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In Vivo Assessment of the Tensor Vastus Intermedius Cross-sectional Area Using Ultrasonography

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SUMMARY

Background. There is growing evidence that the quadriceps muscle group includes a fifth head, the tensor of vastus intermedius (TVI). The purpose of this study was to quantify the anatomic cross-sectional area (CSA) of the TVI using ultrasound.

Methods. Ultrasonography scans were taken from 21 young males and females at rest, at 0° (= full extension), 45° and at 90° of knee flexion and they were repeated a week after to establish reliability. Measurements of the CSA were obtained from the most proximal and the most distal part of the muscle belly and from three different parts toward the course of the tendon.

Results. US evaluation of the CSA displayed high reliability with an intraclass coefficient ($ICC_{3,3}$) ranging from 0.85 to 0.99 and a standard error of measurement ranging from 0.0019 to 0,2789 mm^2. Analysis of variance indicated that the TVI muscle belly was larger proximally than distally and it was smaller at full extension compared with greater flexion angles ($p < 0.05$). The tendon CSA was greater proximally than middle and distal measurement sites ($p < 0.05$) but it did not differ between various knee flexion angles.

Conclusions. Future studies on the quadriceps muscle function and morphology should include examination of the TVI.

KEY WORDS

Quadriceps; architecture; ultrasound; tensor of vastus intermedius; muscle function.

INTRODUCTION

The quadriceps femoris muscle is considered a dominant extensor of the knee joint and a flexor of the hip joint. Traditionally the quadriceps is described as a muscle that is composed of the rectus femoris (RF), the vastus medialis (VM), the vastus intermedius (VI) and the vastus lateralis (VL). In particular, the RF originates from the anterior inferior spine of ilium, the VM originates from the linear aspera, the VL from the greater trochanter and the linea aspera of femur while the VI from the anterior and lateral shaft of femur (1–4). However, literature reports the presence of a fifth head, the tensor of vastus intermedius (TVI) which is located between the VL and the VI (5,6). The function of an additional muscle can alter the mechanics of the patella and it may have an impact on the extensor apparatus of knee.

There are a few studies that examined the morphology of the TVI (5–10); Early cadaveric studies have identified the TVI in 29% (11) or 36% of the specimens (10). Golland *et al.* (11). found that the TVI originates from the anterior aspect of the upper femoral shaft while Willan *et al.* (10) reported that the muscle is located in the distal area between the VL and the VI but the insertion of the TVI was different in all cases. Consequently, this muscle has not been considered as a basic part of the quadriceps in the general population.

Recent studies, however, identified the TVI in all limbs (5–7). Firstly, Grob *et al.* (5) reported that the TVI originates from the anterolateral aspect of the greater trochanter, it is then combined with an aponeurosis merging separately into the quadriceps tendon and then inserting into the medial aspect of the patella (5,7). Further, TVI was supplied by independent muscular and vascular branches of the femoral nerve and lateral circumflex femoral artery (5,7). Four different types of insertion in the patella across subjects were identified (5). The authors commented that the failure to recognize this muscle is likely related to its association with the VL and the VI (5). In another study, Grob *et al.* (7) found that the TVI attaches distally to the quadriceps tendon. Moreover, Raveendranath *et al.* (9) identified the TVI in thirty-six cadaveric lower limbs. They reported that the length (distance between most proximal and most distal points at which muscle fiber can be seen) of the TVI was 145.40 ± 37.55 mm and the aponeurosis (most distal point of muscle fiber to the superior aspect of patella) was 193.55 ± 42.32 mm^2 (9).

The appearance of the TVI has also been examined using diagnostic imaging techniques (6,8). Grob *et al.* (8) confirmed the anatomic descriptions of the TVI in magnetic resonance images (MRI). Rajasekaran and Hall (6) identified the TVI using ultrasound (US) image in all participants. The muscle belly and tendon were identified in the transverse plane. Based on these results, it was suggested that failure to recognize the TVI, may provide an erroneous interpretation of US images of the quadriceps femoris (6). However, in this study, no quantification of the dimensions and the architecture of the identified muscle were presented.

Quantification of the cross-sectional area (CSA) of the muscle could provide a more precise measure for its morphology than a simple description of its anatomical position. Further, the CSA provides an indication of the force potential of the muscle (12,13) although the relationship between CSA and force is not always linear (14–16). Quantification of the morphometry of the TVI may assist in better identification of this specific muscle using US as well as in explanation of the functional role of the muscle in vivo. For example, the clinical significance of this muscle is not fully understood but given its oblique course it may have a role in stabilizing the patella (5). Since the TVI has a proximal muscle belly and a long distal tendon, its morphology may also differ along its length. Therefore the purpose of the present study was firstly, to identify and then to evaluate the reliability of the US examination of the anatomic CSA of the TVI, second, to compare the CSA between different locations along the muscle and the tendon and finally, to examine whether TVI morphology differs between three different flexion angles of the knee joint.

METHODS

Participants

A total of 21 subjects volunteered to participate in this study after signing written informed consent. There were 17 males (age 21.72 ± 1.83 years; mass 78 ± 6.11 kg; height 181 ± 8.23 cm; femur length 42,5 ± 3,19 cm) and 4 females (age 21.3 ± 0.8years; body mass 60.21 ± 3.65 kg; height 170 ± 5.2 cm; femur length 40.4 ± 1.51 cm) . The participants were healthy university students and they had no injury of the lower limbs. The participants gave their informed written consent to the experimental procedure, which was complied with the rules of the local scientific board and met the ethical standards of the journal (17).

Design

All participants underwent US examination of the TVI in three different knee angles (0°, 45°, 90°) for the measurement of the CSA of muscle. The measurements of the CSA of the TVI were obtained from the proximal and the distal portion of the muscle belly and from three different locations along the course of the tendinous portion of the TVI of the dominant leg. The measurements were performed from the same investigator. The participants were re-tested in a separate session, 6-7 days after the initial measurement session to establish the reliability of the measurements. All US examinations were performed in the morning.

Ultrasonographic assessment

Procedure

Tissue movement was recorded using an US devise (GE LOGIQ 400 CL PRO, GE Medical Systems, U.K) with a linear array probe of 10 MHz wave frequency and a length of 6 cm. The image signal was stored in digital form through an analogue to digital converter (Canopus, Model ADVC 100, Grass Valley Inc., USA) at a rate of 25 Hz. Tests were performed with the subject lying in the supine position with the hip joint in neutral position and the knee joint in 0°, 45°,90° in a physiotherapy bed**.** The hip joint was remained in a neutral position during the examination. A twin-axis goniometer (Model TSD 130B, Biopac Systems, Inc., Goleta, Calif., USA) was used to record the knee joint angular position during the examination.

The participants were asked to relax their quadriceps muscles during US examination. In vivo examination of muscle architecture requires precise identification of the scanned muscle path on the surface of the skin. This is particularly important when examining the TVI muscle because the muscle path is not a straight line; instead, the muscle arises from the anterolateral aspect of the greater trochanter and then it is combined with an aponeurosis merging separately into the quadriceps tendon and then inserting into the medial aspect of the patella. First, we measured the length of the femur in all participants as the distance between the greater trochanter (GT) to the outer femoral condyle with a measuring tape. After starting from

GT, the US probe moved sequentially along the length of the femur towards the patella for the identification of the muscle belly and of the tendinous part of the TVI. From the recorded US video images, the TVI was identified and markers were then placed upon the skin, to indicate the start (proximally) and the end (distally) of the TVI along the length of the femur. These markers ensured consistent identification of the TVI in repeated scans. The muscle belly of the TVI is best identified when the transducer is placed in the transversal plane in the anterior thigh approximately 10 cm below the greater trochanter (GT) (**figure 1**). The TVI was identified as the thin muscle located between the VL and the VI (**figure 1**). Afterward, we measured the distance from the GT to the origin of the TVI and also we measured the length of the TVI as the distance from the origin of the muscle to the patella with a measurement tape. Consequently, we used a skin marker to mark upon the skin the 10% (proximal part) and the 90% (distal part) of the muscle belly and the 10% (proximal part) and the 90% (distal part) of the tendinous portion. These markers ensured that we consistently measured the same part of the muscle belly and the tendinous portion of the TVI in repeated scans. Subsequently, transversal-axis images from the four different parts towards the length of the muscle were obtained. This procedure was performed 0° (full knee extension), 45° and 90° of knee flexion of the dominant leg.

ANALYSIS

The muscle belly and the tendinous part of the TVI was identified on the captured US image (**figure 1**). Identification of the CSA was performed by manually digitizing the identified contours using an image-based software (ImageJ version: 1.52a, National Institutes of Health, USA). The TVI was identified between the VL and the VI.

Firstly, we measured the CSA of the most proximal and the most distal end of the muscle belly Second, we took three measurements of the tendinous part: one measurement from the most proximal part of the tendon, a second measurement from the middle area of the tendon (approximately 50% from most proximal area of the tendinous part to the patella) and a third measurement from the distal area of the tendon (just before the tendon of the TVI was

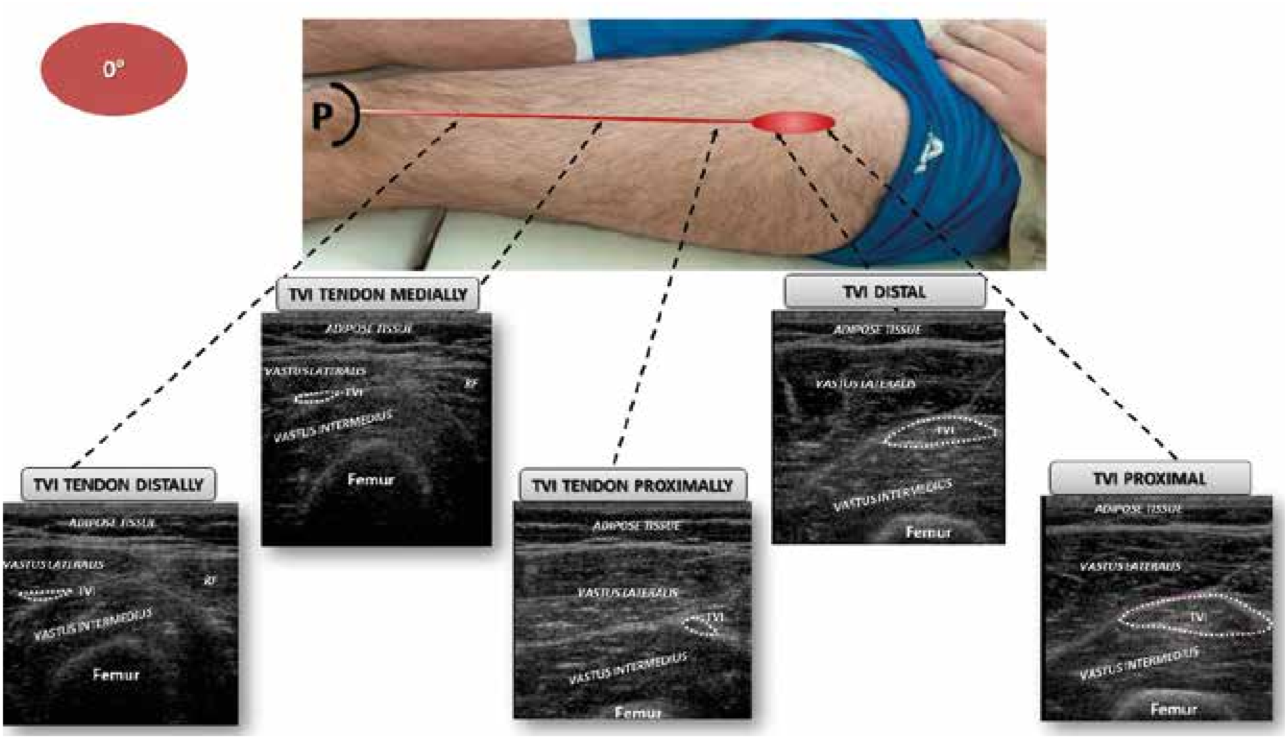

Figure 1. Illustration of ultrasound recording procedure. Following identification of the two visible ends of the tensor vastus intermedius (TVI), cross-sectional images were obtained from the muscle belly (proximally and distaly) and the from the tendon (proximal, middle, distal). The procedure was repeated at knee flexion angles of 0°, 45° and 90° (not illustrated). The cross-sectional area of the TVI is drawn with dotted lines.

blended with the tendon of the RF, the VL, the VI and the VM). Three measurements in each area were taken and the average value was calculated.

STATISTICAL ANALYSIS

Reliability

To examine the test-retest reliability, we calculated the intraclass correlation coefficient ($ICC_{3,3}$) with 95% confidence interval (CI: 95%) based on the average of 3 measurements per measurement cite, per session. An ICC value ≤ 0.50 was considered as low, 0.50 to 0.75 was considered as moderate, ≥ 0.75 was considered as good and ≥ 0.90 was considered as excellent. The agreement between repeated measurements was examined using Bland-Altman analysis, which includes the Bias and the limits of agreement (LoA) (18). The upper and lower LoA was calculated as 1.96* SD representing a measure of random error between measurement sessions. In addition, the standard error of measurement (SEM) was calculated using the following formula:

$$SEM = SD \sqrt{(1 - ICC)}$$

where SD is the standard deviation of the differences between test and retest values.

Measurement site and knee flexion angle

A Kolmogorov-Smirnov test indicated that the data were normally distributed. Analysis of variance (ANOVA) tests were used to compare muscle CSA in two measurement sites (proximal, distal) between the three knee flexion angles (0°, 45°, 90°). A separate ANOVA was used to examine the effects of measurement site (proximal, middle, distal) and knee flexion angle on tendinous CSA. In case of significant F-ratios, simple effects were applied to identify significance between means. If significant, a post-hoc analysis Tukey test was applied to determine significant differences between various pairs of means. The level of significance was set at $p < .05$.

RESULTS

Reliability

The results from the reliability analysis are presented in **tables I** and **II** for the muscle and tendon part, respectively. The ICC values ranged from 0.86 to 0.97 for the muscle belly and from 0.85 to 0.99 for the tendon of the TVI. In absolute terms, the SEM values ranged from 0.0720 mm^2 to 0.2789 mm^2 at the muscle belly and from 0.0019 mm^2 to 0.0827 mm^2 for the tendon. Overall the systematic error was low ranging from -0.0423 mm^2 to 0.0827 mm^2 for the muscle belly and from -0.0153 mm^2 to 0.0061 mm^2 for the tendon.

Effects of measurement site and knee flexion angle

The CSA values for the muscle belly and tendon are presented in **figure 2**. The ANOVA showed a non-statistically significant site by knee flexion angle interaction effect on CSA values ($F_{2,40} = 0.93$, $p > 0.05$). There was, however, a statistically significant main effect of the measurement site, as CSA was greater proximally than distally ($F_{1,20} = 160.81$, $p < 0.05$). There was also a significant main effect of knee flexion angle on CSA ($F_{2,40} = 17.41$, $p < 0.05$). Post-hoc Tukey tests indicated that CSA was smaller at 90° of knee flexion compared to 45° and 0° of knee flexion ($p < 0.05$).

Table I. Reliability values for the proximal and the distal muscle belly cross-section area of the tensor of vastus intermedius.

Knee flexion angle	Test (mm^2)	R-test (mm^2)	$ICC_{2,1}$	SEM (mm^2)	Bias ± Lower LoA	Upper LoA
0°						
Proximal	1.320 ± 0.163	1.319 ± 0.179	0.97	0.0898	0.0008 ± -0.0228	0.0244
Distal	1.229 ± 0.144	1.180 ± 0.180	0.94	0.2284	0.0403 ± -0.0022	0.0827
45°						
Proximal	1.248 ± 0.100	1.224 ± 0.113	0.86	0.2789	0.0239 ± -0.0100	0.0578
Distal	1.122 ± 0.106	1.133 ± 0.121	0.90	0.2152	-0.0113 ± -0.0423	0.0197
90°						
Proximal	1.182 ± 0.130	1.186 ± 0.130	0.97	0.0720	-0.0037 ± -0.0226	0.0153
Distal	1.068 ± 0.120	1.080 ± 0.111	0.94	0.1295	-0.0111 ± -0.0352	0.0129

Measures of reliability: ICC: Intraclass Correlation Coefficient, SEM= standard error of measurement, Bias ± LoA= 95% Limits of agreement.

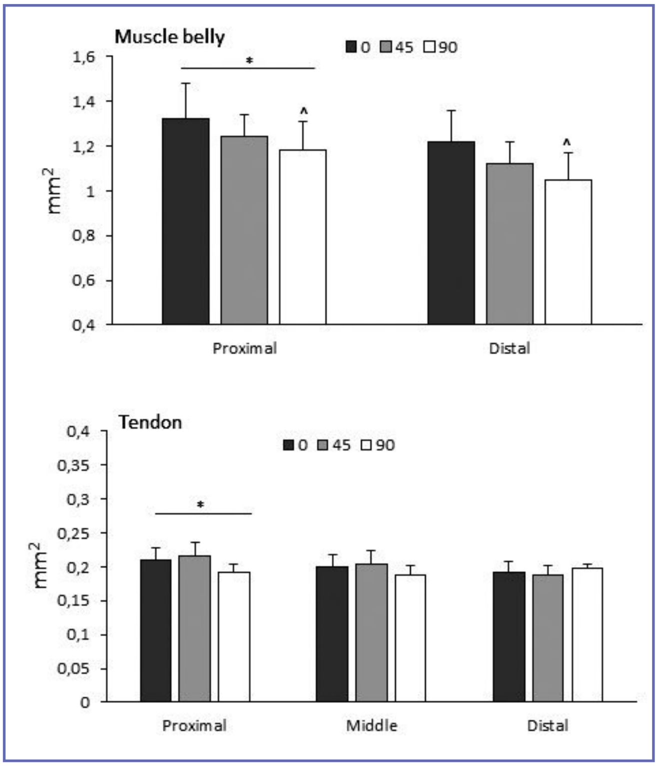

Figure 2. Mean group values of cross-sectional area recorded from the most proximal and most distal position of the muscle belly (upper graph) and tendon (lower graph) at three angles of knee flexion (0°, 45°, 90°). Error bars indicate standard deviation (*significant different compared with the distal position, ^ significantly different compared with the values at knee flexion angles of 45° and 90° $p < 0.05$).

Tendon CSA values are presented in **figure 2**. The ANOVA yielded non-statistically significant interaction and a knee flexion angle main effect ($p > 0.05$). The main effect for measurement site was significant, as CSA was greater proximally than the medial and distal CSA value ($F_{1,20} = 160.81$, $p < 0.05$).

DISCUSSION

The main findings of this study were first, that TVI anatomical CSA was identifiable using US in all individuals, second that the US evaluation of the CSA displayed high test-retest reliability, third, that muscle and tendon belly CSA was larger proximally than distally and, finally, increasing knee flexion angle resulted in a greater CSA of the muscle belly but it did not have an influence on tendon CSA.

In the present study, the TVI was easily identifiable in all participants. This is in agreement with recent cadaveric studies (5–7) as well as studies using diagnostic imaging techniques (6,8). Similar to a previous US study (6), we found that the TVI has a muscle belly which is located proximally and a long distal tendon which coursing obliquely to insert in the middle aspect of the patella (**figure 1**). In addition, the distal part of the tendon is traceable in US images, thus allowing further examination of the TVI morphology along its length. In contrast, these results do not confirm previous anatomical studies which did not identify the TVI in all examined limbs (10,11). We assume that the failure to recognize the TVI by previous studies was down to the large variation of the origin of the TVI. From the results of the present study, it appears that assessment of the TVI should be part of the US quadriceps evaluation.

To our knowledge, this is the first study which examined the anatomical CSA of the TVI determined via US imaging. There are many studies which examined the physiological CSA of the quadriceps femoris (19–25). For example, Blazevitch *et al.* (26) has reported that the CSA of the quadriceps ranges from 6.14 cm^2 (VM) to 29.3 cm^2 (VL). These values are much greater than those reported for the TVI (**figure 2**). The limited field of view of the US imaging device which was used in the present study does not allow quantification and comparison of the TVI CSA relative to the other muscles. Although the anatomical CSA does not have a linear relationship with force generation capacity of the muscle (21), the low CSA values indicates that the TVI relative contribution to the force generated capacity of the quadricep muscle group is low.

The CSA was greater proximally than the most distal position of the muscle belly (**figure 2**). Similarly, the tendon CSA was greater proximally than the CSA obtained from the middle and distal cross-sections (**figure 2**). This is in line with previous studies which showed that CSA of the quadricep muscle components varies along muscle length (26–29). In particular, Narici *et al.* (27) reported that the portion of femur length where the muscle reached the maximal cross-sectional area was different between the quadriceps. Two studies have (26,28) found a greater CSA of the VL, VI and RF proximally than distally. In contrast, Horsman *et al.* (28) reported that the CSA of the VM was larger proximally than distally but Blazevich *et al.* (26) indicated the VM was larger distally than proximally.

The complex architecture between adjacent muscles is not an uncommon phenomenon because the same inter-muscular variation in architecture has been reported for the quadriceps (22) and the hamstrings (30–32). The relatively large muscle belly of the TVI which is located proximally (**figures 1,2**) indicates, that the quadriceps maximum CSA is likely to be recorded in the proximal 1/3 of its length. Within the limitations of our study, it appears that the TVI CSA

is maximally proximally to the hip and this may be taken into consideration when assessment of the CSA of the whole muscle group is necessary.
The CSA was smaller at 90° of knee flexion compared to other knee angles while knee flexion angle did not has an effect on tendon CSA (**figure 2**). The effect of knee flexion angle on TVI CSA has not been previously investigated. One may suggest that the reduction in the recorded CSA in the US image may be due to the lengthening of the quadriceps musculature as the knee flexes. However, Myers et al. [33] indicated that the anatomical CSA of the RF increased from full extension to 90° of knee flexion which is in contrast to the present results. This could be due to differences in architecture between those two muscles, but clearly, more research is necessary to confirm this suggestion**.**
The results of this study indicated high test-retest reliability of the CSA for both the muscle belly (**table I**) and the tendon (**table II**). To our knowledge, the reliability of US evaluation of the TVI has not been previously reported. Reeves et al. reported that US imaging is a valid and a reliable method for the measurement of the CSA (34). Our results are greater than those reported by Delaney *et al.* (35) who reported ICC values which ranged from 0.67 to 0.99 for CSA of the RF. Similarly, high inter-rater reliability (ICC = 0.94) for the RF CSA and a low SEM (1.07 cm²) have also been reported (36). Finally**,** Lima *et al*. (37) found high reliability of the RF anatomical muscle CSA with ICCs ranging between 0.87 and 0.99. As far as the tendon CSA is concerned, the high ICCs for the TVI tendon CSA are in agreement with previous studies on US evaluation of the patellar tendon CSA (38,39). For example, Gellhorn *et al.* (38) reported intra-rater reliability ICCs ranging from 0.87 to 0.96 while Murtagh *et al*. (39) even greater ICCs (0.89 and 0.99). In contrast, Ekizos *et al.* (40) reported low reliability of the patellar tendon CSA which was attributed to the low clarity and the unclear visibility of tissue boundaries in the US images. Subsequently, US imaging constitutes a promising, non-invasive tool to evaluate the architecture of the muscle belly and of the tendon of TVI muscle in vivo.
A limitation of this study is that the tendinous part of the TVI as it inserts into the patella was not examined. Preliminary measurements indicated that the distal part of the TVI tendon was not easily identifiable as it is relatively small in size and it is blended with the tendons of the VL, the VI, the VM, and the RF. Another limitation was that the activation of the muscle during the test was not recorded. Although the participants were asked to relax as much as possible in each testing position, it is possible that muscle activation was not minimal. Furthermore, in the present study, we measured the anatomical CSA instead of the physiological CSA. The physiological CSA is a better predictor of force generation capacity than the anatomical CSA (41,42). Evaluation of the physiological CSA based on US measurements requires determination of the angle of pennation (21). In the case of the TVI, however, evaluation of pennation in longitudinal US images is difficult because the TVI is located between the VL and VI and the orientation of its fascicles relative to its aponeurosis is difficult to visualize.

CONCLUSIONS

The TVI was easily identified using in-vivo US. The muscle belly is located proximally along its length and it displays a greater CSA proximally than distally. The long distal tendon

Table 2. Reliability values for the tendinous-part cross-section area of the tensor of vastus intermedius.

Knee flexion angle	Test (mm²)	R-test(mm²)	$ICC_{2,1}$	SEM (mm²)	Bias ± Lower LoA	Upper LoA
0°						
Proximally	0.210 ± 0.018	0.208 ± 0.016	0.96	0.0135	0.0017 ± -0.0014	0.0048
Medially	0.199 ± 0.018	0.199 ±0.017	0.99	0.0019	-0.0003 ± -0.0012	0.0005
Distally	0.192 ± 0.016	0.193 ± 0.015	0.90	0.0299	-0.0013 ± -0.0057	0.0030
45°						
Proximally	0.216 ± 0.019	0.215 ± 0.019	0.95	0.0181	0.0007 ±- 0.0029	0.0044
Medially	0.204 ± 0.019	0.202 ± 0.019	0.94	0.0221	0.0020 ± -0.0021	0.0061
Distally	0.187 ± 0.015	0.192 ± 0.014	0.86	0.0472	-0.0048 ± -0.00105	0.0010
90°						
Proximally	0.210 ± 0.012	0.213 ± 0.012	0.85	0.0581	-0.0085 ± -0.0153	-0.017
Medially	0.207 ± 0.015	0.212 ± 0.013	0.88	0.0313	-0.0709 ± -0.0120	-0.038
Distally	0.197 ± 0.007	0.194 ± 0.009	0.90	0.0331	-0.0058 ± 0.0106	-0.010

Measures of reliability: ICC: Intraclass Correlation Coefficient, SEM= standard error of measurement, Bias ± LoA= 95% Limits of agreement.

of the TVI has similar CSA along its most proximal first half of this length, while the distal part of the tendon is difficult to identify. Quantification of TVI CSA displayed high test-retest reliability and a low SEM. Consequently, future studies on the quadriceps muscle function and morphology should include examination of the TVI.

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interests.

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