Substantiating the Use of Tendotonometry for the Assessment of Achilles and Patellar Tendon Stiffness: A Systematic Review

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Abstract

Objective: To systematically describe the next relevant aspects of tendotonometry in (1) its validity and reliability, (2) differences between populations, (3) the effect of interventions, and (4) differences between healthy and symptomatic Achilles tendon (AT) and patellar tendon (PT). **Data Sources:** Three online databases (PubMed, Embase, and EBSCOhost) were systematically searched on the 10th of October 2023. All scientific literature concerning the use of tendotonometry in assessing tendon stiffness was collected. Articles were eligible if tendotonometry with a myotonometer digital palpation device was used to assess PT or AT stiffness in adults. **Main results:** Thirty-four studies were included, which were categorized into studies regarding the (1a) reliability and (1b) validity of tendotonometry, (2) differences in stiffness between populations, (3) changes in stiffness due to interventions, (4) stiffness of healthy compared with injured tendons, and (5) other observational studies. The inter-rater and intrarater reliability of tendotonometry appeared to be good in assessing AT and PT stiffness, with only moderate evidence for the AT and inconclusive evidence for the PT. There is high certainty evidence that tendotonometry can detect differences in AT and PT stiffness after training interventions. Inconsistent results were found for the adequacy of tendotonometry to detect differences in AT and PT stiffness between populations. **Conclusions:** This review shows a potential role for tendotonometry in measuring tendon stiffness. However, more research is needed for validating the use of tendotonometry in AT and PT and its exact clinical interpretation.

Key Words: tendotonometry, Achilles tendon, patellar tendon, stiffness

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INTRODUCTION

Achilles tendinopathy and patellar tendinopathy are common in both elite and recreational athletes and can result in recurrent or prolonged symptoms.[1] For patellar tendinopathy, a prevalence of 45% has been reported in elite volleyball athletes.[2] For Achilles tendinopathy, an incidence of 5% was found in recreational runners,[3] 6% in ball game players, and the highest incidence was found in gymnasts, 17%.[4] Because management of tendinopathy can be challenging, prevention is important.

Tendon tissue is highly adaptive to mechanical stimuli. When a tendon is exposed to repetitive stress, changes in the mechanical properties of a tendon occur. Stiffness is 1 of the mechanical properties that change because of training.[5] Depending on the tendon's anatomical location and the training type, stiffness either increases or decreases.[6–8] This leads to the assumption that differences in tendon stiffness are detectable between athletes and nonathletes. Alterations in tendon stiffness have also been found in pathologic tendons. Both an increase and decrease in tendon stiffness have been linked to tendinopathy.[9–13] Animal studies showed that changes in tendon stiffness already occur before the tendon becomes symptomatic in mechanically induced tendinopathy.[9]

Tendotonometry, that is measurement of tendon stiffness, could inform coaches and medical staff about (changes in) the health status of a tendon. By repetitive measurements of tendon mechanical properties, changes therein might be noticed at an early stage. In this way, monitoring tendon stiffness might be helpful in evaluating the effects of load management and strength training, which are important in the prevention and rehabilitation of tendinopathy. Ultrasonography and elastography, commonly used for measuring tendon stiffness, have relatively high equipment costs and require technical expertise.[10–12] Tendotonometry, using a noninvasive hand-held digital palpation device (Figure 1), might be a more feasible alternative for measuring tendon stiffness and other soft tissue properties. The device applies a brief mechanical impulse to the skin, whereafter oscillations occur. The resulting oscillation parameters captured by the device are used to calculate the mechanical properties of

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the underlying tissues.[13,14] Because the device is portable and easy to use, it is suitable for repetitive measurements in sports and/or clinical setting.[15]

The digital palpation device appeared to be a valid and reliable tool for measuring viscoelastic muscle properties in patients with cerebrovascular accidents.[13] Use of tendotonometry to assess tendon stiffness is relatively new, and it is still unknown whether this device is a valid and reliable tool for monitoring tendon stiffness. Therefore, the aim of this review is to systematically describe the next relevant aspects of tendotonometry in (1) its validity and reliability, (2) differences between populations, (3) the effect of interventions, and (4) differences between healthy and symptomatic Achilles tendon (AT) and patellar tendon (PT).

Figure 1. Line drawing of a hand-held digital palpation device. Page et al[16]

METHODS

This systematic review was written in accordance with the PRISMA guidelines.[17] The study protocol was registered with the International Prospective Register of Systematic Reviews (PROSPERO: CRD42022352421).

Search Strategy

A systematic search of the databases PubMed, Embase, and EBSCOhost was performed on the 10th of October 2023. The search strings comprised keywords related to AT and PT and the digital palpation device. The complete search strings can be found in (see **Tables 1-10, Supplemental Digital Content 1-10**, http://links.lww.com/JSM/A439, http://links.lww.com/JSM/A440, http://links.lww.com/JSM/A441, http://links.lww.com/JSM/A442, http://links.lww.com/JSM/A443, http://links.lww.com/JSM/A444, http://links.lww.com/JSM/A445, http://links.lww.com/JSM/A446, http://links.lww.com/JSM/A447, http://links.lww.com/JSM/A448). Studies had to be written in English. No date restrictions were applied to the search.

Study Selection

After removing duplicates, 2 reviewers (L.v.D., R.F.) independently screened the titles and abstracts to identify potentially eligible studies. Studies were eligible for inclusion if (1) a hand-held digital palpation device was used for the assessment of PT or AT stiffness and (2) measurements were performed in adults with healthy or injured tendons, without neurologic conditions and musculoskeletal conditions other than tendon injuries. Articles written in English were included. Furthermore, no specific criteria regarding study types or specific interventions/controls have been applied. In case of uncertainty about the inclusion of an article based on title and abstracts, the full text was retrieved to determine inclusion or exclusion. When no decision could be made, a third reviewer (J.Z.) was included in the screening process for the final decision.

Data Extraction

Data about the study design, study objective, characteristics of the participants (number of participants, type of population, age), stiffness values (N/m) as measured with the digital palpation device, the main results, and the conclusion were extracted from the included studies. Two reviewers (L.v.D., R.F.) worked independently on the data extraction.

Synthesis

Studies were categorized into groups: studies evaluating the validity of the device, the reliability of the device, studies comparing different populations, studies evaluating interventions, studies comparing healthy and injured tendons, and a sixth group containing other observational studies. Results are shown in tables (see **Tables 1-10, Supplemental Digital Content 1-10**, http://links.lww.com/JSM/A439, http://links.lww.com/JSM/A440, http://links.lww.com/JSM/A441, http://links.lww.com/JSM/A442, http://links.lww.com/JSM/A443, http://links.lww.com/JSM/A444, http://links.lww.com/JSM/A445, http://links.lww.com/JSM/A446, http://links.lww.com/JSM/A447, http://links.lww.com/JSM/A448), containing the most important results, such as ICC values for reliability studies, and shown in stiffness values in N/m (SD). Found results were judged based on methodological quality after which conclusions were drawn.

Methodological Quality

The methodological quality of reliability studies, randomized controlled trials (RCT), nonrandomized interventional studies, and cross-sectional studies was assessed by 2 reviewers using, respectively, the Quality Appraisal of Diagnostic Reliability (QAREL) checklist,[18] Cochrane Risk of Bias (RoB) tool, RoB In Non-randomized Studies of Interventions (ROBINS-I) tool, and the NIH quality assessment tool.

The grading of the certainty of evidence (CoE) of the individual studies was performed by 2 reviewers according to the GRADE system.[19] The strength of evidence per subcategory was assessed using the 4 levels of evidence (strong, moderate, some, inconclusive) as defined by Ariëns et al[20]

RESULTS

Figure 2 shows an overview of the search strategy. Out of 191 studies, 34 were included. Despite extensive search efforts, 5 articles could not be retrieved.

All included studies used the MyotonPRO for assessing tendon stiffness. Studies were categorized into groups: 8 studies evaluated the reliability of which 1 also assessed the validity of the device (see **Table 1**, **Supplemental Digital Content 1**, http://links.lww.com/JSM/A439), 6 studies compared different populations (see **Table 2, Supplemental Digital Content 2**, http://links.lww.com/JSM/A440, 1 study also assessed the reliability and is, therefore, mentioned only in Table 1), 12 studies evaluated interventions (see **Table 3**, **Supplemental Digital Content 3**, http://links.lww.com/JSM/A441), 3 studies compared healthy and injured tendons (see **Table 4**, **Supplemental Digital Content 4**, http://links.lww.com/JSM/A442), and 6 were other observational studies (see **Table 5**, **Supplemental Digital Content 5**, http://links.lww.com/JSM/A443). For a summary of the findings per group, see Table 1.

Validity

One study assessed the validity of the MyotonPRO by comparing stiffness values with Youngs modulus obtained with shear wave elastography (SWE).[15] Stiffness values had a high level of agreement with SWE for the AT (ICC = 0.54, P = 0.014).[15]

The methodological quality of this study scored 6 out of 11 questions "yes" or "not applicable." The CoE of this study was scored low. Overall, there is low evidence regarding the validity of the digital palpation device for measuring tendon stiffness.

Reliability

Of the 8 reliability studies, 5 studies assessed the inter-rater and intrarater reliability for measuring the stiffness of the AT,[15,21–24] 1 study assessed the inter-rater and intrarater reliability for measuring the stiffness of the PT,[10] 1 study looked into the intrarater reliability for assessing both AT and PT stiffness,[25] and 1 study compared the standard and short protocol in the digital palpation device with measuring AT stiffness.[26] All 8 studies assessed the reliability in healthy adults with ages varying between 18 and 50 years old.

The inter-rater and intrarater reliability of the digital palpation device for assessing AT stiffness was reported as very good (intraclass correlation, ICC, ranged 0.85-0.98 and 0.86-0.95, respectively).[15,21–25] The inter-rater and intrarater reliability of the digital palpation device for assessing PT stiffness was also reported as very good (ICC ranged 0.74-0.96 and ICC ranged 0.87-0.96, respectively).[10,25] By comparing 10 and 5 taps in 1 AT measurement, it was concluded that the reliability of the short protocol was comparable with the standard protocol.[26] Four studies found a significant increase in AT stiffness when the ankle position was adjusted from neutral to different dorsiflexion angles.[21–24]

Methodological quality of these different studies was comparable, with 5 to 9 out of 11 questions answered "yes" or "not applicable", and most reliability studies showing RoB in 1 item of the QAREL (see **Table 6, Supplemental Digital Content 6**, http://links.lww.com/JSM/A444).

The CoE for the reliability studies was very low to moderate for the PT (2 studies) and low to moderate for the AT (7 studies), based on study design and possible RoB (see **Table 10, Supplemental Digital Content 10**, http://links.lww.com/JSM/A448).

Overall, there is moderate evidence regarding the reliability of the digital palpation device for measuring AT stiffness and inconclusive evidence regarding PT stiffness.

Different Populations

Four of the 6 studies assessed differences in AT and PT stiffness between athletes in different sports and nonathletes. The sports were badminton (senior athletes),[27] basketball,[28] soccer,[29] and breakdance.[30] Two cross-sectional studies with good methodological quality assessed differences in AT stiffness between male and female healthy adults,[22,31] and 1 study assessed AT and PT stiffness in different age groups.[27] For both AT and PT, stiffness significantly increased with age (22.3%, P = 0.02 and 19.1%, P < 0.01 higher stiffness in older than 65 years compared with younger than 45 years in badminton players, and physically active people, respectively).[27] Two studies comparing athletes with controls reported significantly higher PT stiffness for the athlete group,[29,30] while Bravo-Sánchez et al[27] reported significantly lower PT stiffness in badminton athletes than in physically active people.

For AT stiffness, the results of the different studies were inconsistent: Chang et al[28] reported significantly higher AT stiffness in basketball players than in nonathletes, while 2 other studies reported no significant difference in AT stiffness between athletes and nonathletes[27,29]: Deng et al[31] reported no differences in AT stiffness between males and females (1228.6 ± 162.8 N/m in males compared with 1205.4 ± 187.3 N/m in females, P = 0.695), while Ta$\frac{S}{E}$ and Salkin[22] found significantly higher AT stiffness in males than in females (856.1 ± 82.5 N/m in males compared with 781.0 ± 98.1 N/m in females). Participants in both studies were healthy adults with a mean age between 20 and 26 years.

The level of methodological quality varied between these studies, with 8 to 12 out of 14 questions answered "yes" or

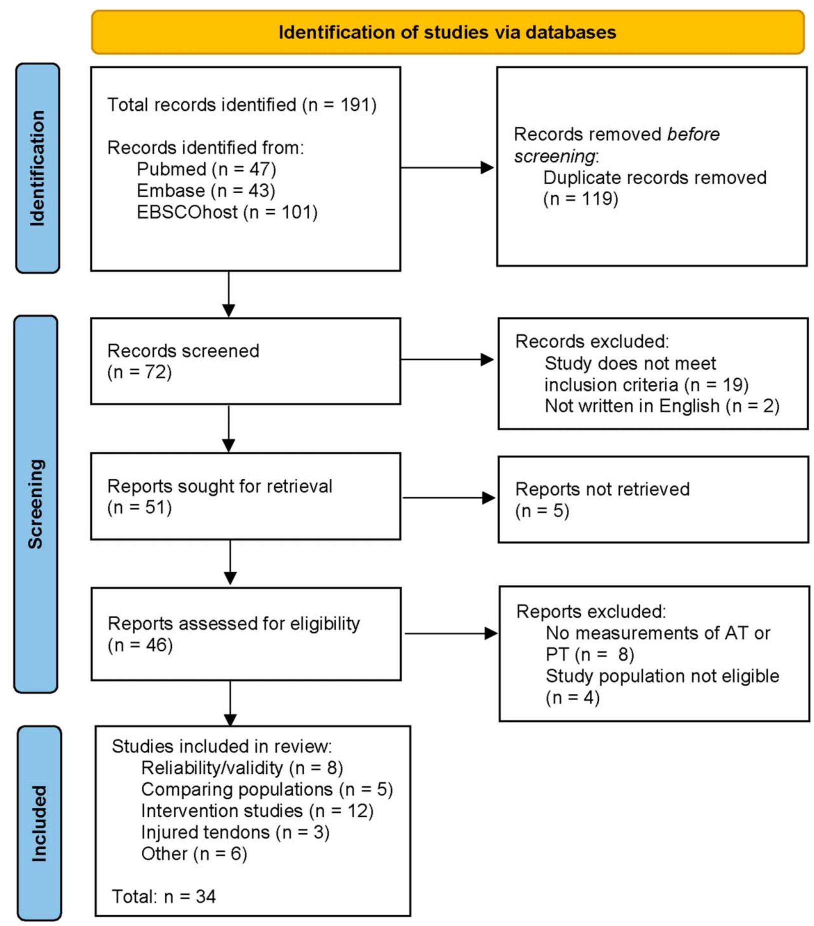

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Figure 2. PRISMA flow diagram.

"not applicable" (see **Table 7, Supplemental Digital Content 7**, http://links.lww.com/JSM/A445). The biggest concerns were about blinding, confounding, and not measuring and reporting variations in exposure to the independent variable, for example, the exact amount of training hours or years of experience in a particular sport.

The CoE of the observational studies was rated as very low to low for the PT (3 studies) and as low for the AT (4 studies). Therefore, the overall evidence of the adequacy of the digital palpation device to detect differences between populations is low.

Training and Treatment Interventions

In 6 of the 12 intervention studies, the intervention consisted of a specific training: resistance training,[32,33] a track cycling time trial,[34] karate fights,[35] and unilateral or bilateral conditioning activities (CA).[36,37] In other studies, the effect of paraffin therapy,[38] stretching exercises,[39,40] 60 days of bedrest,[41] and different massage techniques[42,43] was evaluated. The digital palpation device detected a significant increase in stiffness from pretraining to post-training, in recreational and elite athletes, in PT[32,34] and AT.[32,33,35–37] AT stiffness increased after both a single resistance training session (+13.1%, $P < 0.01$)[33] and a 6-week resistance training program (left AT: +12.8%, $P > 0.01$; right AT: +10.1%, $P > 0.01$).[32] A similar increase in stiffness was found for the PT after 6 weeks of resistance training (left PT: +15.5%, $P > 0.01$; right PT: +18.5%, $P > 0.01$).[32] AT stiffness increased after unilateral CA,[37] while bilateral CA did not affect AT stiffness.[36,37] One RCT, with low overall RoB, reported a significant decrease in AT stiffness between preparaffin and postparaffin therapy.[38] A significant decrease in AT stiffness was also reported after PNF stretching of the triceps surae, followed by PSA.[39] Also in the PT, stiffness decreased after stretching exercises, however, this effect disappeared after 5 minutes.[40] When combined with PSA, stretching exercises did not affect the PT stiffness.[39] Different massage techniques did not influence AT stiffness.[42,43]

The overall RoB in these studies was rated as low to moderate (see **Tables 8 and 9, Supplemental Digital Content 8 and 9**, http://links.lww.com/JSM/A446 and http://links.lww.com/JSM/A447). Three studies assessing the effect of a training intervention had moderate overall RoB. The greatest concerns were about not measuring and controlling for confounding factors.[33,35,36]

The CoE of the interventional studies with a training intervention was rated as high for the PT (3 studies) and

TABLE 1. Key Findings per Subtopic

Subtopic	N articles	Key Findings
Validity		
PT	0	—
AT	1	Stiffness values, obtained with the MyotonPRO, had a high level of agreement with Youngs modulus, obtained with SWE: ICC = 0.54, $P = 0.01$ CoE: low
Reliability		
PT	2	The inter-rater and intrarater reliability for assessing PT stiffness was reported as very good, with ICC ranging between 0.74 and 0.96 and between 0.87 and 0.96, respectively CoE: low
AT	7	The inter-rater and intrarater reliability for assessing AT stiffness was reported as very good, with ICC ranging between 0.85 and 0.98 and between 0.86 and 0.95, respectively CoE: Moderate
Different populations		
PT	3	Included studies reported significant differences in PT stiffness between athletes and nonathletes, although results were conflicted about the direction of this difference One study found that PT stiffness increased with age CoE: low
AT	4	Inconsistent results were reported regarding AT stiffness in athletes and nonathletes, with 1 study reporting higher stiffness in athletes and 2 studies reporting no significant difference between the groups One study found that AT stiffness increased with age CoE: low
Training and treatment interventions		
PT	3	PT stiffness significantly increased from pretraining to post-training. This effect was found with strength training (both after 1 training session and after 6 weeks of training), plyometric exercises, and track cycling. Stretching exercises seam to decrease PT stiffness on the short term CoE: High
AT	6	AT stiffness significantly increased from pretraining to post-training. This effect was found with strength training (both after 1 training session and after 6 weeks of training), plyometric exercises, and karate fights. One study found decreased AT stiffness after paraffine therapy and after stretching exercises. Different massage techniques did not influence AT stiffness CoE: High
Injured and healthy tendons		
PT	0	—
AT	3	Significant lower stiffness values were found in tendinopathic AT than in healthy AT, with lower stiffness values corresponding with worse symptoms CoE: Moderate
Other studies		
PT	2	PT stiffness was not related to oxygen cost during running CoE: low
AT	6	Two studies reported increasing stiffness values with increasing ankle dorsiflexion angles. Higher AT stiffness seams to lead to lower oxygen costs during running and better jump performances CoE: low

AT, Achilles tendon; CoE, certainty of evidence; ICC, intraclass correlation coefficient; PT, patellar tendon; SWE, shear wave elastography.

moderate to high for the AT (6 studies). This results in strong evidence for the adequacy of the digital palpation device to detect an effect of training on PT and AT stiffness.

Healthy and Injured Tendons

No studies were found comparing the stiffness of injured and healthy PT. Three studies compared stiffness between injured and healthy AT.[14,44,45] In 2 studies, the type of injury was symptomatic tendinopathy.[14,45] The mean age in all 3 studies was between 40 and 50 years old. In the study of Morgan et al[14] the participants were adults with symptomatic unilateral tendinopathy and asymptomatic AT.

Significant lower stiffness values were found in affected AT (777 ± 86 N/m), compared with healthy AT (873 ± 72 N/m; $P > 0.05$),[45] with lower stiffness values corresponding with worse symptoms.[14]

The methodological quality of these studies was good (see **Table 9, Supplemental Digital Content 9**, http://links.lww.com/JSM/A447). The CoE of the 3 studies comparing healthy and injured AT was rated as low to good. Thus, there is moderate evidence that the digital palpation device can detect differences between injured and healthy AT.

Other Observational Studies

Five more studies were included that used tendotonometry to assess tendon stiffness. Orner et al[46] measured the stiffness of the AT to generate normal values for tendon stiffness in healthy adults. Huang et al and Cruz-Montecinoz et al measured AT stiffness for different knee and ankle positions in healthy young adults.[47,48] Both studies found increased AT stiffness with ankle dorsiflexion and knee extension. Bravo-Sánchez et al[49] assessed whether asymmetry in AT and PT stiffness was present in elite badminton players. Although there were differences in tendon structure between the dominant and nondominant sides, no differences were found in stiffness values for the AT as well as the PT. Konrad et al[50] assessed AT and PT stiffness in relation to oxygen cost during 70% $\dot{V}O_2max$ running, in recreational male athletes. A significant negative correlation was found between AT but not PT stiffness and oxygen cost. This led them to the conclusion that higher AT stiffness leads to a lower oxygen cost. Wdowski et al[51] assessed the relationship between AT stiffness and countermovement jump height, in recreationally male and female athletes. A significant positive correlation was found between AT stiffness and jump height, leading to their conclusion that greater AT stiffness may improve jump performance.

The level of methodological quality varied between these studies, with 9 to 12 out of 14 questions answered "yes" or "not applicable" (see **Table 7, Supplemental Digital Content 7**, http://links.lww.com/JSM/A445). The greatest concerns were about not assessing the level of exposure more than once over time, whether or not outcome assessors were blinded and handling confounding factors. The CoE of these observational studies was rated as low to moderate.

DISCUSSION

This systematic review aimed to systematically describe the next relevant aspects of tendotonometry in (1) its validity and reliability, (2) differences between populations, (3) the effect of interventions, and (4) differences between healthy and symptomatic AT and PT. A total of 34 studies were included. Only 1 study investigated the validity of tendotonometry comparing the hand-held digital palpation device to shear wave elastography measurements in AT. There is moderate evidence for high inter-rater and intrarater reliability in the assessment of AT stiffness. In the assessment of PT, evidence of the reliability is inconclusive. Strong evidence exists that tendotonometry can detect changes in AT and PT stiffness after different training and treatment interventions. The adequacy of tendotonometry to detect differences between populations and between healthy and injured tendons remains unclear because of inconclusive evidence and limited information available.

Validity

So far only 1 study has evaluated the validity of the digital palpation device by comparing stiffness measurements with SWE in AT.[15] This lack of validation studies is a major concern when interpreting the findings of this review and questions the role of tendotonometry with the digital palpation device in the prevention and management of tendinopathy. Therefore, studies into the validity of tendotonometry with the digital palpation device in measuring tendon stiffness are needed, comparing the digital palpation device with other techniques. Although data on the validity of the digital palpation device in tendon assessment are limited, this device has been found to be valid in measuring muscle stiffness.[52–55] So the validity of the device in measuring tendon stiffness might be promising.

Reliability

When measuring AT stiffness, the digital palpation device appeared to have high inter-rater and intrarater reliability. This finding is in line with previous studies that demonstrated good reliability of the device in the assessment of muscle stiffness.[13] The reliability results of the digital palpation device were relatively constant, with all included studies reporting good to excellent reliability. This is in contrast to highly variable results found in studies assessing the reliability of SWE, commonly used in assessing tendon stiffness.[56] The inconsistent results of SWE[56] might be explained by difficulties with the stabilization of the knee and ankle joints and the precise positioning of the transducer. With the digital palpation device, the influence of the exact positioning of the device seems to be smaller, although the positioning of the knee and ankle can influence the stiffness values[10,23,24] and reliability. A few studies compared the reliability of the digital palpation device between different ankle and knee positions. For the AT, a neutral and relaxed ankle position results in the highest inter-rater and intrarater reliability compared with other ankle positions.[21,22] For the PT, based on the results of 1 study with moderate RoB, 90 degrees of knee flexion with a free-hanging foot should result in the most reliable stiffness measures.[10]

Different Populations

For both the AT and PT, inconsistent results were found for differences in tendon stiffness between athletes and non-athletes.[29,30] Although results seem contradictory, the age difference of the participating athletes (senior vs young adults) between the studies might explain the different results. Tendon stiffness increases with age, and this age-related increase might be slower in athletes than in nonathletes.[27,57] Thus, the sensitivity of the digital palpation device seems sufficient to detect changes in PT stiffness due to athletic and physical activity.

Concerning the stiffness differences found in the AT, the differences in the athletic populations under investigation probably contributed to the inconsistent results.[27,29] The AT can adapt to mechanical loading by increasing or decreasing tendon stiffness, depending on specific loading. A cross-sectional study assessing AT stiffness using ultrasonography in middle-distance runners showed that a stiffer AT correlated with a higher running efficiency,[6] while Kubo et al[8] found lower AT stiffness measured using ultrasonography in better-performing long-distance runners. Other studies have suggested that whether AT stiffness increases or decreases because of running even depends on the foot strike pattern.[5] These results show that adaptation in AT stiffness is quite specific to the loading pattern. Therefore, it is difficult to compare the results of AT stiffness between studies with different athletic populations.

Training and Treatment Interventions

The digital palpation device can detect differences in tendon stiffness after training interventions and paraffin therapy. No changes in stiffness were found after different massage techniques.[42,43] These results align with findings obtained with other measurement methods showing that tendons are highly responsive to diverse training interventions,[7] and that foam rolling does not influence passive tissue stiffness.[58]

It is interesting that all studies with the digital palpation device reported increased AT stiffness after a training intervention. Previous studies showed that AT stiffness, measured using ultrasonography, tends to decrease after several types of training.[59] Results from a randomized crossover study assessing changes in AT stiffness as an acute effect of isometric training suggest that whether AT stiffness increases as a result of training depends on the intensity and the duration of the training. When the intensity is high and the duration long, AT stiffness decreases because of training. When the duration is short, AT stiffness tends to increase as a result of training, regardless of the intensity.[60] The training interventions in this review consisted of plyometric jumps, resistance training, and karate fights, thus mostly exercises of short duration, which probably might have caused the increase in AT stiffness. This shows that the type, duration, and intensity of training might affect the effect of training in terms of tendon stiffness. Thus, future studies should report their training exposure in detail. In addition, further research is necessary to investigate the adaptation of AT and PT to different types of training to find the "normal response," in terms of tendon stiffness.

Healthy and Injured Tendons

Although monitoring tendon stiffness for prevention and rehabilitation of tendinopathy seems a promising application of the portable and easy-to-use digital palpation device,[15] very little information is available about the adequacy of the digital palpation device to detect differences between injured and healthy tendons. For the PT, no studies were found comparing injured and healthy tendons using tendotonometry. A study assessing PT stiffness with SWE in 76 athletes with patellar tendinopathy found increased PT stiffness in injured compared with healthy tendons.[61] Because Feng et al[15] found a high correlation between SWE and tendotonometry, the digital palpation device can likely detect this injury-related increase in PT stiffness as well, yet future research needs to confirm this.

For the AT, 2 studies compared the stiffness as measured with tendotonometry of healthy and affected tendons.[14,45] Both studies found decreased AT stiffness in affected tendons, with lower stiffness corresponding to worse symptoms. These findings align with the results of a prospective study comparing the stiffness as measured with SWE of healthy and affected AT.[62] So far, no clear cutoff value could be determined based on the results with the digital palpation device.[45] Therefore, more research concerning tendon stiffness in pathologic tendons and the use of the digital palpation device in this field is needed. For its applicability in the prevention and rehabilitation of tendon injuries, an important step would be to determine cutoff values for an abnormal tendon response. It is probably best to define these cutoff values in terms of change in tendon stiffness because the exact stiffness values depend on many factors, such as age and gender, as well as the frequency, intensity, time, and type of training. These factors should, therefore, be defined clearly in future studies. When such cutoff values are found, the digital palpation device could play a role in the monitoring of tendon stiffness to detect beneficial or pathologic tendon changes at an earlier stage, which might be helpful in the prevention and rehabilitation of tendinopathy.

This review focused on the stiffness values as measured with the digital palpation device. This is, however, not the only tissue property the digital palpation device can measure. Future research should also focus on the sensitivity of the device for other tendon properties such as frequency, decrement, relaxation time, and creep. These properties must also be investigated in healthy and injured AT and PT to get a complete picture of adaptations in tendon properties with injury.

Strengths and Limitations of This Systematic Review

This review provides a complete overview of the available information about the use of tendotonometry with the digital palpation device in assessing AT and PT stiffness. The search strategy of this systematic review was comprehensive to obtain all relevant information. This strategy led to the inclusion of studies with different objectives. In total, 34 studies were included, however, only 3 to 12 studies could be included for the different categories. A strength of this study is that despite the broad diversity of studies, we thoroughly assessed the quality using specific methodological quality assessment scales. However, this made it difficult to compare the quality of the several studies with different objectives. In addition, owing to the large variation of the studies found (in which leg was measured, in different joint angles, on which tendon, and on which location on the tendon was measured), no meta-analysis could be performed. Thus, some caution is warranted when interpreting the results, especially concerning the low CoE results.

CONCLUSIONS

This review shows a potential role for tendotonometry in measuring tendon stiffness. There is moderate evidence for high inter-rater and intrarater reliability in the assessment of AT stiffness. In the assessment of PT, evidence of the reliability is inconclusive. Strong evidence exists that tendotonometry can detect changes in AT and PT stiffness after different training and treatment interventions. However, more research is needed in validating the use of tendotonometry in AT and PT and its clinical interpretation.

Results from tendotonometry might be interpreted in the context of multiple outcomes to guide the athlete to optimal loading important for both the prevention and management of AT and PT injuries. Before tendotonometry can be used in tendon injury prevention and rehabilitation, a better understanding of the stiffness response of healthy and pathologic tendons to different types of loading is needed.

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