



Reliability and validity of rehabilitative ultrasound images obtained using a hands-free fixed probe in measuring the muscle structures of the tibialis anterior and the gastrocnemius

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Objective: This study aimed to investigate the reliability and validity of muscle thickness (MT) and pennation angle (PA) measurements of the ankle muscle, including the tibialis anterior (TA) and the medial gastrocnemius (MGCM), using a hands-free fixed probe and to compare it with the conventional linear probe.

Design: Observational inter-rater reliability study.

Methods: Thirty-three healthy subjects (20 male, 13 female) were included. In all subjects, ultrasound images were acquired from the TA and MGCM using a hands-free fixed probe and a conventional linear probe in random sequence by two examiners at two time-points within a 7-day interval. MT and PA were calculated on the taken images. Intra-class correlation coefficients (ICC), 95% confidence intervals, standard error of measurement and the Pearson's correlation coefficient were used to estimate reliability and validity. And also, Bland-Altman plots were generated for a visual representation of MT and PA at the TA and MGCM.

Results: The ICC for all intra-rater reliability was 0.943 to 0.995 and that for all inter-rater reliability was 0.928 to 0.993, indicating excellent reliability. A significantly high correlation was observed between MT and PA at the TA and MGCM with use of the hands-free fixed probe and the conventional linear probe ($r > 0.938$; $p < 0.001$).

Conclusions: The hands-free fixed probe provided excellent images for measurement of the MT and PA of the TA and MGCM and is a useful device for making clinical measurements of muscle structure without grasping of the probe.

Key Words: Ankle, Muscle structure, Reliability, Ultrasonography, Ultrasound probe

Introduction

Excessive muscle co-contraction between the tibialis anterior (TA) and the gastrocnemius (GCM) causes stiffness in the ankle joint and limits postural control [1]. The TA provides a peripheral feedback mechanism modulating agonists such as the GCM in maintaining human upright posture and activates reciprocal inhibition that is more likely to be effective for ankle strategy [2]. Young age and healthy status of individuals increases the frequency of using the ankle strat-

egy to maintain posture stability [3,4]. This means they use more reciprocal inhibition by the TA on the GCM, which produces less muscle co-contraction in the ankle joint. Ankle movement is the primary maneuver after perturbation in which muscle contraction at the ankle produces a torque that rotates the body toward the support surface [5]. The location of the center of pressure under each foot provides neutral control of the ankle muscles, including the dorsiflexors and plantarflexors that regulate the body's center of gravity, which controls inverted pendulum during static

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standing or anterior-posterior small perturbation [6]. Therefore, having control of the ankle muscles is important when implementing the ankle strategy.

Studies have reported that strengthening exercises of the ankle muscles or training can improve or reinforce ankle strategy, and evaluation methods such as magnetic resonance image (MRI) or ultrasound imaging system are useful in assessing changes in muscle function [7-9]. In functional movement of the human body, the structure-function relationship of the muscle is an influencing factor of its function [10], and evaluation of muscle structure is useful to confirm if ankle strategy is appropriate or effective in postural control during standing. As compared to MRI, ultrasound imaging is more convenient, cost-effective, and easy to use in evaluation of muscle function, and physical therapists consider it to be more user friendly. In addition, MRI can't be applied during more dynamic situations such as movement by muscle contraction. Ultrasound imaging system provides high quality images of muscle structure including variables of muscle thickness (MT), pennation angle (PA), fascicle length and cross-sectional area [11-13], and can be used during clinical intervention for visual feedback to improve performance [14-16]. Recently introduced personal computer-based ultrasonography devices have promoted lower-cost ultrasound imaging [17,18].

For measurement or intervention with ultrasound imaging system, examiners commonly use the conventional linear probe but need to grasp the probe continuously during image acquisition; moreover, majority of subjects undergoing ultrasound imaging need to maintain in static positions during the examination period. Due to these limiting factors, examiners face difficulty in obtaining measurement values and visual feedback under dynamic functional movements of the patient such as reaching, sit-to-stand position, and walking, and generally have to fix the probe to the limbs and trunk based on arbitrary estimation. Previous reports have indicated a method of using tape or a device to fix the conventional linear probe to the body for a hands-free approach [19-21]; however, to equip or fit the device to the conventional linear probe requires added time and higher cost.

Recently, in order to address the disadvantages of the conventional linear probe, a hands-free fixed probe was developed with hooks attached on the posterior part that can be linked to a strap for fixation to the body, a design that is different from the hands-free probe. As compared to the hands-free probe, the hands-free fixed probe has the advantage of allowing the examiner to perform the imaging technique

without having to hold the probe and to obtain constant ultrasound image with less effort despite the patient's dynamic movement. This study aimed to investigate the reliability and validity of the MT and PA measurements of the ankle muscles, including the TA and medial gastrocnemius (MGCM), by use of a hands-free fixed probe and to compare with the conventional linear probe.

Methods

Participants

In this study, 33 healthy individuals (20 male, 13 female) were recruited. The sample size of the study was calculated by G*Power for Windows software (Free download version 3.1.9.4, Universitat Kiel, Kiel, Germany) with effect size 0.5 and power 0.8. The selection criterion for the subjects was no presence of musculoskeletal pain and having normal range of motion in the lower limbs. The exclusion criteria included musculoskeletal pain, limitation of motion in the lower limbs, and neuromuscular dysfunction due to damage of the central or peripheral nerve system. The study was approved by the Institutional Review Board of Sahmyook University, Seoul (IRB No. SYUIRB 2-7001793- AB-N-012019049HR).

Procedures

MT and PA were measured by using a hands-free fixed probe and conventional linear probe with a personal computer-based muscle viewer (PC-BMW) (MicrUs EXT-1H; TELEMED, Vilnius, Lithuania) [13,17]. Images were acquired with both a hands-free fixed probe and a conventional linear probe at 12 MHz. The hands-free fixed probe is designed with hooks that can link to the strap that wraps around the limbs; the strap allows the probe to be attached to the body and prevents movement during the measurement process (Figure 1). The location of the probe was standardized in all measurements as follows: the location for the TA was marked at 1/3rd of the distance from the inferior border of the patella to the lateral malleolus (Figure 1B) [22]; the location for the MGCM was marked at 30% of the distance from the popliteal crease to the midpoint of the lateral malleolus (Figure 1C) [23]. For assessment of the TA, the subject was placed in supine position on a table with the feet hanging over the edge and neutral position of the hip joint with knee extension. For image acquisition under rest and muscle contraction, subjects were asked to relax their ankle and then perform maximal voluntary contraction. All measurements



Figure 1. (A) Measuring muscle structure using a hands-free fixed probe linked to PC-BMW. The location of the hands-free fixed probe for (B) tibialis anterior and (C) medial gastrocnemius.

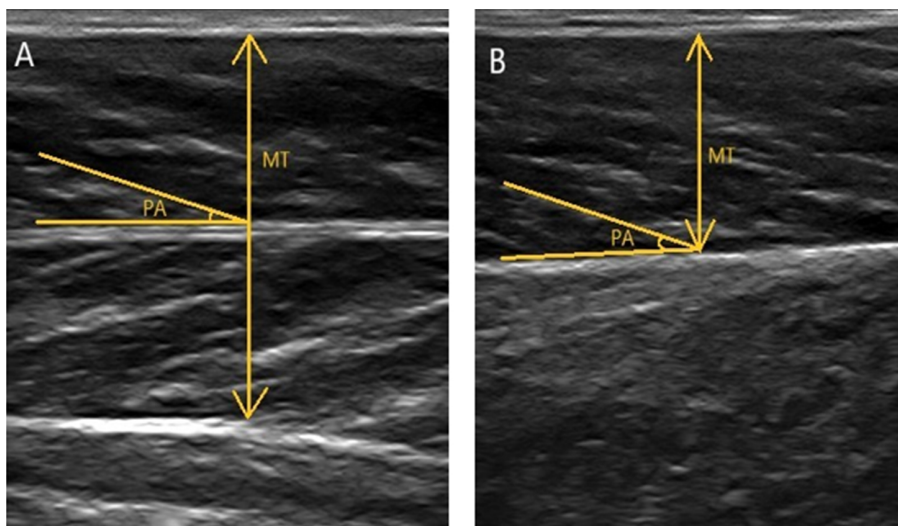


Figure 2. Ultrasound image of muscle thickness (MT) and pennation angle (PA) at (A) tibialis anterior and (B) medial gastrocnemius.

were performed three times with each condition. For assessment of the MGCM, the subject was placed in prone position, and the same protocol as in the TA was applied.

The image was captured when muscle architecture such as the aponeuroses or the PA was clearly distinguishable on the monitor. To calculate the muscle structure of the TA, MT was measured between the superficial and deep aponeuroses, and PA was measured between the muscle fascicles and middle aponeurosis (Figure 2A) [22]. In addition, at the MGCM, MT was measured between the superficial and deep aponeuroses, and PA was measured between the muscle fascicles and the deep aponeurosis (Figure 2B) [23]. Image calculation including MT and PA was performed us-

ing the PC-BMW with a proprietary software (Echo wave II ver. 3.7.1). All measurements were performed by two examiners with two probes on 2 separate days at an interval of 7 days.

Statistical analysis

For descriptive statistics, all demographic data were analyzed. To describe the intra- and inter-rater reliability of the MT and PA of the TA and MGCM during rest and contraction, intra-class correlation coefficients (ICC) and 95% confidence intervals (CI) were calculated. ICC of <0.50 was considered as poor, 0.50 to 0.75 as moderate to good, and >0.75 as excellent reliability [24]. The standard error of measure-

ment (SEM) was calculated using the formula: standard deviation $\times \sqrt{1-ICC}$ based on the reliability coefficients. Bland-Altman plots were generated for visual representation of the MT and PA at the TA and MGCM. To investigate the linear relationship between the hands-free fixed probe and conventional linear probe, the Pearson's correlation coefficient (r) and r^2 were used. Statistical analysis was performed using the IBM SPSS Statistics for Windows, Version 21.0 (IBM Co., Armonk, NY, USA).

Results

Demographic characteristics

Participant characteristics were as follows: Thirty-three healthy participants (20 male individuals and 13 female individuals) with mean age of 22.00 ± 2.75 years were noted; the mean height was 169.90 ± 8.70 cm; the mean weight was 62.78 ± 10.38 kg; the mean body mass index was 21.64 ± 2.28 kg/m² (Table 1).

Intra-rater reliability analysis

Intra-rater reliability data of the MT and PA for the TA and MGCM by two raters at two sessions is shown in Table 2. For the TA, the ICC (95% CI) of MT was 0.991-0.995 (0.942-0.997), and that of PA was 0.973-0.995 (0.945-0.997). For the MGCM, ICC (95% CI) of MT was 0.943-0.992 (0.885-0.996), and that of PA was 0.968-0.994 (0.935-0.997).

Table 1. Demographic characteristics (N =33)

Characteristics	Value
Sex (female/male)	13/20
Age (y)	22.00 (2.75)
Height (cm)	169.90 (8.70)
Weight (kg)	62.78 (10.38)
Body mass index (kg/m ²)	21.64 (2.28)
Dominant side (left/right)	2/31

Values are presented as number only or mean (SD).

Table 2. Intra-rater reliability between repeated measures on the conventional linear probe and hands-free fixed probe for TA & GCM MT and PA (2 days unit: mm/°) (N =33)

Examiner	TA (MT/PA)					MGCM (MT/PA)				
	CP	HP	ICC	95% CI	SEM	CP	HP	ICC	95% CI	SEM
1st day										
E1										
R	25.23 (3.42)/ 8.63 (2.54)	24.86 (3.37)/ 8.86 (2.34)	0.991/ 0.988	0.983-0.996/ 0.976-0.994	0.320/ 0.266	14.52 (2.88)/ 16.74 (5.74)	15.27 (2.75)/ 17.73 (5.17)	0.982/ 0.977	0.964-0.983/ 0.953-0.988	0.379/ 0.826
C	28.40 (3.81)/ 15.93 (4.37)	26.84 (4.20)/ 15.69 (5.05)	0.971/ 0.988	0.942-0.986/ 0.975-0.994	0.691/ 0.545	15.82 (2.93)/ 33.33 (9.41)	15.31 (2.64)/ 32.72 (8.99)	0.972/ 0.968	0.944-0.986/ 0.935-0.984	0.466/ 1.634
E2										
R	24.56 (3.66)/ 8.96 (2.17)	25.47 (3.63)/ 8.85 (2.13)	0.992/ 0.995	0.985-0.996/ 0.989-0.997	0.326/ 0.151	14.00 (2.77)/ 17.40 (3.44)	14.81 (2.66)/ 18.72 (3.33)	0.991/ 0.991	0.982-0.996/ 0.981-0.995	0.259/ 0.325
C	28.05 (4.11)/ 15.07 (3.73)	27.32 (3.66)/ 14.00 (4.01)	0.984/ 0.986	0.967-0.992/ 0.971-0.993	0.490/ 0.459	15.40 (3.07)/ 30.84 (8.29)	14.86 (2.72)/ 30.78 (6.42)	0.988/ 0.973	0.975-0.994/ 0.945-0.987	0.917/ 1.209
2nd day										
E1										
R	25.48 (4.09)/ 8.88 (2.73)	26.14 (3.57)/ 8.67 (2.21)	0.990/ 0.973	0.980-0.995/ 0.945-0.987	0.383/ 0.405	14.89 (2.90)/ 18.29 (3.62)	14.84 (2.77)/ 18.05 (4.67)	0.981/ 0.979	0.961-0.991/ 0.957-0.989	0.388/ 0.602
C	28.63 (3.92)/ 16.59 (5.10)	26.99 (3.69)/ 16.43 (4.93)	0.995/ 0.982	0.989-0.997/ 0.963-0.991	0.273/ 0.668	15.72 (3.40)/ 33.76 (8.93)	15.19 (3.85)/ 31.79 (9.66)	0.943/ 0.994	0.885-0.972/ 0.988-0.997	0.498/ 0.719
E2										
R	24.83 (4.16)/ 8.62 (2.45)	25.84 (4.00)/ 8.87 (2.32)	0.994/ 0.975	0.989-0.997/ 0.950-0.988	0.316/ 0.375	13.45 (2.69)/ 15.75 (3.65)	14.60 (2.91)/ 17.16 (4.68)	0.984/ 0.981	0.967-0.992/ 0.961-0.990	0.360/ 0.567
C	27.63 (4.33)/ 15.39 (3.67)	27.42 (3.68)/ 14.44 (3.32)	0.984/ 0.982	0.968-0.992/ 0.963-0.991	0.504/ 0.470	14.88 (3.07)/ 28.39 (7.11)	15.15 (3.20)/ 29.50 (6.64)	0.992/ 0.994	0.984-0.996/ 0.988-0.997	0.279/ 0.530

Values are presented as mean (SD).

TA: tibialis anterior, MGCM: medial gastrocnemius, MT: muscle thickness, PA: pennation angle, CP: conventional linear probe, HP: hands-free fixed probe, ICC: intra-class correlation coefficient, CI: confidence interval, SEM: standard error of the mean, E1: examiner 1, E2: examiner 2, R: rest, C: contraction.

Table 3. Inter-rater reliability between repeated measures on hands-free fixed probe and the conventional linear probe for TA & MGCM MT and PA (unit: mm/°) (N=33)

Probe	TA (MT/PA)					MGCM (MT/PA)				
	E1	E2	ICC	95% CI	SEM	E1	E2	ICC	95% CI	SEM
HP										
R	24.86 (3.37)/	25.47 (3.63)/	0.991/	0.981-0.995/	0.331/	15.27 (2.75)/	14.81 (2.66)/	0.985/	0.970-0.993/	0.330/
	8.86 (2.34)	8.85 (2.13)	0.988	0.975-0.994	0.243	17.73 (5.17)	18.72 (3.33)	0.940	0.879-0.970	1.065
C	26.84 (4.20)/	27.32 (3.66)/	0.962/	0.922-0.981/	0.764/	15.31 (2.64)/	14.86 (2.72)/	0.992/	0.983-0.996/	0.239/
	15.63 (5.05)	14.00 (4.01)	0.965	0.929-0.983	0.860	32.72 (8.99)	30.78 (6.42)	0.959	0.918-0.980	1.582
CP										
R	25.23 (3.42)/	24.56 (3.66)/	0.993/	0.986-0.997/	0.295/	14.52 (2.88)/	14.00 (2.77)/	0.968/	0.967-0.992/	0.505/
	8.63 (2.54)	8.96 (2.17)	0.984	0.968-0.992	0.298	16.74 (5.74)	17.40 (3.44)	0.928	0.854-0.964	1.264
C	28.40 (3.81)/	28.05 (4.11)/	0.992/	0.983-0.996/	0.352/	15.82 (2.93)/	15.40 (3.07)/	0.993/	0.986-0.997/	0.250/
	15.93 (4.37)	15.07 (3.73)	0.982	0.965-0.991	0.544	33.33 (9.41)	30.84 (8.29)	0.967	0.932-0.983	1.614

Values are presented as mean (SD).

TA: tibialis anterior, MGCM: medial gastrocnemius, MT: muscle thickness, PA: pennation angle, E1: examiner 1, E2: examiner 2, ICC: intra-class correlation coefficient, CI: confidence interval, SEM: standard error of the mean, HP: hands-free fixed probe, CP: conventional linear probe, R: rest, C: contraction.

SEM of the TA was 0.151-0.691, and that of the MGCM was 0.259-1.634.

Inter-rater reliability analysis

For the TA, ICC (95% CI) for all measures was 0.952-0.997 (0.922-0.997), and SEM was 0.243-0.860. For the MGCM, ICC (95% CI) was 0.928-0.993 (0.879-0.996), and SEM was 0.239-1.614 (Table 3). Bland-Altman plots for inter-rater reliability between the two examiners (E1 and E2) are shown in Figure 3.

Correlation between MT and PA taken from two probes

Good correlation was observed among the hands-free fixed probe and conventional linear probe measurement values of MT and PA ($r > 0.938$; $p < 0.001$) by E1 and E2 (Table 4).

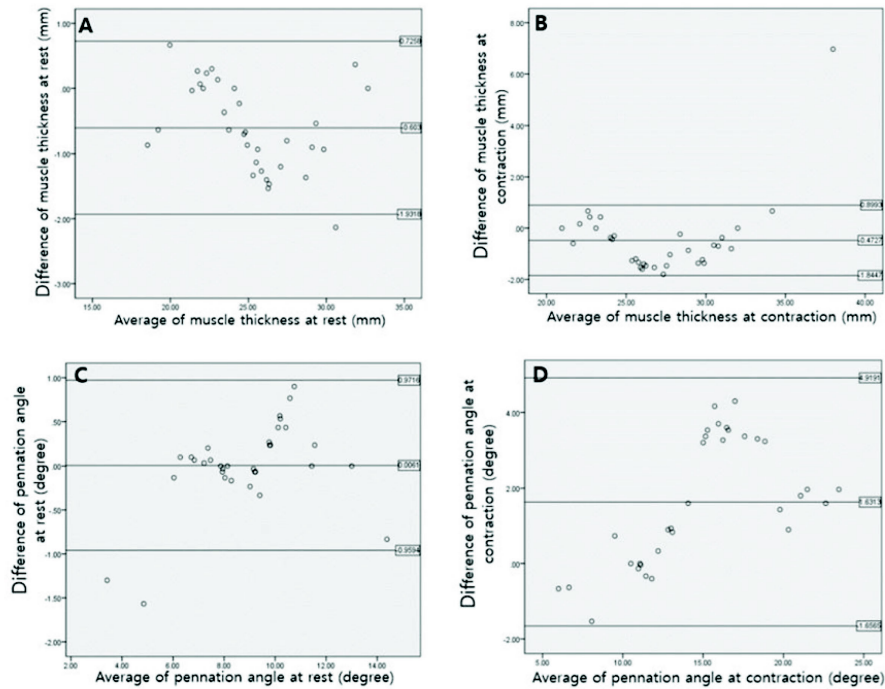
Discussion

In ultrasound imaging to assess muscle structure or provide visual feedback, examiners usually use a hand-held conventional linear probe with continuous manual grasp to obtain consistent images during the measurement period, which is a disadvantage that limits functional evaluation of the muscle during dynamic performance or voluntary movement; the hands-free fixed probe was developed to overcome this limitation. As compared to the hands-free probe, the special design of the hands-free fixed probe contributes

to rapid and cost-effective equipping of the device or fitting to the conventional linear probe. Therefore, in this study, we determined the reliability and validity of the measurements made by use of a hands-free fixed probe versus a conventional linear probe. Our results showed that the ICC for all intra-rater reliability of 0.943 to 0.995 was obtained and that for all inter-rater reliability of 0.928 to 0.993 were obtained, indicating excellent reliability. A significantly high correlation was observed between MT and PA of the TA and MGCM assessed by the hands-free fixed probe and conventional linear probe ($r > 0.938$; $p < 0.001$).

In this study, MT and PA measurements of the TA assessed by the hands-free fixed probe achieved excellent intra-rater reliability (ICC of TA MT: E1=0.990-0.995 and E2=0.984-0.994; ICC of PA: E1=0.973-0.988 and E2=0.975-0.995; SEM range: 0.273-0.691 mm and 0.151-0.668, respectively) and inter-rater reliability (ICC of MT: 0.962-0.992; ICC of PA: 0.965-0.988). McCreesh and Egan [25] reported that with ultrasound, the TA MT using a conventional linear probe achieved excellent inter-rater reliability (ICC [95% CI]: 0.992-0.997 [0.981-0.998]), with no difference between longitudinal and transverse measurement values. In our study, we obtained longitudinal measurement values of the TA because those images clearly differentiate the landmarks of the aponeuroses in the image analysis, which enabled calculation of both PA and MT and excellent reliability of both MT and PA at the TA.

Tibialis anterior



Medial Gastrocnemius

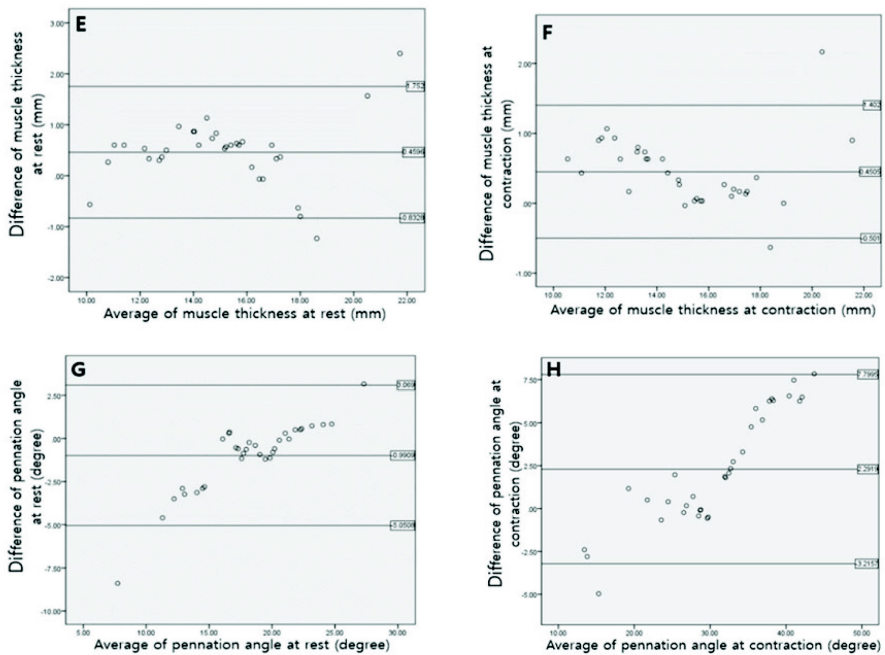


Figure 3. Bland-Altman plots illustrating the difference of ultrasound image for tibialis anterior (A-D) and medial gastrocnemius (E-H) between examiners 1 and 2 for inter-rater reliability.

Moreover, MT and PA at the MGCM assessed with the hands-free fixed probe showed excellent intra-rater reliability (ICC of MGCM MT: E1=0.943-0.982 and E2=0.984-0.992; ICC of PA: E1=0.968-0.994 and E2=0.973-0.994; SEM range: 0.259-0.498 mm and 0.325-1.634, respectively) and inter-rater reliability (ICC of MT: 0.968-0.993;

ICC of PA: 0.928-0.967). The results of our study are comparable to those of excellent reliability of the MGCM measurement values using the developed probe (ICC: 0.988-0.997) in Barber *et al.* [26,27] and other studies on the MGCM muscle structure using a similar method [13]. However, our results indicated higher SEM for PA compared to that for MT,

Table 4. Correlations between TA & GCM MT and PA measurements taken from hands-free fixed probe and the conventional linear probe (N =33)

Examiner	TA (MT/PA)			MGCM (MT/PA)		
	Pearson's correlation coefficient (r)	p-value	r ²	Pearson's correlation coefficient (r)	p-value	r ²
E1						
R	0.983/0.979	<0.001/<0.001	0.966/0.958	0.966/0.960	<0.001/<0.001	0.932/0.918
C	0.949/0.985	<0.001/<0.001	0.897/0.970	0.951/0.938	<0.001/<0.001	0.902/0.877
E2						
R	0.985/0.990	<0.001/<0.001	0.969/0.979	0.983/0.982	<0.001/<0.001	0.965/0.963
C	0.974/0.975	<0.001/<0.001	0.947/0.949	0.983/0.978	<0.001/<0.001	0.964/0.956

TA: tibialis anterior, MGCM: medial gastrocnemius, MT: muscle thickness, PA: pennation angle, E1: examiner 1, E2: examiner 2, R: rest, C: contraction.

and under contraction as compared to rest, which may be due to the higher standard deviation of PA at the MGCM under contraction.

We compared the validity of measurement of MT and PA at the TA and MGCM between the hands-free fixed probe and the conventional linear probe; our results indicated high correlation among TA measurement values by the two probes (MT: E1=0.983 and E2=0.985 at rest; E1=0.949 and E2=0.974 at contraction; PA: E1=0.979 and E2=0.990 at rest; E1=0.985 and E2=0.975 at contraction) and among those at the MGCM by the two probes (MT: E1=0.966 and E2=0.983 at rest; E1=0.951 and E2=0.983 at contraction; PA: E1=0.960 and E2=0.982 at rest; E1=0.938 and E2=0.978 at contraction). The results of our study are comparable to those of other studies assessing validity between newly developed ultrasound devices or methods and conventional devices or methods [13,17,26,27].

The hands-free fixed probe eliminates the need to hold the probe during the measurement process by the ultrasound imaging system, and the data obtained are submitted to an built-in PC-BMW software with the capability of simultaneous measurement and image analysis. Reports have indicated that PC-BMW has excellent reliability [13,17], and PC-BMW connected to a hands-free fixed probe provides added advantage. Our study has the limitation of not conducting the measurements under dynamic conditions or activities; further study is needed to assess muscle structure in situations including dynamic performance or functional movement. Our finding suggests that the hands-free fixed probe provides excellent images for measurement of MT and PA of the TA and MGCM and is a potentially useful clinical device for measurement of muscle structure without having to hold onto the probe.

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Conflict of Interest

The authors declared no potential conflicts of interest with respect to the authorship and/or publication of this article.

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