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original research

Subcutaneous Thigh Fat Assessment: A Comparison of Skinfold Calipers and Ultrasound Imaging

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Context: Skinfold calipers (SC) typically are used to determine subcutaneous fat thicknesses. Identifying the exact separation of muscle and fat can complicate measurements. Ultrasound imaging (USI) might provide a better technique for analyzing subcutaneous fat thicknesses.

Objective: To compare measurements from SC and USI in assessing subcutaneous thigh fat thickness.

Design: Descriptive laboratory study.

Setting: Laboratory.

Patients and Other Participants: Twenty healthy adults (13 men, 7 women; age = 26.9 ± 5.4 years, height = 173.9 ± 7.3 cm, mass = 77.4 ± 16.1 kg) participated.

Intervention(s): Participants were seated in 90° of knee flexion and 85° of trunk extension. A standardized template was used to identify measurement sites over the vastus medialis obliquus (VMO), distal rectus femoris (dRF), proximal rectus femoris (pRF), and vastus lateralis (VL). Three measurements at each of the 4 sites were made in random order and were averaged for each measurement tool by the same investigator.

Main Outcome Measure(s): Fat thickness was measured in millimeters with SC and USI. Measurements at each site were compared using Pearson product moment correlations and Bland-Altman plots.

Results: Strong correlations between measures were found at the VMO ($r = .90$, $P < .001$), dRF ($r = .93$, $P < .001$), pRF ($r = .93$, $P < .001$), and VL ($r = .91$, $P < .001$). Mean differences between measures ranged from 1.7 ± 2.4 mm (dRF) to 3.7 ± 2.6 mm (pRF), indicating that the SC resulted in larger thicknesses compared with USI. Limits of agreement, as illustrated by the Bland-Altman plots, were fairly wide at each site: from −3.38 mm to 7.74 mm at the VMO, from −3.04 mm to 6.52 mm at the dRF, from −1.53 mm to 8.87 mm at the pRF, and from −3.73 mm to 8.15 mm at the VL. All plots except for the VL demonstrated increasing overestimation via the SC as fat thicknesses increased.

Conclusions: We found strong correlations between the SC and USI; however, the large limits of agreement and increasing mean differences with larger fat thicknesses were a concern in terms of using this tool. When measuring subcutaneous fat thickness of the thigh, SC tended to overestimate thickness in individuals with higher fat values.

Key Words: agreement, anthropometry, body composition

Key Points

- Measurements of subcutaneous fat thickness of the thigh taken with the skinfold calipers and ultrasound imaging were strongly correlated, whereas limits of agreement were wide.
- Compared with ultrasound imaging, the skinfold calipers tended to overestimate subcutaneous fat thickness of the thigh at the vastus medialis obliquus, distal rectus femoris, and proximal rectus femoris, and this overestimation increased as fat thickness increased.
- Clinicians and researchers should use caution when interpreting the results of measurements taken with skinfold calipers, especially in large individuals.

Site-specific skinfold-thickness measurements have been used to determine duration of cryotherapy treatments,[1,2] depth of thermocouple placement when measuring skeletal muscle temperature,[3,4] and total body fat percentage.[5] This technique is relatively inexpensive, noninvasive, and widely used in most therapeutic clinics.[6] However, accurate measurement might be difficult to attain in all individuals, especially in those with adipose tissue that does not separate well from the underlying muscle or when the end range of the tool is too small to capture the entire subcutaneous fat thickness. In addition, interrater reproducibility of measurements using skinfold calipers (SC) is not high,[7] resulting in clinicians questioning the accuracy of the measurement.

The accurate measurement of subcutaneous tissue thickness is important in therapeutic modality application and research, and Petrofsky[8] recently suggested that subcutaneous fat might affect the conduction of electric stimulation. The assessment of thermal responses to therapeutic ultrasound[4] and cryotherapy[1,2] is affected by adipose thickness. During laboratory study, the muscular interface can be difficult to identify with SC. Therefore, the thermocouple might not be placed properly into the muscle, usually at depths of 1 to 2 cm beyond the subcutaneous tissue, resulting in inaccurate temperature estimations at the target tissue. When thermocouples are inserted to evaluate temperature changes in various depths of tissue, subcutaneous tissue thickness often is assessed by

Figure 1. Template over the vastus medialis obliquus and vastus lateralis.

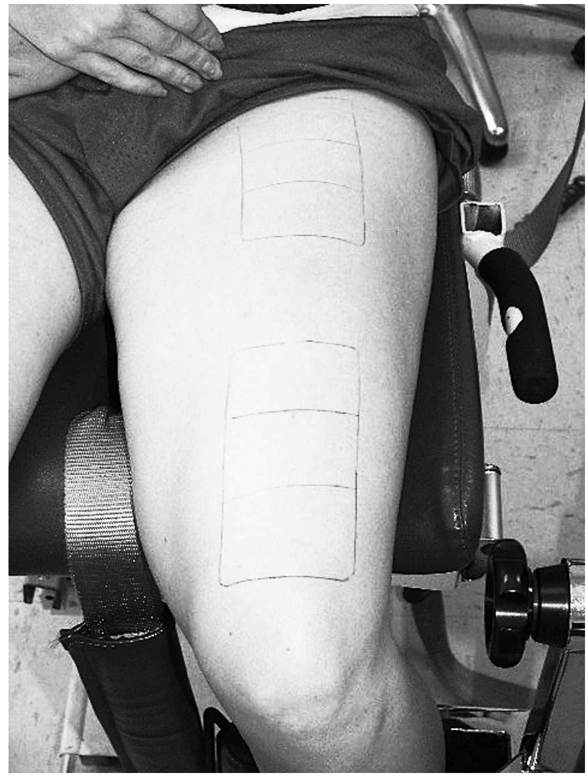

Figure 2. Template over the proximal rectus femoris and distal rectus femoris.

using SC and dividing the measurement in half.[1,3,4] Thus far, this method has not been challenged for accuracy.

Advances in technology have resulted in the use of ultrasound imaging (USI) within clinical settings. Although more expensive than SC, USI has been shown to be comparable to the criterion standard of magnetic resonance imaging in image clarity, is portable, and is noninvasive.[6] Compared with magnetic resonance imaging, USI has been deemed a valid tool for measuring visceral and abdominal subcutaneous fat.[9] Orphanidou et al[10] found that computed tomography and SC had similar agreement but that computed tomography and USI did not. They did not compare USI and SC. With advances in technology, their results might differ now. With USI, subcutaneous fat thickness measurements can be taken without pinching the skin and can be used on individuals of all sizes. The images obtained are clear, and structures of interest can be identified visually.

Subcutaneous fat thickness at specific locations, such as the gastrocnemius or thigh, is important to measure accurately, especially when proper injury management might depend on it. Therefore, the purpose of our study was to compare subcutaneous fat-thickness measurements of the thigh taken with SC and USI.

METHODS

Design

We used a correlational design in which all participants were measured with SC and USI. Four regions of the anterior thigh were identified with a template, and measurements were recorded in the same area in all participants with both measurement devices. The order of measurements was counterbalanced. This was part of a larger study in which we examined how electrode type and placement on the thigh affected analysis of quadriceps muscle activation. We were interested in examining the possible effects of fat thickness under the electrode pads on muscle activation in the position relative to that specific testing. The position was also consistent with a thermal treatment to the anterior thigh because the modality typically would be applied with the participant sitting rather than standing.

Participants

Twenty healthy individuals (13 men, 7 women; age = 26.9 ± 5.4 years, height = 173.9 ± 7.3 cm, mass = 77.4 ± 16.1 kg) volunteered to participate in our study. Participants were recruited via fliers and word of mouth in a university community. They were excluded if they had experienced a lower extremity injury in the 6 weeks before the study, had undergone lower extremity surgery in the year before the study, or had an open wound to the anterior thigh. All participants provided written informed consent, and the Institutional Review Board of Health Sciences Research at the University of Virginia approved the study.

Procedures

The participants sat in a standardized position using a dynamometer (System 3 PRO; Biodex Medical Systems, Inc, Shirley, NY) with their knees in 90° of flexion and their trunks in 85° of extension. Before testing, a template was used to trace a 12 × 7–cm rectangular area over each

Table 1. Pearson Product Moment Correlation Between Skinfold Caliper and Ultrasound Imaging at Each Measurement Site

Measurement Site	Pearson Product Moment Correlation Coefficient[a]
Vastus medialis obliquus	0.901
Distal rectus femoris	0.925
Proximal rectus femoris	0.927
Vastus lateralis	0.909

[a] Indicates $P < .05$.

measurement site on the dominant leg: vastus medialis obliquus (VMO), distal rectus femoris (dRF), proximal RF (pRF), and vastus lateralis (VL) (Figures 1 and 2). The *dominant leg* was defined as the leg with which the participant would kick a ball. The superior aspect of the VL measurement site was positioned at the height of the greater trochanters, with the medial edge aligned with the anterior-superior iliac spine. The inferior aspect of the VMO measurement site was positioned 2 cm proximal to the superior pole of the patella, with the medial edge aligned with the middle of the patella. Each measurement site then was divided horizontally into thirds, creating 3 equal 4 × 7–cm boxes.

Pinch Caliper Measurements. In the middle box of each template, a Lange SC (Beta Technology, Santa Cruz, CA) was used to measure subcutaneous fat thickness. Three measurements were taken in each middle box, for a total of 12 measurements. The clinician (N.M.S.) taking the SC measurement was right-hand dominant, so with her left thumb and forefinger she lifted the skin away from the muscle and pinched it together. With her right hand she placed the jaws of the SC inferior to the pinch and completely released her thumb from the handle. The reading was recorded after the first rapid fall on the dial. The fat thickness recorded by the SC was divided in half to represent the subcutaneous fat layer over the muscle.

Ultrasound Imaging. Ultrasound imaging (LOGIQ Book XP; GE Healthcare Products, Milwaukee, WI) was used to measure subcutaneous fat thickness in each middle box. An 8-MHz linear array was used while capturing the image in B-mode. Ultrasound gel was applied liberally to the center of the template before placing the transducer on the skin. After a clear image was identified, the image was saved. This procedure was repeated 3 times for a total of 12 images. The images were labeled with the participant number and site (VMO, dRF, pRF, VL) of measurement. On a subsequent day, the clinician (N.M.S.) who obtained the images opened the saved images and measured the subcutaneous fat thickness using the measurement tool on the USI machine.

Statistical Analysis

The main outcome measures were fat thicknesses obtained in millimeters from both the SC and USI. Four separate Pearson product moment correlations were used to determine the relationship between the thigh fat-thickness measurements using both the USI and SC at all 4 sites. Similarly, 4 Bland-Altman plots were constructed to assess the agreement between the 2 measurements at all 4 measurement sites. Mean differences were calculated by subtracting USI scores from SC scores, and the limits of agreement (LOA) were calculated by adding ±2 SDs of the mean differences to the mean differences. The α level was set a priori at .05. The statistical analysis was performed using SPSS (version 16; SPSS Inc, Chicago, IL).

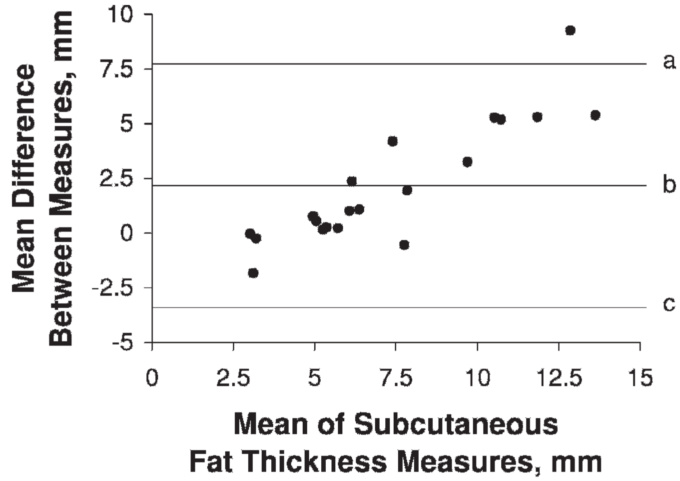

Figure 3. Bland-Altman plot for the vastus medialis obliquus. [a] Indicates upper limit of agreement. [b] Indicates average mean difference. [c] Indicates lower limit of agreement.

RESULTS

All Pearson product moment correlation coefficients were strong and in the positive direction, indicating that a small subcutaneous fat-thickness measurement via the SC matched with a small subcutaneous fat thickness measurement via USI on the same participant (Table 1). For the Bland-Altman plots, LOA values were fairly wide, as follows: from −3.38 mm to 7.74 mm at VMO, from −3.04 mm to 6.52 mm at dRF, from −1.53 mm to 8.87 mm at pRF, and from −3.73 mm to 8.15 mm at VL, (Figures 3 through 6). The calculations for LOA are presented in Table 2.

DISCUSSION

From our study, the SC appeared to overestimate subcutaneous fat thickness compared with USI, especially at increased levels of subcutaneous fat thickness. Although the correlations were strong between the 2 measurement tools, the LOA values were wide, indicating a possible discrepancy between the 2 tools, as noted by observing the Bland-Altman plots (Figures 3 through 6). For the VMO, dRF, and pRF, differences in measurement values for smaller subcutaneous fat thickness were close to zero, indicating that both tools provided similar data in this region. However, as the fat thickness increased to greater than 7.5 mm, the difference increased between the 2 tools, resulting in overestimation of subcutaneous fat thickness by the SC. For athletic trainers, particularly those conducting research, knowledge of this overestimation might affect duration of cryotherapy treatments, depth of thermocouple implantation, assessment of total body-fat percentage, and provision of patients with accurate fat-thickness measurements.

Although they were observed between the SC and USI, strong correlations do not always mean that 2 measurement tools agree with one another.[11] Based on the graphic distribution of the VMO, dRF, and pRF plots, the SC were

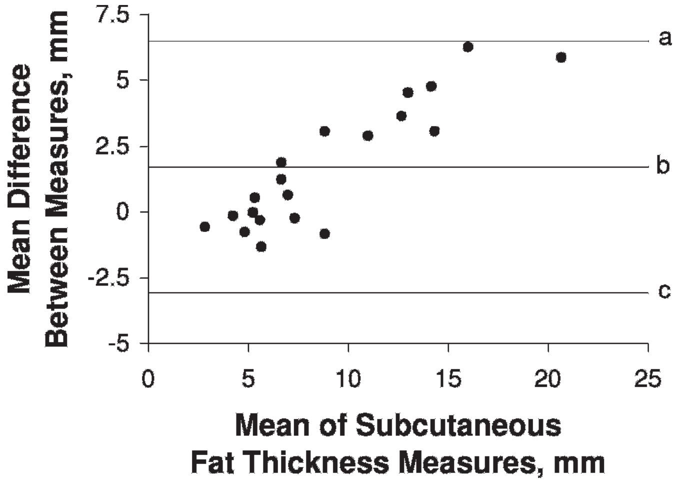

Figure 4. Bland-Altman plot for the distal rectus femoris. [a] Indicates upper limit of agreement. [b] Indicates average mean difference. [c] Indicates lower limit of agreement.

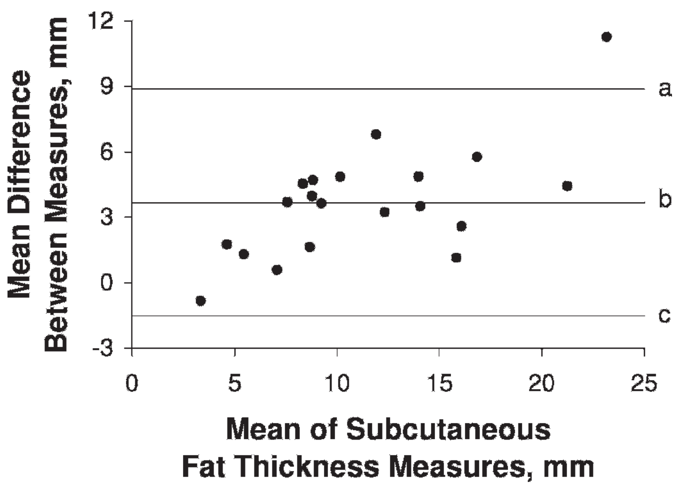

Figure 5. Bland-Altman plot for the proximal rectus femoris. [a] Indicates upper limit of agreement. [b] Indicates average mean difference. [c] Indicates lower limit of agreement.

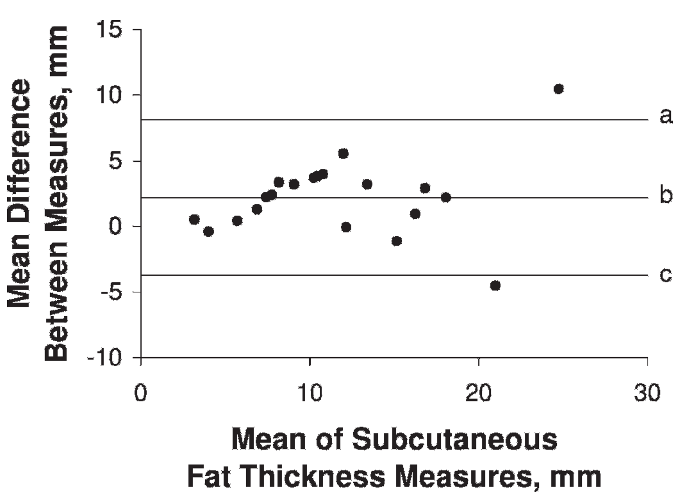

Figure 6. Bland-Altman plot for the vastus lateralis. [a] Indicates upper limit of agreement. [b] Indicates average mean difference. [c] Indicates lower limit of agreement.

Table 2. Limits of Agreement[a] for Bland-Altman Plots for Skinfold Caliper Versus Ultrasound Imaging at Each Measurement Site

Measurement Site	Difference (Mean ± SD), mm
Vastus medialis obliquus	2.18 ± 2.78
Distal rectus femoris	1.71 ± 2.39
Proximal rectus femoris	3.67 ± 2.60
Vastus lateralis	2.21 ± 2.97

[a] The upper limit was +2 SD, and the lower limit was −2 SD.

more likely than USI to overestimate the fat thickness in individuals with greater subcutaneous fat thickness. The evidence as to which tool might overestimate or underestimate subcutaneous fat in the VL was inconclusive because the plot had no obvious pattern, unlike the other 3 plots.

Bland and Altman[11] gave 5 reasons why a high correlation might not necessarily indicate high LOA. First, a correlation indicates the relationship between 2 measures and not the LOA between them.[11] To find a correlation, the points need to fall along any straight line, but for LOA, the points need to fall on a line of equality.[11] Second, a change in the measurement scale (millimeters to centimeters) would not change the correlation, but it would change the agreement.[11] For example, if the SC measurements in our study were not divided in half (twice the value reported), the correlation still would be the same, but the SC measurements would be almost twice as large as the USI measurements, resulting in even larger LOA. Third, the range of values in the sample determines a correlation. If the range is wide, the correlation will be higher than if the range is narrow.[11] Therefore, broad sampling is necessary to compare tools. Fourth, a correlation has an associated significance value; in the case of using 2 measurement tools to measure the same thing, it would be difficult to not have a significant finding ($P < .05$).[11] Therefore, significance values really do not mean anything in agreement testing.[11] Fifth, data that seem to lack agreement even before analysis can result in a high correlation.[11] If strong correlations (0.90) can become "stronger," the interpretation of correlations might need to be altered.[11]

Skinfold calipers are readily available in many clinics and are used to assess body-fat percentage and to identify the beginning of the muscular interface for thermocouple insertion. This is accomplished by dividing the skinfold measurement by 2.[12–14] With the possibility of overestimating subcutaneous fat, calculation of body fat might be incorrect, resulting in a situation in which athletes aim to lose more body fat than needed. Using skinfold thickness at 3 sites (including the thigh for both men and women) to calculate body-fat percentage, Hingorjo et al[15] found that body mass index underpredicted obesity compared with body-fat percentage. Based on our results, we believe that body-fat percentage also might have been inaccurate in that study because one of their measurements was taken at the thigh. When SC are used to measure subcutaneous fat, especially in people with 7.5 mm or more fat in the thigh, the results actually might overestimate body-fat percentage, thus overpredicting obesity. When compared with the previous criterion standard of body-fat percentage (underwater weighing), the SC overestimated body-fat percentage by 6.2%.[16] In addition, if thermocouples are inserted into the muscle to record muscular temperature, the thermocouple might go too far or not far enough into the muscle, resulting in inaccurate temperature readings for the specified depth. Subcutaneous fat greatly affects the time required for underlying muscle to cool.[17] If thermocouples are not being positioned properly in the muscle, optimal treatment times cannot be assessed accurately.

Skinfold calipers also have restrictions for the population on which they can be used because the tools have an end range (roughly 60 mm), often leaving the athlete or clinician embarrassed. However, USI can be used on any person, as long as he or she has no open wounds or infection into which the gel would be placed. Although we focused on the thigh, other areas of interest, such as the pectoralis major, triceps, subscapularis, and abdomen, need to be examined for subcutaneous-fat thickness because these areas also are used in the calculation of the 7-site body-fat percentage.[18] Furthermore, the assessment of abdominal fat, which has a greater effect on cardiovascular health risks, can be measured more accurately with USI because fatty infiltrate can be seen within and around muscle.[9] Measurements at the calf also should be validated because this is a common site for modality assessment of the temperature of skeletal muscle. Both tools have advantages, but USI allows for real-time assessment of anatomic structures.[4]

CONCLUSIONS

We found strong correlations between the SC and USI; however, the large LOA and increasing mean differences with larger fat thicknesses were concerning. When measuring subcutaneous-fat thickness of the thigh, the SC tended to overestimate in individuals with more adipose in the measurement region. Clinicians and researchers need to be cautious when using the SC and interpreting the results, especially in larger individuals.

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