark (2 cm from the calcaneal insertion) in the sagittal plane. Contours were drawn at 2 mm proximal and distal to the landmark (4 mm total)</td>
</tr>
<tr>
<td>Rudavsky et. al [39]</td>
<td>Supine position with the left knee flexed to 90°</td>
<td>From proximal to distal</td>
<td>Unilateral</td>
<td>25</td>
<td>From the disappearance of the inferior pole of the patella, extending 1 cm distally</td>
</tr>
<tr>
<td>van Ark et al. [3]</td>
<td>Supine position with the left knee flexed to 100°</td>
<td>From proximal to distal</td>
<td>Unilateral</td>
<td>25</td>
<td>From the disappearance of the inferior pole of the patella, extending 3 cm distally</td>
</tr>
<tr>
<td>Authors</td>
<td>Position</td>
<td>Alignment</td>
<td>Bilaterality</td>
<td>Contours</td>
<td>Description</td>
</tr>
<tr>
<td>-------------------------</td>
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<td>------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Waugh et al. [48]</td>
<td>Prone position</td>
<td>Foot placed in stabilizer used achieves perpendicular alignment. UTC transducer placed at 5/10 degree dorsiflexion</td>
<td>Bilateral</td>
<td>25</td>
<td>A scan 2.5 cm proximal of the insertion of the Achilles tendon was located. The Achilles tendon border was outlines 2 mm either side of this slice location in the sagittal plane and the two contours interpolated to create a 20 scans x 0.2 mm region of interest</td>
</tr>
<tr>
<td>Heyward et al. [16]</td>
<td>Prone position</td>
<td>Maximum ankle dorsiflexion</td>
<td>Unilateral</td>
<td>25</td>
<td>Achilles mid-portion (from 2 cm proximal to the upper border of the calcaneus in a proximal direction)</td>
</tr>
<tr>
<td>Rudavsky et al. [38]</td>
<td>Supine position</td>
<td>Left knee flexed to 90°</td>
<td>Unilateral</td>
<td>25</td>
<td>from the disappearance of the inferior pole of the patella, extending two centimeters distally</td>
</tr>
<tr>
<td>Esmaeili et al. [14]</td>
<td>Standing on a raised level surface with the great toe and knee touching the wall in a standardized lunge position</td>
<td>Distal to proximal</td>
<td>Bilateral</td>
<td>25</td>
<td>Achilles tendon: Multiple contours (from the disappearance of the calcaneus to the musculotendinous junction Patellar tendon: over a distance of 3 cm starting from the disappearance of the inferior pole of the patella</td>
</tr>
<tr>
<td>Stanley et al. [43]</td>
<td>Standing on a raised level surface with the great toe and knee touching the wall in a standardized lunge position</td>
<td>Distal to proximal</td>
<td>Unilateral</td>
<td>17</td>
<td>0.5 cm proximal to the insertion of the Achilles to the calcaneus, continuing to the musculotendinous junction or a length of 6 cm</td>
</tr>
<tr>
<td>Hernández G et al. [15]</td>
<td>Sitting position</td>
<td>Foot placed in a high surface and knee flexed 90°</td>
<td>Bilateral</td>
<td>Not described</td>
<td>7 contours were drawn (total free length of the tendon)</td>
</tr>
<tr>
<td>Bedi et al. [4]</td>
<td>Standing on a raised level surface with the great toe and knee touching the wall in a standardized lunge position</td>
<td>Distal to proximal</td>
<td>Uni/Bilateral</td>
<td>25</td>
<td>Achilles: Multiple contours (from the disappearance of the calcaneus to the musculotendinous junction No greater than 5 mm</td>
</tr>
<tr>
<td>Study</td>
<td>Achilles Position</td>
<td>Patellar Position</td>
<td>Contours</td>
<td>Maximum Tilt</td>
<td></td>
</tr>
<tr>
<td>-------------------------------</td>
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<td>-----------------------------------------------------------------------------------</td>
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<td></td>
</tr>
<tr>
<td>Docking et al. [10]</td>
<td>Standing on a raised level surface with the great toe and knee touching the wall in a standardized lunge position</td>
<td>Patellar tendon: Supine position, knee flexed at 60º</td>
<td>Distal to proximal</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Distal to proximal</td>
<td>Patellar: Proximal to distal</td>
<td>Uni/Bilateral</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td></td>
<td>From the disappearance of the calcaneus to the musculotendinous junction</td>
<td>Patellar tendon: over a distance of 3 cm starting from the disappearance of the inferior pole of the patella</td>
<td>No greater than 5 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Docking and Cook [8]</td>
<td>Standing on a raised level surface with the great toe and knee touching the wall in a standardized lunge position</td>
<td>Patellar tendon: Supine position, knee flexed at 60º</td>
<td>Distal to proximal</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Patellar: Proximal to distal</td>
<td>Uni/Bilateral</td>
<td>From disappearance of the calcaneus to the musculotendinous junction</td>
<td>No greater than 5 mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>From the disappearance of the calcaneus to the musculotendinous junction</td>
<td>Patellar tendon: over a distance of 3 cm starting from the disappearance of the inferior pole of the patella</td>
<td>No greater than 5 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wezenbeek et al. [49, 50]</td>
<td>Prone position with ankle in approximately 5-10º of dorsiflexion</td>
<td>Patellar tendon: Supine position, knee flexed at 60º</td>
<td>Distal to proximal</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Patellar: Proximal to distal</td>
<td>Uni/Bilateral</td>
<td>From the disappearance of the calcaneus to the musculotendinous junction</td>
<td>5 mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Patellar tendon: over a distance of 3 cm starting from the disappearance of the inferior pole of the patella</td>
<td>Patellar tendon: over a distance of 3 cm starting from the disappearance of the inferior pole of the patella</td>
<td>No greater than 5 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Masci et al. [31]</td>
<td>Prone position with maximal ankle dorsiflexion</td>
<td>Patellar tendon: Supine position, knee flexed at 60º</td>
<td>Distal to proximal</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Patellar: Proximal to distal</td>
<td>Uni/Bilateral</td>
<td>From the disappearance of the calcaneus to the musculotendinous junction</td>
<td>No greater than 5 mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Patellar tendon: over a distance of 3 cm starting from the disappearance of the inferior pole of the patella</td>
<td>Patellar tendon: over a distance of 3 cm starting from the disappearance of the inferior pole of the patella</td>
<td>No greater than 5 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>van Ark et al. [2]</td>
<td>Supine position with ~100º of knee flexion</td>
<td>Patellar tendon: Supine position, knee flexed at 60º</td>
<td>Distal to proximal</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Patellar: Proximal to distal</td>
<td>Uni/Bilateral</td>
<td>From the apex of the patella to 2 cm distally</td>
<td>No greater than 5 mm</td>
<td></td>
</tr>
<tr>
<td>Mascal et al. [30]</td>
<td>Prone position with maximal ankle dorsiflexion</td>
<td>Patellar tendon: Supine position, knee flexed at 60º</td>
<td>Distal to proximal</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Patellar: Proximal to dister</td>
<td>Uni/Bilateral</td>
<td>From the apex of the patella to 2 cm distally</td>
<td>No greater than 5 mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Patellar tendon: over a distance of 3 cm starting from the disappearance of the inferior pole of the patella</td>
<td>Patellar tendon: over a distance of 3 cm starting from the disappearance of the inferior pole of the patella</td>
<td>No greater than 5 mm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rosengarten et al. [36]</td>
<td>Standing on a raised level surface with the great toe and knee touching the wall in a standardized lunge position</td>
<td>Patellar tendon: Supine position, knee flexed at 60º</td>
<td>Distal to proximal</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Patellar: Proximal to dister</td>
<td>Uni/Bilateral</td>
<td>From the apex of the patella to 2 cm distally</td>
<td>No greater than 5 mm</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Patellar tendon: over a distance of 3 cm starting from the disappearance of the inferior pole of the patella</td>
<td>Patellar tendon: over a distance of 3 cm starting from the disappearance of the inferior pole of the patella</td>
<td>No greater than 5 mm</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

No greater than 5 mm
<table>
<thead>
<tr>
<th>Study</th>
<th>Description</th>
<th>Localization</th>
<th>Side(s)</th>
<th>Tenderness Measurement</th>
<th>Endpoint Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>de Jonge et al. [19]</td>
<td>Prone position with feet hanging over the edge and with ankle in approximately 5-10º of dorsiflexion</td>
<td>Not described</td>
<td>Unilateral</td>
<td>9</td>
<td>From 3 to 5 cm proximal to the calcaneal insertion</td>
</tr>
<tr>
<td>de Jonge et al. [20]</td>
<td>Prone position with ankle dorsiflexion of 15º</td>
<td>Proximal to distal</td>
<td>Unilateral</td>
<td>9</td>
<td>5 contours: maximum thickness and 1.5 cm proximal and distal from the segment of maximum thickness</td>
</tr>
<tr>
<td>Docking et al. [11]</td>
<td>Participants stood on an elevated platform, with their toes and knee against a wall.</td>
<td>Distal to proximal</td>
<td>Uni/Bilateral</td>
<td>25</td>
<td>From the point that the calcaneus disappeared to the musculotendinous junction</td>
</tr>
<tr>
<td>Wong et al. [51]</td>
<td>Standing on a raised level surface with the great toe and knee touching the wall</td>
<td>Distal to proximal</td>
<td>Unilateral</td>
<td>25</td>
<td>From the disappearance of the calcaneus to the musculotendinous junction</td>
</tr>
<tr>
<td>de Vos et al. [46]</td>
<td>Prone position with feet hanging over the edge, with dorsiflexion</td>
<td>Not described</td>
<td>Unilateral</td>
<td>9</td>
<td>5 contours: 1.5 cm proximal and distal from the thickest segment (total 3 cm)</td>
</tr>
<tr>
<td>de Vos et al. [47]</td>
<td>Prone position with ankle dorsiflexion of 15º</td>
<td>Not described</td>
<td>Unilateral</td>
<td>9</td>
<td>5 contours: 1.5 cm proximal and distal from the thickest segment (total 3 cm)</td>
</tr>
<tr>
<td>van Schie et al [42]</td>
<td>Prone position with maximal ankle dorsiflexion</td>
<td>Proximal to distal</td>
<td>Unilateral</td>
<td>9</td>
<td>Mean of the thickest part of the tendon and 2 mm proximal and distal</td>
</tr>
</tbody>
</table>
Table 3. Characteristics and results of the included articles

<table>
<thead>
<tr>
<th>Author/Year</th>
<th>Design</th>
<th>Subject Characteristics</th>
<th>Pathology (Achilles/patellar tendinopathy)</th>
<th>Clinical application</th>
<th>Follow-up</th>
<th>Results</th>
<th>Practical applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Docking et al., 2018 [12]</td>
<td>Prospective cohort</td>
<td>Achilles tendon: 23.9 Patellar tendon: 23.8</td>
<td>Achillles tendon: 163 Patellar tendon: 171</td>
<td>Yes (elite)</td>
<td>Yes and No</td>
<td>Predicting Single scan</td>
<td>A percentage of DIS above ∼2.5% was a significant risk factor for the presence of symptoms at baseline. Percentage of DIS showed a weak relationship with severity of symptoms at baseline.</td>
</tr>
<tr>
<td>Docking et al., 2018 [9]</td>
<td>Prospective Cohort</td>
<td>Achilles tendon: 23.9 Patellar tendon: 23.9</td>
<td>Achilles tendon: 149 Patellar tendon: 152</td>
<td>Yes (elite)</td>
<td>Yes and No</td>
<td>Diagnosis Single scan</td>
<td>Abnormal tendons contained greater mCSA of AFS compared with normal tendons. Patellar tendon showed significant difference between</td>
</tr>
<tr>
<td>Study</td>
<td>Design</td>
<td>Statin users:</td>
<td>Controls:</td>
<td>Treatment</td>
<td>Follow-up</td>
<td>Outcome</td>
<td>Notes</td>
</tr>
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</tr>
<tr>
<td>de Sá et al., 2018 [40]</td>
<td>Cross-sectional</td>
<td>66</td>
<td>63</td>
<td>Yes</td>
<td>No</td>
<td>Diagnosis/Predicting Single scan</td>
<td>The proportion of echo-type I patterns [ST 70 (10%), CG 74 (13%)] were equivalent in the two groups.</td>
</tr>
<tr>
<td>Rudavsky et al., 2018 [39]</td>
<td>Prospective cohort</td>
<td>Range from 11 to 18</td>
<td>57 (34:23)</td>
<td>Yes</td>
<td>No</td>
<td>Monitoring 2 yrs</td>
<td>Nine percentage of adolescent dancers developed pathology during this study. Only 2 of 5 participants who developed pathology reported pain associated with their tendon.</td>
</tr>
<tr>
<td>van Ark et al., 2018 [3]</td>
<td>Randomized clinical trial</td>
<td>22.7</td>
<td>18 (16:2)</td>
<td>Yes</td>
<td>Yes</td>
<td>Monitoring 4 wk</td>
<td>Outcomes of treatments for patellar tendinopathy need to be</td>
</tr>
<tr>
<td>Study</td>
<td>Design Type</td>
<td>Exercise Program</td>
<td>Predicting</td>
<td>Time</td>
<td>Outcome</td>
<td></td>
<td></td>
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<tr>
<td>-------------------------------</td>
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<tr>
<td>Wezenbeek et al., 2018 [50]</td>
<td>Prospective cohort</td>
<td>Yes (recreational)</td>
<td>No</td>
<td>2 yrs</td>
<td>Structural parameters (echo-types) did not predict Achilles tendinopathy.</td>
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<td></td>
<td>UTC evaluation should not be the sole basis in predicting the development of tendinopathy.</td>
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<tr>
<td>Waught et al., 2018 [48]</td>
<td>Prospective</td>
<td>Yes (recreational)</td>
<td>No</td>
<td>12 wk</td>
<td>Decrease in echo-type I seen after longer rest training compared to shorter rest training. The change in echo-type was not related to the change in young’s modulus.</td>
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<td></td>
<td>UTC can be used to assess tendon response to loading; should preferably be used in combination with other analyses.</td>
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<tr>
<td>Heyward et al., 2017 [16]</td>
<td>Randomised crossover</td>
<td>Yes (recreational)</td>
<td>No</td>
<td>2.7 d</td>
<td>No significant changes on echo-types (I-IV) over the period. Significant effects of time were found for echo-types III and IV (decrease).</td>
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<td>Low to moderate loads may be beneficial in the treatment, management or rehabilitation of Achilles tendinopathy.</td>
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</tr>
<tr>
<td>Prospective cohort</td>
<td>Ballet dancers from 11 to 18</td>
<td>Yes (recreational)</td>
<td>No</td>
<td>2 yrs</td>
<td>Tendon disorganization Presence of tendon structure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Study</td>
<td>Design</td>
<td>Age Median (Range)</td>
<td>Sex</td>
<td>Intervention</td>
<td>Monitoring</td>
<td>Follow-up</td>
<td>Results</td>
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<tr>
<td>Rudavsky et al., 2017 [38]</td>
<td>Control from 21 to 40</td>
<td></td>
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<td></td>
<td></td>
<td>(echo-types III + IV) increased; there was a greater increase in the group with abnormalities.</td>
</tr>
<tr>
<td>Esmaeili et al., 2017 [14]</td>
<td>Prospective cohort</td>
<td>23.7 (26:0)</td>
<td>Yes</td>
<td>(professional)</td>
<td>No</td>
<td>18 wk</td>
<td>Both limbs and tendons showed increased echo-type I. Training load had inconsistent effects on changes in tendon structure.</td>
</tr>
<tr>
<td>Stanley et al., 2017 [43]</td>
<td>Prospective cohort</td>
<td>19.76 (9:12)</td>
<td>Yes</td>
<td>(semi-professional)</td>
<td>No</td>
<td>Baseline, 1, 2, and 3 mo</td>
<td>Increase in echo-type I. Overall positive adaptation (shift from type II to type I) in tendon structure during season.</td>
</tr>
<tr>
<td>Hernández G et al., 2016 [15]</td>
<td>Cohort</td>
<td>22.6 (20:0)</td>
<td>Yes</td>
<td>(professional/recreational)</td>
<td>No</td>
<td>Diagnosis</td>
<td>UTC cannot differentiate symptomatic and</td>
</tr>
<tr>
<td>Study</td>
<td>Design</td>
<td>Subjects</td>
<td>Number of Cases</td>
<td>Eligibility</td>
<td>Intervention</td>
<td>Follow-up</td>
<td>Outcomes</td>
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<tr>
<td>Bedi et al., 2016 [4]</td>
<td>Prospective</td>
<td>32</td>
<td>15 (13:2)</td>
<td>Yes (professional/semi-professional)</td>
<td>Monitoring</td>
<td>25 mo</td>
<td>Decrease in echo-types III and IV; increase in echo-types I and II. UTC offers an objective method to evaluate healing of Achilles tendons.</td>
</tr>
<tr>
<td>Docking et al., 2016a [10]</td>
<td>Prospective</td>
<td>Achilles tendon: 28.17 Patellar tendon: 24.04</td>
<td>Achilles tendon: 66 (63:3) Patellar tendon: 50 (49:1)</td>
<td>No/Yes (sedentary/elite athletes)</td>
<td>Diagnosis</td>
<td>Single scan</td>
<td>Echo-types I and II were significantly lower in the pathological tendon in comparison to normal tendons and echo-types III and IV were significantly increased. UTC can possibly detect 'pathological' tendons, inconclusive is if this results in tendon symptoms.</td>
</tr>
</tbody>
</table>
| Docking et al., 2016b [8] | Prospective | 23.8     | 18 (18:0)       | Yes (professional) | Monitoring | 5 mo | Echo-type I increased and echo-types II-IV decreased, suggesting a tendon improved at the end of the preseason. UTC can detect changes in tendon in response to load. | }
<table>
<thead>
<tr>
<th>Study</th>
<th>Design</th>
<th>Age</th>
<th>Sports participation</th>
<th>Sports intensity</th>
<th>Monitoring</th>
<th>Diagnosis</th>
<th>UTC detection</th>
<th>UTC role</th>
</tr>
</thead>
<tbody>
<tr>
<td>Masci et al., 2016 [31]</td>
<td>Prospective</td>
<td>40</td>
<td>18 (14:4)</td>
<td>Yes (recreational/ professional)</td>
<td>Yes</td>
<td>Single scan</td>
<td>UTC detects tendon disorganization in the medial part of the Achilles tendon.</td>
<td>UTC can complement US and color Doppler by demonstrating disorganized focal medical Achilles tendon structure indicative of plantaris tendon involvement in tendinopathy.</td>
</tr>
<tr>
<td>van Ark et al., 2016 [2]</td>
<td>Prospective</td>
<td>17.2</td>
<td>41 (30:11)</td>
<td>Yes (recreational)</td>
<td>No</td>
<td>Monitoring</td>
<td>Each day of a 5-day volleyball tournament</td>
<td>No significant changes in tendon structure (echo-types I-IV) over the tournament period. Either structure is stable enough, UTC is useless or tournament/time insufficient to bring about change?</td>
</tr>
<tr>
<td>Wezenbeek et al., 2017 [49]</td>
<td>Cross-sectional</td>
<td>17.9</td>
<td>70 (29:41)</td>
<td>Yes (recreational)</td>
<td>No</td>
<td>Diagnosis</td>
<td>Single scan</td>
<td>Tendon structure: 54.6% echo-type I, 42.8% echo-type II, 2.2% echo-type III, and 0.3% echo-type IV. More echo-type II at insertion than mid-portion. Female tendons contained more echo-type II (in insertion and mid-portion) of tendon or gender of participant.</td>
</tr>
<tr>
<td>Study</td>
<td>Design</td>
<td>No. of patients</td>
<td>Gender</td>
<td>Recreational</td>
<td>Follow-up</td>
<td>Clinical Findings</td>
<td>Implications</td>
<td></td>
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<tr>
<td>Masci et al., 2015 [30]</td>
<td>Prospective</td>
<td>39</td>
<td></td>
<td>Yes (recreational)</td>
<td>6 mo</td>
<td>Increase in echo-types I + II and decrease in III + IV at 6 months</td>
<td>UTC can assess structural response to treatment</td>
<td></td>
</tr>
<tr>
<td>Rosengarten et al., 2015 [36]</td>
<td>Prospective</td>
<td>23.8</td>
<td></td>
<td>Yes (professional)</td>
<td>Baseline, 1, 2 and 4 d</td>
<td>Difference in UTC results between groups. There was a transient change (day 2) in tendon structure (disorganization) in those with normal tendons that returned to baseline at day 4.</td>
<td>UTC may be able to detect changes in tendon structure in response to load.</td>
<td></td>
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<tr>
<td>de Jonge et al., 2015a [19]</td>
<td>Case-control</td>
<td>Type 1 diabetics: 23</td>
<td></td>
<td>No/Yes (sedentary/recreational)</td>
<td>No</td>
<td>UTC shows definite abnormalities in type 2 diabetes patients (possibly also type 1) possibly predictive of tendinopathy.</td>
<td>Screening for high risk of development.</td>
<td></td>
</tr>
<tr>
<td>de Jonge et al., 2015b [20]</td>
<td>Prospective</td>
<td>Symptomatic group: 49.7</td>
<td></td>
<td>Yes (sedentary/recreational)</td>
<td>Yes</td>
<td>Difference in echo-types between symptomatic and asymptomatic</td>
<td>UTC has no correlation with clinical measure (VISA-A score).</td>
<td></td>
</tr>
<tr>
<td>Study</td>
<td>Design</td>
<td>Patient groups</td>
<td>Tendinopathy group</td>
<td>Healthy group</td>
<td>Asymptomatic</td>
<td>Asymptomatic tendon</td>
<td>UTC result</td>
<td>Diagnosis</td>
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<tr>
<td>Docking et al., 2015 [11]</td>
<td>Prospective</td>
<td>Tendinopathy group: 30.3</td>
<td>Tendinopathy group: 21 (20:1)</td>
<td>Healthy group: 6 (5:1)</td>
<td>Yes (recreational/professional)</td>
<td>Yes</td>
<td>Diagnosis</td>
<td>Single scan</td>
</tr>
<tr>
<td>Wong et al., 2015 [51]</td>
<td>Prospective case-control</td>
<td>Diabetic patient: 37.9</td>
<td>Diabetic group: 7 (5:2)</td>
<td>Control group: 10 (4:6)</td>
<td>Yes (recreational)</td>
<td>No</td>
<td>Monitoring</td>
<td>Baseline, 2 and 4 d after the run.</td>
</tr>
<tr>
<td>Study</td>
<td>Type of Study</td>
<td>Participants</td>
<td>Follow-Up</td>
<td>Monitoring</td>
<td>Outcome</td>
<td>Remarks</td>
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<tr>
<td>de Vos et al., 2012 [46]</td>
<td>Prospective</td>
<td>Group over 4</td>
<td>No/Yes</td>
<td>Monitoring</td>
<td>UTC assesses tendon structure, though this seems unrelated to symptoms.</td>
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<tr>
<td></td>
<td>clinical trial</td>
<td>days post</td>
<td>(sedentary/</td>
<td>Baseline,</td>
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<tr>
<td></td>
<td></td>
<td>exercise.</td>
<td>recreational)</td>
<td>2, 8, 16,</td>
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<td></td>
<td></td>
<td></td>
<td>and 24 wks</td>
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<td></td>
<td></td>
<td></td>
<td>No correlation between Visa-A and UTC. An improvement on echo-types I</td>
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<td></td>
<td></td>
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<td>and II was observed without correlation to symptom severity.</td>
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<tr>
<td>de Vos et al., 2011 [47]</td>
<td>Randomized</td>
<td>PRP group: 49</td>
<td>No/Yes</td>
<td>Monitoring</td>
<td></td>
<td>UTC assesses tendon structure response to treatment(s).</td>
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<tr>
<td></td>
<td>clinical trial</td>
<td>(8.1)</td>
<td>(sedentary/</td>
<td>Baseline 6,</td>
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<td></td>
<td></td>
<td>Saline group:</td>
<td>recreational)</td>
<td>12, and 24</td>
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<td></td>
<td></td>
<td>50 (9.4)</td>
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<td>wk</td>
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<td>PRP group: 27</td>
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<td>Improvement in tendon structure after 24 weeks.</td>
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<td></td>
<td>(13:14)</td>
<td></td>
<td></td>
<td>No difference in change of echo-type between treatment groups.</td>
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<tr>
<td>van Schie et al., 2010 [42]</td>
<td>Case-control</td>
<td>Symptomatic:</td>
<td>Not</td>
<td>Diagnosis</td>
<td></td>
<td>UTC useful in monitoring response to treatment.</td>
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<td></td>
<td></td>
<td>44.9</td>
<td>described</td>
<td>Single</td>
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<td></td>
<td></td>
<td>Asymptomatic:</td>
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<td>scan</td>
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<td></td>
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<td>43.6</td>
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<td></td>
<td></td>
<td>Symptomatic:</td>
<td></td>
<td></td>
<td>Symptomatic tendons showed less echo-types I + II than asymptomatic.</td>
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<td></td>
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<td>group: 26</td>
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<td></td>
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<td>(12:14)</td>
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<td></td>
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<td>Asymptomatic:</td>
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<td>26 (16:10)</td>
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UTC methods
Generally, studies employed one of 2 positions to perform the scan of the Achilles tendon: the standing position [4, 8, 10, 11, 14, 36, 43, 51] and the prone position [9, 12, 19, 20, 30, 31, 40, 42, 46–49]. Of the studies that positioned patients in prone position, different angles of dorsiflexion were used: 5 to 10 degrees [19, 48–50], 15 degrees [20, 47], maximum dorsiflexion [16, 30, 31, 42] and neutral position [9, 12] and in two studies this was not specified [40, 46].

In scanning the patellar tendon, patients were positioned sitting with knee flexion of 90 degrees [15] or in supine position in four different angles of knee flexion, 60 [8], 90 [38, 39], 100 [2, 3], or 120 degrees [9, 12].

Most studies that performed a UTC scan of the Achilles tendon performed the scan from distal to proximal [4, 8–12, 14, 16, 30, 31, 36, 43, 51]. The patellar tendon was usually scanned from proximal to distal [2, 3, 8, 38, 39] although one study scanned from distal to proximal [15].

The most frequently used window size was 25, $n = 16$ [2–4, 8–12, 14, 30, 31, 36, 39, 40, 43, 48, 51]. Two authors used a window size of 17 [49, 50] and 3 authors used a window size of 9 [19, 20, 42, 46, 47]. One study did not specify the window size used [15].

Role of UTC in predicting tendinopathy
Of the 3 studies that investigated the Achilles tendon [12, 19, 50], one study found that UTC could possibly predict the onset of tendinopathy or symptoms in different populations [19]. However, the prospective studies with the largest sample size determined that UTC structure could not predict the development of tendinopathy in young healthy individuals and elite male Australian football players [12, 50]. The studies that investigated the patellar tendon based their results on the amount of disorganized tissue structure (DIS) (echo-types III and IV together). One study observed that a higher amount of DIS might increase the risk of developing tendinopathy [38]. Other authors observed that the amount of echo-types III and IV at baseline do not predict future symptoms [12].

Role of UTC in diagnosing tendinopathy
UTC was used for diagnosis in 8 studies investigating the Achilles tendon [8, 9, 11, 12, 31, 40, 42, 49] and four studies assessing the patellar tendon [8, 9, 12, 15]. Of the AT studies, 2 studies identified that UTC can accurately differentiate between symptomatic and asymptomatic tendons [12, 42]. Van Schie et al. [42] found a diagnostic accuracy of 83% when a threshold of 75% echo-types I and II was set to differentiate between asymptomatic (above 75%) and symptomatic (below 75%) tendons. Docking et al. [12] observed that a higher percentage of echo-types III and IV increases the capacity of UTC to identify subjects with tendinopathy. The same authors found that a percentage above 6% of echo-types III and IV was a significant risk factor for the presence of symptoms at baseline measurement [12]. Other authors also observed that symptomatic tendons show significantly higher percentage of echo-types III and IV compared to asymptomatic tendon [8, 9, 11]. In addition,
to the UTC echo-type analysis, some authors also investigated the mean cross-sectional area (mCSA) of the aligned fibrillar structure (AFS) (echo-types I and II together) and DIS. Docking et al. [9] observed that mCSA of AFS in the symptomatic group was similar to the asymptomatic group and the mCSA of DIS was significantly higher in the symptomatic group. Docking and Cook [8] observed that a significantly higher amount of mCSA of AFS and DIS in the symptomatic group compared to the asymptomatic group.

Masci et al. [31] observed that UTC can complement US/Doppler investigation, identifying the involvement of the plantaris tendon in AT cases. One study showed that different factors should be considered when analyzing UTC images (age, gender, tendinopathy location etc) [49]. One study investigated the influence of medication on the Achilles tendon structure and observed no negative effects of statin [40].

Of the studies investigating patellar tendons, one study observed similar findings as found in the AT patients – a higher percentage of echo-types III and IV increases the capacity of the UTC to identify the subjects with tendinopathy. Docking et al. showed that a percentage of DIS above 2.5% was a significant risk factor for the presence of symptoms. Other studies found that symptomatic tendons have a higher percentage of echo-types III and IV and, consequently, less percentage of echo-types I and II compared with asymptomatic subjects [8, 9]. When the mCSA was investigated, 2 studies observed that mCSA of AFS and DIS were higher in the symptomatic group compared to the asymptomatic group [8, 9]. One study showed that UTC does not differentiate between asymptomatic and symptomatic patellar tendons [15].

**Role of UTC in monitoring changes in tendon structure and/or tendinopathy**

A total of fifteen studies used UTC to monitor changes on Achilles or patellar tendons. Of the twelve studies performed a UTC analysis in Achilles tendon, [4, 10, 14, 16, 20, 30, 36, 43, 46–48, 51] six studies investigated the changes on asymptomatic tendon structure as an adaptation to load, [10, 14, 16, 36, 43, 51] four studies investigated the effect of different treatment modalities on tendon structure [20, 46–48] and two studies investigated the structural effect of surgical tendinopathy treatment [4, 30]. Three studies investigated the patellar tendon [2, 3, 39], two investigating the effect of load on asymptomatic tendons [2, 39] and one investigating the effect of an exercise treatment [3]. Of the studies that investigated the effect of load on Achilles tendon structure, four studies showed a positive adaptation [10, 14, 16, 43], one study showed no changes [51], and one study showed that 2 days after exercise tendon structure showed a transient response and returned to baseline at day 4 [36]. Of the studies that assessed tendon structure after either conservative or surgical treatment, five studies [4, 20, 30, 46, 47] showed that there was an increase in echo-type I and a decrease in echo-type II and one study showed a decrease in echo-type I after training with a short rest period (3-s) [48]. Regarding the studies investigating the patellar tendon, one study showed no significant changes after 5-days volleyball tournament [2], one study showed no significant changes after conservative treatment [3] and one study showed a tendon maladaptation in adolescent ballet dancers [39].
DISCUSSION

This study aimed to determine the clinical applicability of UTC in predicting, diagnosing and monitoring of tendon structure and/or tendinopathy. A systematic review of all literature providing information on the role of UTC in imaging of tendons was conducted, and a total of 27 studies included, most concerning analysis of the Achilles tendon.

Despite the fact that prior research showed that conventional US can predict the onset of AT and PT [32] the results of the studies included in this review suggest that UTC might not predict the development of AT when the whole tendon is contoured and a percentage threshold is set; perhaps this is a result of the methods of UTC analysis as previous studies show ultrasound is predictive of new symptoms [32]. Several studies assessed the total volume of the Achilles tendon, whereas studies using conventional US focused specifically on pathological regions [32]. In addition, the use of window size 25 and lack of information regarding contour distance may also influence the image interpretation, as important (future) pathology may be missed. Regarding the results for the patellar tendon, the use of UTC to predict the development of future symptoms is inconclusive when based on percentage of echo-types III and IV [42]. However, it may be important to consider the level of healthy tissue using echo-types I and II. To be able to predict future symptomatic pathology, however, UTC images of healthy controls of which some eventually develop tendinopathy are required. Given the relatively low incidence of AT and PT in the general population, the required subject number is very difficult to achieve; this explains the low number of predictive UTC studies. Of the included studies attempting to predict tendinopathy using UTC, different study designs and populations were employed; this makes comparing the results of these studies difficult because of heterogeneity. More uniform studies into the predictive value of UTC are needed.

The results of this review showed that UTC might be able to provide additional diagnostic data in patients with AT; however UTC appears to offer little benefit over and above conventional imaging for the PT [7, 13, 28, 29]. Pathological Achilles tendons show a lower percentage of echo-types I and II and consequently a higher percentage of echo-types III and IV [6, 8, 31, 49]. However, despite the presence of disorganized structure, UTC alone cannot differentiate between asymptomatic and symptomatic tendons. A possible explanation for these findings might be the fact that pathology may develop prior to the presence of clinical symptoms [32, 45]. A previous study using UTC which showed that tendon structure of the contralateral, asymptomatic, tendon is also compromised corroborates with this explanation [11]. In addition to that, some authors suggests that tendons with higher percentage of echo-types III and IV (DIS structure) would also present a higher area of AFS that allows the tendon to function without presenting symptoms. However, the number of studies using UTC for tendinopathy diagnosis is still low (n = 9) and the absence of reference (gold standard) values for the UTC echo-types makes it difficult to use this tool for diagnosing tendinopathy.

In addition to providing additional diagnostic information in AT, UTC shows potential in its
ability to monitor the effect of load/treatment on Achilles and patellar tendon structure. UTC seems to be able to detect subtle changes on tendon structure as a result of loading. However, the use of this tool to monitor the effect of a rehabilitation protocol is not clear yet, especially given that the association between UTC echo-types and the clinical outcome is inconclusive. This lack of association is also observed for the conventional imaging outcomes and the tendon might need to be investigated in a long-term follow-up to observe the (changes on) tendon structure after treatment [7, 35].

Unlike conventional techniques, UTC provides objective information on tendon structure that can potentially be used in multiple phases of tendinopathy management (predicting, diagnosing and monitoring). These objective parameters can be used to detect (mal) adaptation to load and/or treatment and provide quantifiable information in the diagnostic and monitoring phases. For example, UTC is an interesting imaging tool to be correlated with the continuum model [5]. This model proposes that tendon pathology occurs in several phases, and using UTC, it might be possible to identify the current phase and the tendon’s response to the load/treatment performed. More research into adaptive and maladaptive responses to loading and treatment however is required. Athletes should preferably be followed longitudinally to determine specific thresholds for pathology based on echo-types. In addition, this imaging pathology should be correlated to the clinical picture and to the golden standard, histology, to conclude on UTC’s role in diagnosing injuries specifically. The latter would require correlations between human tendon biopsies and UTC, to substantiate the true pathology seen by echo-types. Previous research investigated these correlations in the equine superficial digital flexor and showed that the UTC is a valid tool to quantitatively measure tendon structural integrity [41].

Limitations and future directions
A limitation of this review is the lack of methodological quality assessment of the included studies. We opted for a narrative, descriptive, approach to this review. Additionally, the included studies showed to be heterogeneous in methods, designs and aims enabling data pooling.

In contrast to the heterogeneity in study design and methods, the included studies tended to focus on the same tendinopathy, that is, mid-portion AT; however this matches the incidence rates in the general population [1, 18]. The lack of studies on PT makes conclusions about UTC’s potential in tendinopathies, difficult to determine. The results of our review also showed that many of the same authors contributed to the scientific literature concerning UTC, potentially increasing bias in methodologies and interpretational expertise. We therefore believe more authors should investigate the potential of UTC, taking various populations into consideration: e.g. subjects with different level of activity, larger range of age and, again, with different locations of tendinopathy.

UTC standard methodology
Because the results show a wide variation in the UTC methods applied, no standard synthesized recommendations for UTC use based can be made.
Standardization of the UTC methodology is necessary to ensure homogeneity of scientific results and facilitate analyses and comparisons. Furthermore, this standard methodology can be applied in clinical practice. The standard methodology regarding UTC scanning should include patient positioning, direction of the scan and tendon side, and the parameters for the imaging analysis should include window size, area of interest and interval between the contours. Based on the methodology used in the studies included in this review and on the expertise of the authors concerning UTC equipment, this manuscript proposes such a standard methodology for UTC scanning and imaging analysis for Achilles and patellar tendons.

The proposed standardized method is shown in Table 4.

### Table 4. Recommendations for UTC administration and analysis

<table>
<thead>
<tr>
<th>Patient position</th>
<th>Direction of the scan</th>
<th>Side</th>
<th>Window size</th>
<th>Area of interest (ROI)</th>
<th>Interval between contours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Achilles tendon</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patient prone with ankle in maximum dorsiflexion</td>
<td>Distal to proximal</td>
<td>Bilateral</td>
<td>9 or 17</td>
<td>Insertion – From the upper border of the calcaneus to 2 or 3 cm proximal.</td>
<td>No greater than 5mm</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Mid-portion – from 2 cm proximal to the upper border of the calcaneus to 6 cm proximal. Minimum of a 2 cm ROI.</td>
<td></td>
</tr>
<tr>
<td>Patellar tendon</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Patient supine with knee in flexion between 90 – 100º</td>
<td>Proximal to distal</td>
<td>Bilateral</td>
<td>9 or 17</td>
<td>From the patella appendix to 3 cm distally.</td>
<td>No greater than 5mm</td>
</tr>
</tbody>
</table>

Regarding the scanning of unilateral or bilateral, the included studies show that in a research setting it is sufficient to scan unilaterally. However, because the contralateral, asymptomatic tendon often shows a compromised structure [11] it is recommended to scan bilaterally in clinical practice. This allows clinicians to detect abnormalities that might increase the risk of future tendinopathy [32]. Similar to the studies included in this review, we recommend patients be positioned according to the authors preference in scanning the Achilles tendon, as no superiority of a single position has been shown. More important than the position is a maximum level of tension on the Achilles tendon,
and this requires scanning in maximum dorsiflexion. In scanning the patellar tendon a supine position with the knee flexed 90 to 100 degrees is recommended, allowing for the necessary tendon tension. In line with the studies included in this review, we recommend the Achilles tendon is scanned distal to proximal and patellar tendon proximal to distal, as this ensures that the proximal calcaneus and apex of the patella are identified before start scanning, both of these landmarks are important for identifying the exact position along the tendons. This improves objectively and is critical for accurate repeated measurements.

Regarding imaging analysis, the majority of the studies included in this review used the window size of 25. However, based on the UTC algorithm [49] using window sizes of 9 or 17 allows images to be analyzed in greater detail [49]. More sensitive settings might be utilized in order to draw accurate conclusions. Therefore, we recommend that UTC images should be analyzed using window size 17 or 9. Moreover, based on the studies included in this review, we also suggest that contours should be drawn no greater than 5 mm apart as contouring at greater lengths can lead to false interpolation of the tendon either including tissue external to the tendon or missing tendon tissue, thereby giving false results.

Regarding the tendon area selected for analysis, three different sites of the Achilles tendon can be analyzed depending on the zone of pathology: (1) full length (from the disappearance of the calcaneus to the musculotendinous junction), (2) insertion (from the disappearance of the calcaneus to 2 cm proximal) and (3) mid-portion (from 2 to 6 cm proximal to the upper border of the calcaneus in a proximal direction). However, as the insertion and mid-portion show a different distribution of echo-types [49], and it is believed that insertional and mid-portion AT are distinct clinical and tendon pathologies [24], we recommend analyzing the insertion and mid-portion separately. For the patellar tendon images, since tendinopathy is frequently observed in the inferior pole of the patella [34], the analysis of the proximal area (from apex to 3 cm distally) is recommended.
CONCLUSION AND RECOMMENDATIONS

The results of this review showed a potential clinical role for UTC in monitoring changes in tendon structure and/or tendinopathy. The echo-types that UTC provides might be interpreted in the context of multiple outcomes to guide the athlete to optimal loading and the patient to adequate recovery. In conclusion, UTC analysis seems to have an important potential for monitoring changes in tendon structure and/or tendinopathy but further studies need to consider the methodology they use and its exact clinical interpretation. Additional research is needed validating the use of UTC in human tendon and more research is needed investigating the UTC potential in predicting and diagnosing tendinopathy.
REFERENCES


Part II

Outcome after Achilles tendon rupture