

RELIABILITY AND MEASUREMENT ERROR OF THE PROXIMAL, MEDIAL AND DISTAL PORTIONS OF THE VASTUS LATERALIS MUSCLE THICKNESS MEASURED WITH THE EXTENDED-FIELD-OF-VIEW ULTRASONOGRAPHY

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Abstract:

The image obtained by static ultrasonography (US), despite being a validated measure to identify muscle thickness (MT), has a visualization capacity limited by the size of the transducer. The extended field of view (EFOV) is a more recent technique of obtaining muscle images by the US, which allows observing MT over the entire length of the muscle. The purpose of the study was to determine the reliability and the intra- and inter-rater error of the MT measurement in the proximal, medial and distal portions of the vastus lateralis using the EFOV US. Twenty-five men (age = 24 ± 4 years) paid a visit to the laboratory. Two independent US technicians identified the anatomical landmarks and collected the images using EFOV US, with a 4 cm linear transducer, 10 MHz frequency and 6 cm image depth. After all collections, the third researcher codified the images, which were sent to two independent image raters. After a week, the images were shuffled, recoded and sent back to the same evaluators. The values of the typical error of the measurement, coefficient of variation and intraclass correlation coefficient of intra- and inter-rater ranged between 0.01 and 0.03 cm, 0.47 and 2.32%, 0.990 and 0.998, respectively, for the two evaluators. The Bland-Altman analysis indicated high agreement and homoscedastic error of all comparisons. The high reliability and low errors observed, less than the increments typically found in training studies, reveal the great potential for EFOV US to determine MT in different portions of the vastus lateralis muscle.

Key words: *anatomy, data accuracy, hypertrophy, lower extremity, muscle tissue, quadriceps muscle*

Introduction

Muscle thickness (MT) is commonly defined as the longitudinal distance between the superficial and deep aponeurosis (Hodson-Tole & Lai, 2019). MT is directly associated with the anatomical cross-sectional area and muscle volume (Franchi, et al., 2018). Therefore, the MT measurement can be considered an important variable that allows monitoring the modifications resulting from different treatments such as resistance training (Schoenfeld, et al., 2019), electrical stimulation (Devrimsel, Metin, & Beyazal, 2019) and stretching routines (Lima, Carneiro, Alves, Peixinho, & Oliveira, 2015).

Ultrasonography (US) is a valid method for determining MT when compared to computerized tomography (CT) and magnetic resonance imaging (MRI), gold standard methods (Dupont, et al., 2001; Juul-Kristensen, Bojsen-Møller, Holst, & Ekdahl,

2000). Dupont et al. (2001) determined the validity of MT measurements using the US, compared to CT and MRI, showing correlation coefficient values ranging between 0.88 and 0.99. US does not expose the subject to radiation such as CT (Sipilä & Suominen, 1993) and it is much cheaper than MRI and, therefore, more widely available in clinical and research settings (Lixandrão, et al., 2014).

Static US has a limitation of visualizing only a smaller muscle area in a typical US scan, which is a function of the transducer size used (Ahtiainen, et al., 2010). Lately, a new technique, the extended field-of-view (EFOV) US method, has gained popularity (Earp, Newton, Cormie, & Blazevich, 2015; Simpson, Kim, Bourcet, Jones, & Jakobi, 2017; Soares, Nogueira, & Gomes, 2021). EFOV US allows image registration far beyond the simple size of the transducer since a continuous scan of the area of interest is registered by the rendering of sequential

images processed by dedicated software for such. Therefore, a much larger muscle visualization area is possible in a single session (Scott, et al., 2012).

The main advantage of EFOV US is the possibility of visualizing the proximal, medial and distal portions of a particular muscle, such as the vastus lateralis, enabling the identification of different portions, as has been shown in more recent studies (Oranchuk, Nelson, Storey, & Cronin, 2020; Soares, et al., 2021). It is also possible to evaluate other muscle architecture variables, such as fascicle length and angle, with no need to estimate with prediction equations (Ando, et al., 2014). Another advantage is the possibility of visualizing aponeuroses in a non-linear way, reducing the chances of overestimating them (Pimenta, Blazevich, & Freitas, 2018).

For example, in resistance training studies, it is common to observe different adaptation magnitudes in muscle architecture at different muscle sites, such as the proximal, medial and distal portions (Earp, et al., 2015; Ema, Wakahara, Miyamoto, Kanehisa, & Kawakami, 2013; Mangine, et al., 2018; Trindade, et al., 2019). One cannot assume that absolute and relative measurement error is similar at different muscle portions. Thus, a reliable tool with high consistency of measurement is needed to monitor possible changes in different portions of the muscle of interest, such as in the case of selective muscle hypertrophy, as a result of some intervention.

Based on our group's recent yet unpublished systematic review with meta-analysis we observed that the vastus lateralis muscle is used most in resistance training studies, primarily when muscle thickness is assessed with US. Researchers have great interest in the vastus lateralis site, mainly due to the ease of performing the measurement. However, several of these studies use careless ways of performing this measurement. Practically none used the panoramic measurement and very few reported the error of such measurement to get accurate values. This is particularly when we are often looking at small changes in muscle hypertrophy.

Therefore, the study aimed to determine the reliability and measurement error of the proximal, medial and distal portions of the vastus lateralis MT measured by EFOV US. The secondary aim was to determine the difference in absolute and relative MT errors in different portions of the vastus lateralis. The results and the protocol proposed in the present study may provide a basis for determining MT in different muscle portions, facilitating and standardizing identifications of possible measurement changes.

Materials and methods

Study sample

The study included twenty-five young male university students (age = 24 ± 4 years; body mass

= 76.4 ± 11.6 kg; stature = 176.0 ± 7.0 cm), apparently healthy according to the PAR-Q questionnaire. All volunteers were informed about the risks, procedures, purpose of the study and signed an informed consent form before starting the procedures. The Research Ethics Committee of Hospital Universitário Pedro Ernesto approved this study under protocol number 3.957.153 and the study was performed following the ethical standards of the Helsinki Declaration.

Study design

Participants made one visit to the laboratory under the recommendation of not performing any physical activity that required vigorous physical effort 24 hours before collecting the images. Upon entering the laboratory, all volunteers were at rest for 20 minutes. Later, an experienced researcher performed anthropometric measurements to characterize the sample.

Two independent US technicians, previously trained to perform the measurements, collected the ultrasound images separately. At the moment of data collection, the US technicians performed the markings of the anatomical points to set the positioning of the guide rail. Three images were collected of each subject and those that best presented the clarity and sharpness of the MT were selected for further analysis. Once the first finished collecting the images, all markings were erased so that the second US technician could repeat the procedure not influenced by the previous one. Each US technician needed an average of 10 minutes to perform anatomical landmarks, position the guide rail and start collecting the images.

The third researcher who did not participate in the evaluation of the images, codified all of them and distributed them to two independent image raters to determine the measurements of MTs. After seven days, the third researcher shuffled and recoded the images and forwarded them to the image raters for further measures. The third researcher also discarded low-quality, cloudy and non-linear images.

Identification of anatomical landmarks

While the subject stood standing, several anatomical landmarks were identified, always on the right side of the body. A guide rail, specifically developed to assist in the displacement of the linear transducer, with an interior of 13 centimeters, would be later positioned in the lateral region of the thigh. Before placing the guide rail, anatomical landmarks were determined as follows: the upper edge of the iliac crest, the upper edge of the greater trochanter of the femur, the upper limit of the lateral epicondyle of the tibia and the midpoint of the upper edge of the patella. After marking the anatomical points, the proximal region equivalent

to 40% was identified between the upper edge of the greater trochanter of the femur and the upper limit of the lateral epicondyle of the tibia, as shown in Figure 1a.

Acquisition of ultrasound images

The volunteer was positioned on a stretcher, in the supine position, with the right knee supported by Styrofoam, in generating a slight flexion and preventing the rotation of the knee. An anthropometer positioned between the upper edge of the iliac crest and the midpoint of the upper edge of the patella helped the positioning of the track, pre-setting an angle of 15° with the sagittal plane, as shown in Figure 1b. A linear transducer was coated with a water-based conductive gel (Multigel, Minas Gerais, Brazil) and moved longitudinally and steadily from proximal to distal muscle portion, generating a 13 centimeters panoramic image. Two independent US technicians identified and marked the external anatomical landmarks and made three images.

The images were collected using an ultrasound device (GE Logiq e, GE Healthcare, USA), in B mode, using proprietary software (GE LogicView, GE Healthcare, USA) with a 4-centimeter linear transducer and a frequency of 10 MHz, with 6 centimeters image depth.

Determination of muscle thickness

Two image raters independently measured proximal (MTp), medial (MTm) and distal muscle thickness (MTd) to determine the reliability and measurement error. MTp was defined as the longitudinal distance between the deep and superficial aponeuroses on the left edge. MTm was the distance between the deep and superficial aponeuroses immediately to the center of the vastus lateralis muscle. MTd was the longitudinal distance between the deep and superficial aponeuroses on the right edge, as shown in Figure 1c.

Image analysis, editing and investigation of the variables of interest were carried out using an open-source image processing program (ImageJ, ver. 1.50f, National Institutes of Health, USA). Image J routine to assess the images followed the recommendations by Soares et al. (2021).

Statistical analysis

The normality of the data distribution was tested using the Shapiro-Wilk statistics. The typical error of the measurement (TEM) and the coefficient of variation (CV) was calculated as suggested by Hopkins (2000) and Atkinson and Nevill (1998), respectively.

Reliability was determined with an intraclass correlation coefficient (ICC) using a two-way model,

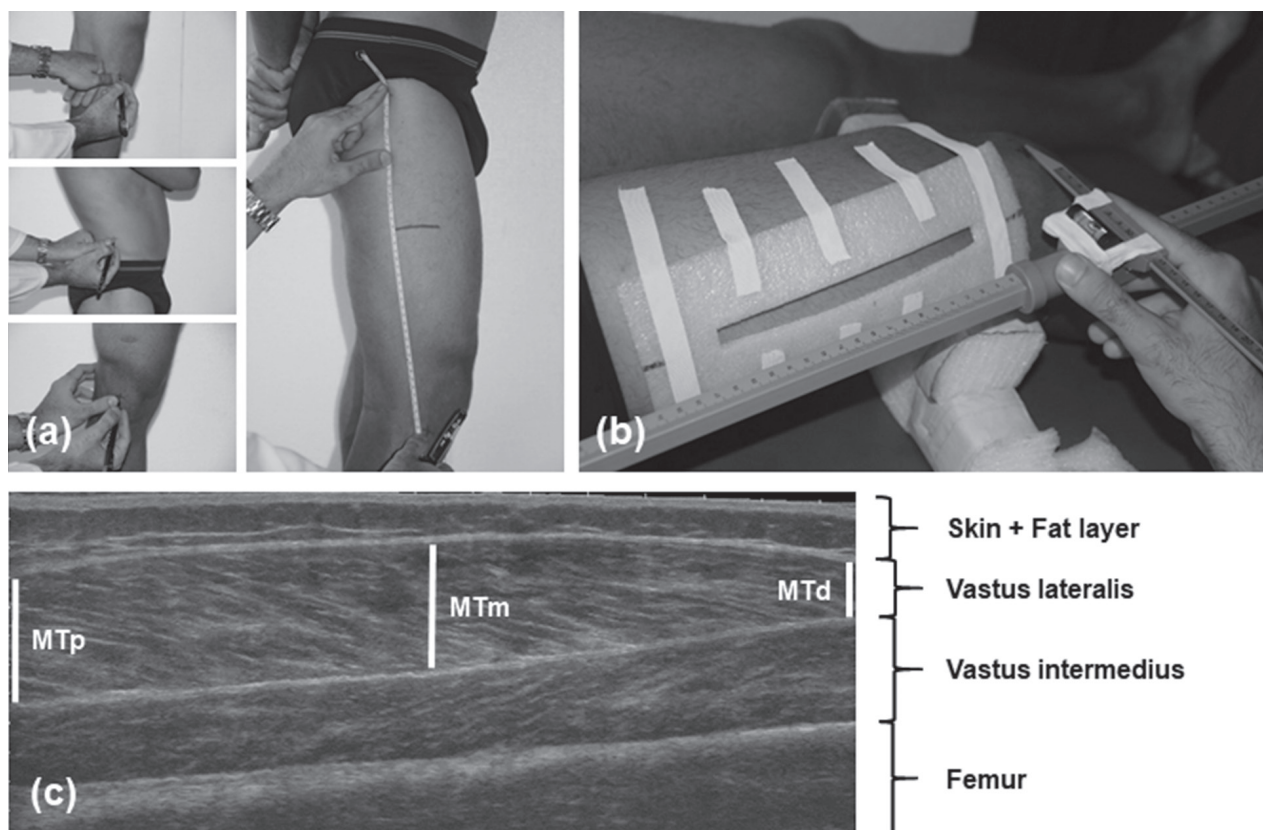


Figure 1. Marking of anatomical landmarks (a); positioning of the guide rail (b); panoramic ultrasound image with measurements of muscle thickness in the proximal (MTp), medial (MTm) and distal (MTd) portions (c).

mixed-effects, single measures and absolute agreement, based on the forms defined by McGraw and Wong (1996) and the model suggested by Shrout and Fleiss (1979). A Bland-Altman analysis was used to assess the degree of agreement of the measures followed by the Pearson correlation coefficient (r) values between the difference and mean of the pairs of measures (Bland & Altman, 1986).

A one-way ANOVA with Bonferroni *post hoc* test was used to determine if there was a difference in the general distribution of the MT error in the different portions of the vastus lateralis muscle from their absolute differences and relative differences by individual CVs.

Commercially available statistical packages Statistical Package for the Social Sciences for Windows, version 21.0 (IBM SPSS Inc., Chicago, IL, USA) and GraphPad Prism for Windows, version 7.0 (GraphPad Software Inc., San Diego, CA, USA) were used for the analyses. All statistical analyses were tested at the 0.05 level of confidence.

Results

The Shapiro-Wilk test demonstrated no departure from normality for all portions of the vastus lateralis muscle analyzed by image raters and US technicians.

Tables 1 and 2 show the reliability and error analysis of the intra-rater measurement of the vastus lateralis in the proximal, medial and distal portions

determined by image raters 1 and 2, respectively, for both US technicians.

Table 3 shows the reliability and error values observed in inter-rater analysis and between US technicians’ measurements of the proximal, medial and distal portions of the vastus lateralis muscle.

The Bland-Altman analysis showed high agreement between the pairs of measures and characteristics of homoscedastic error for all combinations, as shown in Table 4. Pearson’s r values ranged from |0.006 to 0.500|.

Figure 2 shows the difference in the general distribution of the MT error in the different portions of the vastus lateralis muscle from their relative differences (p=0.000), but not between absolute differences (p=0.301). There was a significant difference between MTp and MTm errors against MTd (p=0.000), but not between MTp and MTm (p=1.000) from their relative differences.

Discussion and conclusions

Previous studies have shown that the vastus lateralis MT measurements obtained through the static US showed high reliability (Ema, et al., 2013; Franchi, et al., 2018; Lima & Oliveira, 2013; Mangine, et al., 2018; Raj, Bird, & Shield, 2012; Ruas, Pinto, Lima, Costa, & Brown, 2017). Several measurements will be necessary if the evaluator wishes to observe the MT along the muscle length (Ema, et al., 2013; Mangine, et al., 2018). EFOV

Table 1. Intra-rater analysis of test and retest for the proximal, medial and distal portions of the vastus lateralis muscle thickness (MT) for ultrasonography technician 1

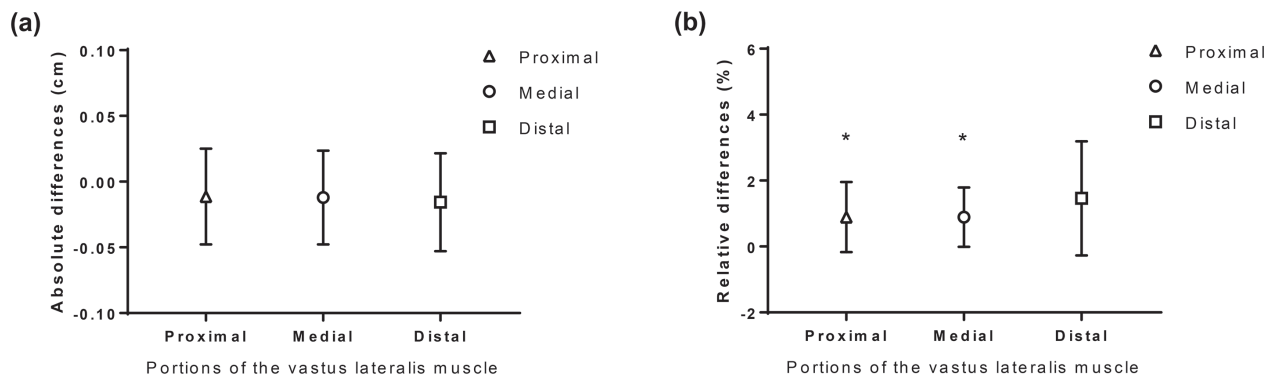
	MT Portion	Mean ± SD (cm)	TEM (cm)	CV (%)	ICC (p)
Image rater 1	Proximal	2.21 ± 0.37	0.02	0.99	0.995 (0.000)
	Medial	2.21 ± 0.31	0.03	1.10	0.991 (0.000)
	Distal	1.37 ± 0.43	0.03	1.76	0.996 (0.000)
Image rater 2	Proximal	2.23 ± 0.35	0.02	0.76	0.996 (0.000)
	Medial	2.23 ± 0.30	0.02	0.63	0.995 (0.000)
	Distal	1.40 ± 0.43	0.01	0.90	0.998 (0.000)

Note. CV: coefficient of variation; ICC: intraclass correlation coefficient; SD: standard deviation; TEM: typical error of measurement.

Table 2. Intra-rater analysis of test and retest for the proximal, medial and distal portions of the vastus lateralis muscle thickness (MT) for ultrasonography technician 2

	MT Portion	Mean ± SD (cm)	TEM (cm)	CV (%)	ICC (p)
Image rater 1	Proximal	2.20 ± 0.37	0.03	0.98	0.995 (0.000)
	Medial	2.24 ± 0.39	0.03	1.03	0.996 (0.000)
	Distal	1.37 ± 0.38	0.03	1.61	0.994 (0.000)
Image rater 2	Proximal	2.20 ± 0.36	0.02	0.47	0.998 (0.000)
	Medial	2.25 ± 0.39	0.02	0.73	0.997 (0.000)
	Distal	1.39 ± 0.38	0.02	0.71	0.998 (0.000)

Note. CV: coefficient of variation; ICC: intraclass correlation coefficient; SD: standard deviation; TEM: typical error of measurement.



* Significant differences from distal portion (p = 0.000)

Figure 2. Mean and standard deviation of the general distribution of the muscle thickness error in the different portions of the vastus lateralis muscle from their absolute (a) and relative (b) differences.

US reduces the number of collections, speeds up the evaluation process and allows a single image to observe the proximal, medial and distal portions of the muscle of interest (Oranchuk, et al., 2020; Soares, et al., 2021).

The current literature shows high ICC values for MT of the vastus lateralis muscle, ranging between 0.88 to 0.99 in the studies that used static US (Franchi, et al., 2018; Mangine, et al., 2018) and 0.94 to 0.96 for the EFOV US method (Oranchuk, et al., 2020; Soares, et al., 2021). The present study showed ICC values above 0.99 for all testing conditions, indicating results slightly higher than those previously observed. Although the ICC is one of the most commonly used statistical models to observe reliability, it is not sensitive to systematic changes in measurement since it has lower results with a more homogeneous sample (Atkinson & Nevill, 1998). Thus, it must be accompanied by other analyzes such as Bland-Altman and TEM. In the present investigation, TEM ranged from 0.01 to 0.03 centimeters. The absolute errors of the measurements were lower than the previous studies reviewed (Lima & Oliveira, 2013; Oranchuk, et al., 2020; Soares, et al., 2021), as shown in Table 5.

Also, the Bland-Altman analysis showed a high agreement between the pairs of measures considering the agreement limit of 1.96 standard deviations. This analysis demonstrated a low absolute

difference between the measurements made by image raters 1 and 2 in the images collected by both US technicians, as shown in Table 4. Pearson's low r values ($r \leq 0.5$) between the mean and the intra-subject difference indicated homoscedastic error for all pair comparisons. Our laboratory experience has shown that strict adherence to the technical recommendations for identifying anatomical landmarks and the constant practice of measurements resulting from several repetitions during the learning process has improved the quality of the results obtained in low error and high reliability.

In previously published studies, coefficient of variation (CV) values showed that different portions of the vastus lateralis muscle showed percentages varying between 1.5% to 3.8% (Ema, et al., 2013; Lima & Oliveira, 2013). The present study observed similar values where CVs varied between 0.47% to 2.32% for all US technicians and image raters tested. However, it is possible that the CV showed in the present study is not necessarily related to the use of EFOV US. One possible explanation may be related to methodological care and the previous definition of the measurement sites for the present study's proximal, medial and distal portions. Using a fixed position in the image, the evaluators could repeat the second assessment at the almost exact location or very close to it.

Table 3. Inter-rater analysis (minimum and maximum) for the proximal, medial and distal portions of the vastus lateralis muscle thickness (MT) for ultrasonography technician 1 (T1) and ultrasonography technician 2 (T2)

	MT Portion	Mean ± SD (cm)	TEM (cm)	CV (%)	ICC (P)
T1	Proximal	2.22 ± 0.36	0.02 - 0.03	1.03 - 1.24	0.990 - 0.993 (0.000)
	Medial	2.20 ± 0.30	0.02 - 0.03	0.66 - 0.98	0.990 - 0.996 (0.000)
	Distal	1.39 ± 0.43	0.03 - 0.03	1.59 - 2.32	0.991 - 0.995 (0.000)
T2	Proximal	2.21 ± 0.36	0.03 - 0.03	0.60 - 0.93	0.994 - 0.996 (0.000)
	Medial	2.25 ± 0.39	0.03 - 0.03	0.88 - 1.08	0.994 - 0.995 (0.000)
	Distal	1.38 ± 0.38	0.02 - 0.03	1.23 - 1.40	0.994 - 0.996 (0.000)

Note. CV: coefficient of variation; ICC: intraclass correlation coefficient; SD: standard deviation; TEM: typical error of measurement.

Table 4. Results of the Bland-Altman analysis for muscle thickness measurements of the vastus lateralis muscle in different portions

Comparisons	US Technician 1		US Technician 2	
	Bias ± SD Bias (cm)	95% LA (cm)	Bias ± SD Bias (cm)	95% LA (cm)
Proximal Portion				
IR 1 (day 1x2)	0.013 ± 0.034	-0.055 – 0.081	0.004 ± 0.036	-0.066 – 0.074
IR 2 (day 1x2)	-0.004 ± 0.033	-0.070 – 0.062	-0.004 ± 0.025	-0.053 – 0.044
IR 1x2 (day 1)	-0.014 ± 0.045	-0.102 – 0.075	-0.010 ± 0.026	-0.061 – 0.041
IR 1x2 (day 2)	-0.030 ± 0.035	-0.099 – 0.038	-0.018 ± 0.027	-0.071 – 0.034
IR 1x2 (day 1x2)	-0.018 ± 0.041	-0.098 – 0.063	-0.014 ± 0.029	-0.071 – 0.042
IR 1x2 (day 2x1)	-0.026 ± 0.046	-0.117 – 0.064	-0.014 ± 0.035	-0.082 – 0.054
Medial Portion				
IR 1 (day 1x2)	-0.009 ± 0.042	-0.092 – 0.074	-0.011 ± 0.036	-0.080 – 0.059
IR 2 (day 1x2)	-0.002 ± 0.029	-0.060 – 0.056	-0.003 ± 0.033	-0.062 – 0.068
IR 1x2 (day 1)	-0.020 ± 0.033	-0.084 – 0.045	-0.022 ± 0.035	-0.092 – 0.047
IR 1x2 (day 2)	-0.013 ± 0.025	-0.062 – 0.037	-0.008 ± 0.038	-0.083 – 0.067
IR 1x2 (day 1x2)	-0.022 ± 0.039	-0.098 – 0.054	-0.019 ± 0.039	-0.096 – 0.057
IR 1x2 (day 2x1)	-0.011 ± 0.031	-0.072 – 0.051	-0.012 ± 0.041	-0.091 – 0.068
Distal Portion				
IR 1 (day 1x2)	-0.016 ± 0.037	-0.088 – 0.057	0.009 ± 0.040	-0.088 – 0.071
IR 2 (day 1x2)	-0.016 ± 0.020	-0.055 – 0.023	-0.001 ± 0.022	-0.042 – 0.044
IR 1x2 (day 1)	-0.021 ± 0.043	-0.105 – 0.062	-0.020 ± 0.039	-0.097 – 0.056
IR 1x2 (day 2)	-0.022 ± 0.039	-0.099 – 0.055	-0.010 ± 0.035	-0.080 – 0.059
IR 1x2 (day 1x2)	-0.038 ± 0.044	-0.124 – 0.049	-0.019 ± 0.030	-0.078 – 0.040
IR 1x2 (day 2x1)	-0.006 ± 0.042	-0.089 – 0.077	-0.012 ± 0.038	-0.085 – 0.062

Note. IR: image rater; LA: limits of agreement; SD: standard deviation; US: ultrasonography.

Table 5. Reliability and measurement error of the vastus lateralis muscle thickness (MT) using static or extended-field-of-view (EFOV) ultrasonography of the current and previous studies

Source	n (M:W)	Age in years Mean ± SD	Scanning Method	Condition	Statistical Index
Current study	25 (25:0)	24 ± 4	EFOV	Intra-rater Inter-rater	ICC = 0.991-0.998; CV = 0.47-1,76%; TEM = 0.01-0.03 cm ICC = 0.990-0.996; CV = 0.60-2,32%; TEM = 0.02-0.03 cm
Soares et al. (2021)	12 (12:0)	24 ± 6	EFOV	Intra-rater	ICC = 0.964; CV = 2.93%; TEM = 0.07 cm
Oranchuck et al. (2020)	26 (26:0)	29 ± 5	EFOV	Intra-rater	ICC = 0.94-0.96; CV = 2,4-3,8%; TEM = 0.15-0.26 cm
Magine et al. (2018)	10 (10:0)	25 ± 3	Static	Inter-rater	ICC = 0.88-0.92; SEM = 0.15-0.39 cm
Franchi et al. (2017)	9 (9:0)	24 ± 2	Static	Intra-rater	ICC = 0.99; SEM = 1.65%
Ruas et al. (2017)	10 (10:0)	23 ± 2	Static	Intra-rater	ICC = 0.97; SEM = 0.10 cm
Ema et al. (2013)	10 (10:0)	22 ± 2	Static	Intra-rater	ICC = 0.976-0.991; CV = 1.5-2.1%
Lima et al. (2013)	14 (4:10)	22 ± 2	Static	Intra-rater	ICC = 0.95-0.97; CV = 3.12-3.84%; TEM = 0.10-0.11 cm
Raj et al. (2012)	21 (11:10)	68 ± 5	Static	Intra-rater	ICC = 0.96

Note. CV: coefficient of variation, ICC: intraclass correlation coefficient, SEM: standard error of measurement, TEM: typical error of measurement.

Despite the present study results showing low percentage changes in CV, the distal portions showed the highest values. Such a condition was observed in both intra- and inter-rater comparisons. This phenomenon can be explained by the lower absolute mean values of MTd than MTp and MTm. Thus, the identical absolute variation in the MT measurement represents a distinct percentage variation in the different portions, thus having a more significant relative impact in the distal region due to the proportionality of the measurement. This hypothesis is reinforced by observing similar absolute differences, but not of relative differences in the three portions of the MT, as shown in Figure 2. TEMs and distal CVs in the present study continued to be lower or similar to those observed in the literature (Ema, et al., 2013; Oranchuk, et al., 2020).

The current study analyzed reliability and intra- and inter-rater error of MTp, MTm and MTd and showed high reliability ($ICC \geq 0.990$ and $p = 0.000$) and low measurement errors ($CV \leq 2.32\%$). Thus, it is suggested that EFOV US may be precise enough to identify muscle hypertrophy, considering that knee extension training studies showed average increments of 8 to 10% (Ema, et al., 2013; Guilhem,

Cornu, Maffiuletti, & Guével, 2013) in the vastus lateralis MT, which seems superior to the measurement errors observed here.

The high reliability of the intra- and inter-rater MT and low error (absolute and relative) of the measurement, smaller than those typically found in training studies, indicate a great potential for determining the MT. Therefore, it is suggested that from a single scan, the EFOV US method presented here may be an ideal and practical inexpensive way to monitor sectorial adaptations of the vastus lateralis muscle resulting from resistance training, electrical stimulation and stretching routine. However, the present study analyzed only a single muscle.

It is suggested that further studies be carried out to determine the reliability and error of the measurement of other muscles or muscle groups due to anatomical differences. There is also a need to investigate the sensibility of the proposed technique in assessing small MT changes in a training study comparing the US measurements with those provided by MRI, the current golden standard, and very high cost. This study is already underway in our laboratory.

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