Association of strength, power, and function with muscle thickness, echo intensity, and lean tissue in older males

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Abstract

Purpose: Dual-energy x-ray absorptiometry (DXA) appendicular lean tissue is used to screen older adults for sarcopenia. However, emerging data indicates that ageing-related muscle atrophy largely occurs within specific muscles, which may be masked using appendicular lean tissue. Comparisons between appendicular lean tissue and site-specific measures of muscle in relation to strength and physical function are needed to advance our understanding of these features in the context of poor muscle function in aged adults. Our primary objective was to compare correlations between lean tissue and site-specific muscle characteristics in relation to strength and physical function in older males.

Methods: Older males (≥ 65 years) were evaluated for muscle strength, physical function (6-minute walk and 30-second sit-to-stand), and muscle size (appendicular and site-specific) and composition (echo intensity) using DXA and ultrasound.

Results: Of the 32 older males (75.4±7.9 years), 12 had low appendicular lean tissue. All DXA and ultrasound muscle characteristics were associated ($r=0.39$ to 0.83, $p<0.05$) with torque or power producing capabilities. Except for the knee flexors, no differences in correlation coefficients were observed between muscle thickness or regional lean tissue in relation to muscle strength. Neither DXA nor ultrasound muscle characteristics were associated with physical function.

Conclusions: In older males, ultrasound-based muscle thickness and DXA lean tissue provided similar associations with strength.

Bullet points:

- Lean tissue and muscle thickness provide similar associations with strength

- Muscle thickness can distinguish low and normal appendicular lean tissue in older adults

Keywords: ultrasound, dual-energy x-ray absorptiometry, sarcopenia, aging

Introduction

Sarcopenia is a progressive ageing-related condition that is characterized by impairments in muscle strength, mass, and composition (i.e., increased intramuscular adipose tissue) (Cruz-Jentoft et al. 2018), which is associated with risk of falls and poor physical function (Landi et al. 2012). Identification of older adults with sarcopenia is important for providing targeted therapies (e.g., nutritional interventions) to mitigate the progression of this condition. Appendicular lean tissue mass measured using dual-energy x-ray absorptiometry (DXA) is the primary metric for identifying older adults with low muscle mass. While appendicular lean tissue provides surrogate measures of the muscle mass contained within the upper and lower limbs (Chen et al. 2007), we, and others, have observed that compared with younger adults, older adults display smaller muscle thickness for the rectus abdominis (~30-35% smaller) and quadriceps (~25-30% smaller) muscles in comparison to several other limb muscle groups (Abe et al. 2014a, 2014c; Ata et al. 2019; Kara et al. 2020; Paris et al. 2020, 2021). Focusing ageing-related assessments of skeletal muscle tissue to those muscle groups that present with earlier and significant declines may provide more sensitive markers for characterizing the progression of muscle atrophy. However, these muscle group specific measures of muscle size (and composition) have not been compared with DXA appendicular lean tissue mass in the context of strength, power, and physical function in older adults. A more thorough comparison of DXA lean tissue and site-specific measures of skeletal muscle size and composition in relation to strength and functional capacity of older adults will assist with developing protocols for identification of older adults with sarcopenia.

Ultrasound has emerged as a portable, non-invasive, and cost-effective tool to quantify site-specific muscle mass and composition (Paris and Mourtzakis 2016; Mourtzakis et al. 2017). Ultrasound-measured muscle thickness is strongly associated with volume and whole-body indices of muscle mass measured using reference methods such as magnetic resonance imaging (Sanada et al. 2006) and DXA (Takai et al. 2014; Paris et al. 2017). Muscle echo intensity, a surrogate ultrasound-based measure of muscle composition, is associated with increased intramuscular adipose and connective tissue infiltration (Young et al. 2015; Akima et al. 2016; Stock and Thompson 2020) and increases with advancing age for several muscle groups across the body (Fukumoto et al. 2015; Paris et al. 2020). Therefore, ultrasound represents a promising tool to assess site-specific muscle mass and composition in the progression of sarcopenia.

The primary objective of this study was to compare the correlation coefficients between skeletal muscle function and characteristics of skeletal muscle tissue derived using ultrasound (thickness and echo intensity) or DXA (appendicular and regional lean tissue) in a cohort of older males. Skeletal muscle function included evaluation of upper and lower body isometric torque and isokinetic power, and physical function (e.g., 30-second sit to stand). As a secondary objective, we compared lean tissue, muscle thickness, echo intensity, and muscle function between older males with normal versus low appendicular lean tissue mass.

Methods

Study design and participants

We recruited 32 community dwelling older (≥ 65 years old) males to attend 2 data collection sessions over of the course of 7-14 days, which included analysis of body composition, physical function, and muscle strength. Recruitment was limited to males due to the necessity for sex-specific analyses (e.g., muscle strength) and the larger age-related impairments in skeletal muscle mass in males with advancing age (Paris et al. 2020). Participants were excluded if they had: 1) a neuromuscular disorder, 2) oral or intra-venous contrast within the past

3 weeks, 3) a prosthetic joint replacement, 4) a history of cancer or cerebrovascular disease, or 5) participated in structured exercise sessions within the past 6 months. Prior to all laboratory visits, participants were instructed to refrain from moderate to vigorous physical activity for 48 hours and alcohol consumption for 24 hours. This study was approved by a human research ethics committee at the University of Waterloo. Written informed consent was obtained from all participants in accordance with established protocols for human research.

Anthropometry

Participant's height and body mass were obtained while wearing a cloth hospital gown using a stadiometer (to the nearest 0.1 cm) and balance beam scale (to the nearest 0.1 kg), respectively. Waist circumference was measured to the nearest 0.1 cm by placing the inferior border of a flexible tape measure at the top of the iliac crest.

Ultrasound landmarking

Landmarking was performed on participants in a supine or prone posture on a table, with their feet secured in neutral rotation using a foot strap. The upper arm was imaged on the anterior and posterior surface, 60% distal from the acromial process to the lateral epicondyle of the humerus. Anterior forearm images were captured on the anterior surface, 30% distal from the radial head to the styloid process of the radius. Anterior abdomen images were taken 3 cm right of the umbilicus. Anterior thigh images were taken two-thirds the distance from the anterior superior iliac spine to the superior pole of the patella. The posterior upper leg image was taken 50% the distance between the greater trochanter and lateral epicondyle of the femur, on the posterior surface. The anterior and posterior lower leg images were taken 30% distal from the head of the fibula to the lateral malleolus. During landmarking, participants remained supine or prone for 20 minutes prior to image acquisition to mitigate shifts in fluid distribution (Berg et al. 1993).

Ultrasound image acquisition

Images were taken in the transverse plane using a real time B-mode ultrasound imaging device (M-turbo, Sonosite, Markham, ON), which was equipped with a multi-frequency linear array transducer (L38xi: 5-10 MHz). Adjustable parameters gain, time-gain-compensation, and dynamic range (50%) were held constant throughout acquisition. To minimize tissue compression during imaging, the ultrasound transducer was generously coated with water-soluble transmission gel, as previously described (Paris et al. 2017). Medial-lateral movement of the transducer was allowed for all landmarks to centre the muscle within the field of view. All landmarks were imaged twice.

Muscle thickness and echo intensity

Muscle thickness was analyzed for each landmark by measuring the vertical distance between the upper margin of either the underlying bone or the deep muscle fascia (anterior abdomen and anterior lower leg) and the superior muscle fascia. Muscle echo intensity was evaluated by selecting the largest rectangular area within the muscle fascia borders, as previously described (Caresio et al. 2014). Specific muscles analyzed were the rectus abdominis (anterior abdomen), tibialis anterior (anterior lower leg), biceps brachii (anterior upper arm), rectus femoris (anterior upper leg), lateral gastrocnemius (posterior lower leg), and triceps brachii (posterior upper arm). Muscle thickness and echo intensity were measured once per image (two images per landmark) by a single trained investigator and averaged for each landmark (Figure 1). Ultrasound measures of muscle thickness and echo intensity have been previously demonstrated to be a reliable technique in older adults for several muscle groups (Strasser et al. 2013; Nijholt et al. 2017) Muscle thickness and echo intensity measurements were performed using ImageJ (NIH, Bethesda, MD, version 1.53e) by a single trained investigator.

Dual-energy x-ray absorptiometry

A certified medical radiation technologist performed all whole body DXA scans (Hologic discovery QDR4500, Hologic, Toronto, ON). Hologic software (version 13.2) was used to segment the body into the head, torso, left and right arms, and left and right legs. Appendicular lean tissue index was calculated by dividing the sum of the lean soft tissue (i.e., fat- and bone-free mass) in the arms and legs by height squared (kg/m^2). Participants were classified as low appendicular lean tissue if they were <7.0 kg/m^2 (Cruz-Jentoft et al. 2018). Custom region of interest boxes were placed around: 1) the lower arm, horizontally across the medical epicondyle of the humerus, and 2) the lower leg, horizontally across the tibial plateau. Upper arm and upper leg lean tissue was calculated by subtracting the lower arm or leg lean tissue from the total arm or leg lean tissue, respectively.

Isometric torque and isokinetic power

All participants performed 1 familiarization session for maximal isometric torque and isokinetic power prior to the testing session, which has been shown improve maximal muscle activation of older adults for strength assessment (Jakobi and Rice 2002). An isokinetic dynamometer (Biodex System 3, Biodex Medical Systems, New York) was used to assess the peak isometric torque of the knee and elbow flexors and extensors and peak isokinetic power of the knee extensors. Participants were seated against the backrest with a hip angle of 85° and straps placed tightly across the participant's waist and chest.

Maximal voluntary isometric torque of the elbow extensors and flexors was performed at 90° of flexion (confirmed using a goniometer). Alternating between flexion and extension, 6 contractions (each lasting 5 seconds) were performed with 30 seconds of rest between trials. Maximal voluntary isometric torque of the knee extensors and flexors was performed at 60° of flexion. Alternating between flexion and extension, 6 contractions (each lasting 5 seconds) were performed with 30 seconds of rest between trials. Maximal voluntary isokinetic power for the knee extensors was evaluated for 3 contractions at 1.05 rad/s (60°/s) and 3 contractions at 3.14 rad/s (180°/s), with one minute of rest between trials. For isokinetic power, participants began with their knee at 90° and extended as rapidly and forcefully as possible until 30° deg of flexion. The highest value for maximal torque or peak power across all trials was used for further analysis.

Handgrip strength

Grip strength of the right hand was assessed using a Jamar hand-held dynamometer according to a standardized protocol (Roberts et al. 2011). Briefly, participants were seated upright in a chair with their right arm placed on the armrest and their elbow flexed to 90°. Participants squeezed with as much force as possible for 3 seconds. Three trials were performed with 1 minute of rest between contractions.

Physical function

The six-minute walk test was performed using two cones placed 20 m apart. Participants were instructed complete as many “laps” as possible between the cones within 6 minutes (without running or jogging) according to a standardized protocol (Crapo et al. 2002). A 30-second sit-to-stand test was performed with participants’ arms crossed over the chest to prevent assistance during standing. Participants were instructed to fully stand up and sit down as many times as possible within 30 seconds. The chair's seated surface was approximately 46 cm from the ground.

Statistical analysis

Differences between older adults presenting with low or normal appendicular lean tissue were evaluated using independent sample t-tests. Due to differences in sample size between groups, Hedges' g was used to compute effect sizes and 95% confidence intervals (CI). Pearson correlation coefficients were used to evaluate associations between skeletal muscle characteristics (muscle thickness, echo intensity, or lean tissue mass) and isometric torque, isokinetic power, or physical function. To examine if correlation coefficients were different between muscle thickness or regional lean tissue mass in relation to isometric torque or isokinetic power, a Pearson and Filon's z was used within the cocor software package (Diedenhofen and Musch 2015). Sample size estimates (n=32) were based on expected correlation coefficients between muscle size (thickness, lean tissue, and metrics of strength and power (expected r=0.35). Multiple linear regression was used to evaluate the combined effects of muscle thickness and echo intensity on associations with isometric torque or isokinetic power.

Statistical significance was set as $p<0.05$. To correct for multiple comparisons between older adults with low vs. normal appendicular lean tissue index, a Holm-Bonferroni correction was used to maintain a family wise error rate of 0.05 for torque and power (n=9), muscle thickness (n=8), and echo intensity (n=6), independently. Similarly, to correct for multiple correlation coefficients, a Holm-Bonferroni correction was used to maintain a family wise error rate of 0.05 for isokinetic torque or power (n=26) and physical function (n=16). All statistical analyses were performed using SPSS (version 26, IBM, USA), unless previously noted.

Results

Males classified as low appendicular lean tissue (n=12) were older ($p<0.001$) and had a lower body mass index (BMI) ($p=0.004$) compared with those with normal appendicular lean tissue (n=20) (Table 1). Compared with the normal appendicular lean tissue group, the low appendicular lean tissue group had lower maximal isometric torque of the knee extensors ($p=0.048$), knee flexors ($p=0.009$), and elbow flexors ($p=0.008$) and peak isokinetic power for knee extensors at 60 °/s ($p=0.049$) (Table 2).

Muscle thickness for all evaluated landmarks was smaller ($p<0.05$) in the low compared with normal appendicular lean tissue group, except for the anterior lower leg ($p<0.05$), which was larger in the low appendicular lean tissue group (Table 3). All muscle thicknesses were significantly associated with appendicular and corresponding limb lean tissue mass (Supplementary Table S1). The low appendicular lean tissue group displayed higher echo intensity of the anterior upper leg ($p=0.003$) and anterior lower leg ($p=0.016$) compared to the normal appendicular lean tissue group (Table 4).

Maximal isometric torque of the knee extensors was significantly associated with anterior upper leg muscle thickness ($r=0.50$, $p=0.023$) and echo intensity ($r=-0.41$, $p=0.038$) and appendicular ($r=0.52$, $p=0.017$) and upper leg ($r=0.70$, $p<0.001$) lean tissue (Table 5). Peak isokinetic power of the knee extensors at 60 and 180 °/s were significantly associated with anterior upper leg muscle thickness ($r=0.55$, $p=0.010$; $r=0.62$, $p=0.002$) and echo intensity ($r=-0.47$, $p=0.025$; $r=-0.48$, $p=0.028$) and appendicular ($r=0.57$, $p=0.007$; $r=0.57$, $p=0.007$) and upper leg ($r=0.71$, $p<0.001$; $r=0.63$, $p=0.002$) lean tissue. Maximal isometric torque of the knee flexors was significantly associated with the posterior upper leg muscle thickness ($r=0.39$, $p=0.025$) and appendicular ($r=0.69$, $p<0.001$) and upper leg ($r=0.71$, $p<0.001$) lean tissue (Table 5).

Maximal grip strength was significantly associated with anterior forearm thickness (r=0.53, p=0.015) and appendicular (r=0.63, p=0.002) and lower arm (r=0.65, p=0.001) lean tissue (Table 5). Maximal isometric torque of the elbow extensors was significantly associated with posterior upper arm muscle thickness (r=0.71, p<0.001) and echo intensity (r=-0.59, p=0.005) and appendicular (r=0.66, p<0.001) and upper arm (r=0.83, p<0.001) lean tissue. Maximal isometric torque of the elbow flexors was significantly associated with anterior upper arm muscle thickness (r=0.58, p=0.006) and echo intensity (r=-0.43, p=0.040) and appendicular (r=0.58, p=0.006) and upper arm (r=0.65, p=0.001) lean tissue (Table 5). Apart from maximal isometric torque of the knee flexors (p=0.010), no differences were observed (p>0.05) for the correlation coefficients between ultrasound muscle thickness or DXA regional lean tissue in relation to isometric torque or isokinetic power (Table 5).

Significant correlations were observed between muscle thickness and echo intensity for the anterior upper arm (r= -0.47, p=0.007), posterior upper arm (r= -0.63, p=0.001), and anterior upper leg (r= -0.66, p<0.001). In a multiple linear regression of muscle thickness and echo intensity, muscle thickness for the anterior upper leg and anterior and posterior upper arm (p<0.05), but not echo intensity (p>0.05), were significantly associated with their corresponding torque or power, except for the anterior upper leg muscle thickness and isometric torque (p=0.06) (Table 6).

After correction for multiple comparisons, muscle thickness, echo intensity, appendicular lean tissue, and lower body lean tissue were not associated (p>0.05) with six-minute walk or 30-second sit to stand tests (Table 7).

Discussion

Here, we demonstrated that DXA lean tissue (appendicular and regional) and ultrasound site-specific muscle thickness provide similar correlation coefficients with static and dynamic muscle strength in older males. However, upper leg lean tissue mass provided a stronger association with isometric knee flexor torque than the posterior upper leg muscle thickness. While both muscle thickness and echo intensity were correlated with isometric torque and isokinetic power, echo intensity was not independently associated with muscle strength when combined with muscle thickness using multiple linear regression. Compared with older males who had normal appendicular lean tissue mass, all muscle thicknesses were thinner and muscle echo intensity of the rectus femoris and tibialis anterior were greater in the low appendicular lean tissue group.

Ageing-related losses in skeletal muscle mass and function are thought to begin around the 5th decade of life and accelerate with advancing age (Mitchell et al. 2012). Even amongst apparently healthy, community dwelling older adults, these ageing-related impairments in muscle tissue progress at a subclinical level; however, there is significant variability in the severity and rate of progression of sarcopenia between individuals (Larsson et al. 2019). Due to this significant variability and the deleterious impact on mobility, independence, health care costs, and rates of mortality, operationalizing a definition of sarcopenia is prudent to enable identification of older adults who may require targeted therapies to mitigate further deterioration (Prado and Heymsfield 2014).

DXA measured appendicular lean tissue mass is typically suggested as the primary metric to evaluate ageing-related changes in muscle mass (Cruz-Jentoft et al. 2018). However, as we and others have previously shown, aging is associated with more prominent atrophy of specific muscle groups, such as the rectus abdominis and quadriceps (Abe et al. 2011; Paris et al. 2020, 2021). Yet, it remains unclear whether site-specific skeletal muscle atrophy differs in individuals with low vs. appendicular lean tissue mass. Here, we observed that older males with low appendicular lean tissue mass presented with smaller muscle thickness (~13-23%) across all sites except for the anterior lower leg (~8.5%), which was larger. These increases in the anterior lower leg muscle thickness may be related to increased intramuscular adipose tissue or disturbances in fluid balance, as we also observed increased echo intensity of the tibialis anterior muscle in the low compared to normal appendicular lean tissue group. Several other publications have also observed smaller muscle thicknesses for the biceps (~10%), quadriceps (~15-25%), and gastrocnemius muscles (~15-20%) amongst frail (Akazawa et al. 2016), pre-sarcopenic (Minoru et al. 2017), sarcopenic (Kuyumcu et al. 2016; Minoru et al. 2017), functionally-dependent (Akazawa et al. 2016), and weak (Minoru et al. 2017; Chang et al. 2018) older males and females when compared to older adults with normal muscle mass or strength. Increased muscle echo intensity (~17%) has also been observed in the quadriceps (Akazawa et al. 2016; Minoru et al. 2017), but not the biceps (Chang et al. 2018) or gastrocnemius (Chang et al. 2018) muscles in these same cohorts of older adults, which is in agreement with our observations. Taken together, these data suggest that typical ageing-related atrophy may occur in specific muscle groups (e.g., quadriceps); however, the progression towards a reduced capacity (e.g., low muscle mass) may involve more global muscle atrophy. Therefore, appendicular lean tissue may be a useful index for identification of those older adults with progressed losses in muscle mass, whereas regional or site-specific measures may be more sensitive to early ageing-related losses.

In relation to isometric torque or isokinetic power, both ultrasound muscle thickness and appendicular or regional lean tissue provided similar correlation coefficients (excluding posterior upper leg), indicating both metrics may be useful for the characterization of sarcopenia in older males. In line with our findings, Thiebaud et al., 2017 observed similar correlations between 1 repetition maximum knee extension and flexion strength with either anterior to posterior thigh muscle thickness ratio (r= 0.39 to 0.52) or appendicular lean tissue mass (r= 0.46 to 0.56). Furthermore, the anterior to posterior upper arm muscle thickness ratio and appendicular lean tissue mass displayed similar associations with 1 repetition maximum for chest press (r= 0.54 and r= 0.65, respectively) and lat-pull down (r= 0.41 and r= 0.56, respectively) (Thiebaud et al. 2017). However, these associations were evaluated across young, middle-aged, and older males; whereas our study only focused on older males. In a more direct comparison, Tsukasaki et al., 2020 examined quadriceps cross-sectional area (using computed tomography) and DXA lean tissue mass in relation to isometric knee extensors torque in 1818 adults (40-89 years of age). Although quadriceps cross-sectional area provided statistically stronger associations with muscle strength than DXA appendicular or thigh lean tissue, the correlation coefficients were of similar magnitude (males – cross-sectional area: 0.50, DXA: 0.46; females – cross-sectional area: 0.49, DXA: 0.40) (Tsukasaki et al. 2020). These data indicate that ultrasound is a clinically relevant alternative tool to evaluate muscle size and draw inferences in relation to skeletal muscle strength and power, providing an alternative tool to DXA for assessment of sarcopenia in older adults. Furthermore, these data highlight that site-specific muscle size may provide an earlier marker for identifying low skeletal muscle mass in older adults.

A potential advantage that ultrasound provides over DXA appendicular lean tissue in the assessment of sarcopenia, is the ability to quantify a surrogate of muscle composition (echo intensity) in addition to muscle thickness, which may provide complementary metrics for evaluating ageing-related muscle degradation. While we observed that echo intensity was correlated with isometric torque and isokinetic power, when both echo intensity and muscle thickness were included as covariates in multiple linear regression, echo intensity was not independently associated with muscle strength and did not improve the coefficient of determination in comparison to muscle thickness alone. However, Watanabe et al., 2013 observed that both muscle thickness and echo intensity of the rectus femoris were significantly associated with maximal isometric knee extensor torque in multiple-linear regression (B-coefficients 0.381 and -0.294). These discrepancies are potentially due to the moderate associations between muscle thickness and echo intensity in our cohort, whereas Watanabe et al., 2013 did not observe any correlation. However, others have also observed inverse associations (r= -0.59) between muscle thickness and echo intensity (Varanoske et al. 2020). This discrepancy between our findings and those of Watanabe et al., 2013 is somewhat surprising given that we recruited males of a similar age range (~65-90 years), but may potentially be due to differences in ethnicity (Japanese vs. Caucasian) or ultrasound imaging protocol (e.g. standing vs. supine). However, data from the Healthy Ageing and Body Composition study demonstrated that mid-thigh cross-sectional area explained a much larger proportion of the variance ($R^2 = 0.304$ men and $R^2 = 0.248$ women) in isometric knee extension torque than thigh muscle intramuscular adipose tissue ($R^2 = 0.016$ men and $R^2 = 0.030$ women) (Goodpaster et al. 2001). These data agree with our findings, suggesting that the majority of the variance in muscle strength is explained by metrics of muscle mass (thickness, cross-sectional area), rather than composition (echo intensity).

In relation to physical function, after correcting for multiple comparisons, neither DXA nor ultrasound characteristics of muscle were associated with the six-minute walk or 30-second sit to stand test; however, rectus abdominis echo intensity displayed moderate (r= -0.47) associations with 30-second sit to stand. Others have observed that the ratio between the anterior and posterior thigh muscle thickness is associated with zig-zag walking time, but not gait speed (Abe et al. 2014b). Marcus et al., 2012 observed associations between six-minute walk distance and thigh intramuscular adipose tissue (r= -0.33) and muscle cross-sectional area (r= 0.38) in 109 older adults. While we did not observe any association between function and thigh thickness or echo intensity, the older adults Marcus et al., 2012 recruited were likely of poorer functional capacity, as they had at least 2 comorbidities, were at risk of falling or had experienced a fall in the past 12 months, and had a shorter six-minute walk distance (409.9 ±120.3 compared with 540.9 ±87.8 m).

An important limitation of this study is the lack of participants presenting with sarcopenia (according to recent guidelines of low muscle strength and mass) (Cruz-Jentoft et al. 2018). In our cohort, several participants presented with low appendicular lean tissue mass (n=12), but only 2 had a low grip strength (<27 kg), which limit the generalizability of these findings to individuals with sarcopenia. Furthermore, the individuals with low appendicular lean tissue were significantly older (81.9 vs. 71.5 years) than those with normal appendicular lean tissue, making it challenging to disentangle the effects of advancing age versus skeletal muscle atrophy for site-specific comparisons of muscle thickness and lean tissue. In addition, our analyses only focused on older males, which limiting our understanding of site-specific measures of skeletal muscle mass and composition in relation to strength and function of older females.

Conclusions

In older males, site-specific measures of muscle thickness and DXA lean tissue provided similar correlation coefficients with static and dynamic muscle strength. These data highlight that both appendicular lean tissue and site-specific measures of muscle size (thickness, regional lean tissue), are useful tools for assessing muscle mass in older adults for the identification of sarcopenia.

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REFERENCES

Abe, T., Loenneke, J.P., Thiebaud, R.S., and Loftin, M. 2014a. Age--related muscle loss of the anterior and posterior thigh assessed by means of MRI/CT and ultrasound. J. Trainology **3**(2): 47–52. doi:10.17338/trainology.3.2_47.

Abe, T., Ogawa, M., Thiebaud, R.S., Loenneke, J.P., and Mitsukawa, N. 2014b. Is muscle strength ratio a criterion for diagnosis of site-specific muscle loss? Geriatr. Gerontol. Int. **14**(4): 837–844. doi:10.1111/ggi.12179.

Abe, T., Sakamaki, M., Yasuda, T., Bemben, M.G., Kondo, M., Kawakami, Y., and Fukunaga, T. 2011. Age-related, site-specific muscle loss in 1507 Japanese men and women aged 20 to 95 years. J. Sport. Sci. Med. **10**(1): 145–150.

Abe, T., Thiebaud, R.S., Loenneke, J.P., Loftin, M., and Fukunaga, T. 2014c. Prevalence of site-specific thigh sarcopenia in Japanese men and women. Age (Dordr). **36**(1): 417–26. doi:10.1007/s11357-013-9539-6.

Akazawa, N., Okawa, N., Tamura, K., and Moriyama, H. 2016. Relationships between intramuscular fat, muscle strength and gait independence in older women: A cross-sectional study. Geriatr. Gerontol. Int.: 1–6. doi:10.1111/ggi.12869.

Akima, H., Hioki, M., Yoshiko, A., Koike, T., Sakakibara, H., Takahashi, H., and Oshida, Y. 2016. Intramuscular adipose tissue determined by T1-weighted MRI at 3 T primarily reflects extramyocellular lipids. Magn. Reson. Imaging **34**(4): 397–403. doi:10.1016/j.mri.2015.12.038.

Ata, A.M., Kara, M., Kaymak, B., Gürçay, E., Çakır, B., Ünlü, H., Akıncı, A., and Özçakar, L.

2019. Regional and total muscle mass, muscle strength and physical performance: The potential use of ultrasound imaging for sarcopenia. Arch. Gerontol. Geriatr. **83**(January): 55–60. doi:10.1016/j.archger.2019.03.014.

Berg, H.E., Tedner, B., and Tesch, P.A. 1993. Changes in lower limb muscle cross-sectional area and tissue fluid volume after transition from standing to supine. Acta Physiol. Scand. **148**(4): 379–385. doi:10.1111/j.1748-1716.1993.tb09573.x.

Caresio, C., Molinari, F., Emanuel, G., and Minetto, M.A. 2014. Muscle echo intensity: reliability and conditioning factors. Clin. Physiol. Funct. Imaging **5**(35): 393–403. doi:10.1111/cpf.12175.

Chang, K.V., Wu, W.T., Huang, K.C., Jan, W.H., and Han, D.S. 2018. Limb muscle quality and quantity in elderly adults with dynapenia but not sarcopenia: An ultrasound imaging study. Exp. Gerontol. **108**: 54–61. Elsevier Inc. doi:10.1016/j.exger.2018.03.019.

Chen, Z., Wang, Z., Lohman, T., Heymsfield, S.B., Outwater, E., Nicholas, J.S., Bassford, T., LaCroix, A., Sherrill, D., Punyanitya, M., Wu, G., and Going, S. 2007. Dual-energy X-ray absorptiometry is a valid tool for assessing skeletal muscle mass in older women. J Nutr **137**(1541-6100 (Electronic)): 2775–2780.

Crapo, R., Casaburi, R., Coates, A., Enright, P., MacIntrye, N., McKay, R., Johnson, D., Wanger, J., Zeballos, R., Bittner, V., and Mottram, C. 2002. American Thoracic Society ATS Statement : Guidelines for the Six-Minute Walk Test. Am. J. Respir. Crit. Care Med. **166**: 111–117. doi:10.1164/rccm.166/1/111.

Cruz-Jentoft, A.J., Baeyens, J.P., Bauer, J.M., Boirie, Y., Cederholm, T., Landi, F., Martin, F.C., Michel, J.P., Rolland, Y., Schneider, S.M., Topinková, E., Vandewoude, M., and Zamboni,

M. 2018. Sarcopenia: European consensus on definition and diagnosis. Age Ageing **39**(4): 412–423. doi:10.1093/ageing/afq034.

Diedenhofen, B., and Musch, J. 2015. Cocor: A comprehensive solution for the statistical comparison of correlations. PLoS One **10**(4): 1–12. doi:10.1371/journal.pone.0121945.

Fukumoto, Y., Ikezoe, T., Yamada, Y., Tsukagoshi, R., Nakamura, M., Takagi, Y., Kimura, M., and Ichihashi, N. 2015. Age-Related ultrasound changes in muscle quantity and quality in women. Ultrasound Med. Biol. **41**(11): 3013–3017. doi:10.1016/j.ultrasmedbio.2015.06.017.

Goodpaster, B.H., Carlson, C.L., Visser, M., Kelley, D.E., Scherzinger, A., Harris, T.B., Stamm, E., and Newman, a B. 2001. Attenuation of skeletal muscle and strength in the elderly: The Health ABC Study. J. Appl. Physiol. **90**(6): 2157–2165.

Jakobi, J.M., and Rice, C.L. 2002. Voluntary muscle activation varies with age and muscle group. J. Appl. Physiol. **93**(2): 457–462. doi:10.1152/japplphysiol.00012.2002.

Kara, M., Kaymak, B., Ata, A.M., Özkal, Ö., Kara, Ö., Baki, A., Şengül Ayçiçek, G., Topuz, S., Karahan, S., Soylu, A.R., Çakir, B., Halil, M., and Özçakar, L. 2020. STAR - Sonographic Thigh Adjustment Ratio: A Golden Formula for the Diagnosis of Sarcopenia. Am. J. Phys. Med. Rehabil. **99**(10): 902–908. doi:10.1097/PHM.0000000000001439.

Kuyumcu, M.E., Halil, M., Kara, Ö., Çuni, B., Çağlayan, G., Güven, S., Yeşil, Y., Arık, G., Yavuz, B.B., Cankurtaran, M., and Özçakar, L. 2016. Ultrasonographic Evaluation of the Calf Muscle Mass and Architecture in Elderly Patients With and Without Sarcopenia. Arch. Gerontol. Geriatr. **65**: 218–224. doi:10.1016/j.archger.2016.04.004.

Landi, F., Liperoti, R., Russo, A., Giovannini, S., Tosato, M., Capoluongo, E., Bernabei, R., and Onder, G. 2012. Sarcopenia as a risk factor for falls in elderly individuals: Results from the ilSIRENTE study. Clin. Nutr. **31**(5): 652–658. Elsevier Ltd. doi:10.1016/j.clnu.2012.02.007.

Larsson, L., Degens, H., Li, M., Salviati, L., Lee, Y. Il, Thompson, W., Kirkland, J.L., and Sandri, M. 2019. Sarcopenia: Aging-related loss of muscle mass and function. Physiol. Rev. **99**(1): 427–511. doi:10.1152/physrev.00061.2017.

Marcus, R.L., Addison, O., Dibble, L.E., Foreman, K.B., Morrell, G., and Lastayo, P. 2012. Intramuscular adipose tissue, sarcopenia, and mobility function in older individuals. J. Aging Res. **2012**: 629–637. doi:10.1155/2012/629637.

Minoru, Y., Yosuke, K., Daisuke, I., Nishio, N., Abe, Y., Kakehi, T., Fujimoto, J., Tanaka, T., Ohji, S., Otobe, Y., Koyama, S., Okajima, Y., and Arai, H. 2017. Differential Characteristics of Skeletal Muscle in Community-Dwelling Older Adults. J. Am. Med. Dir. Assoc. **18**(9): 807.e9-807.e16. Elsevier Inc. doi:10.1016/j.jamda.2017.05.011.

Mitchell, W.K., Williams, J., Atherton, P., Larvin, M., Lund, J., and Narici, M. 2012. Sarcopenia, dynapenia, and the impact of advancing age on human skeletal muscle size and strength; a quantitative review. Front. Physiol. **3**: 1–18. doi:10.3389/fphys.2012.00260.

Mourtzakis, M., Parry, S., Connolly, B., and Puthucheary, Z. 2017. Skeletal muscle ultrasound in critical care: A tool in need of translation. Ann. Am. Thorac. Soc. **14**(10): 1495–1503. doi:10.1513/AnnalsATS.201612-967PS.

Nijholt, W., Scafoglieri, A., Jager-wittenaar, H., Hobbelen, J.S.M., and Der, C.P. Van. 2017. The reliability and validity of ultrasound to quantify muscles in older adults : a systematic review. doi:10.1002/jcsm.12210.

Paris, Letofsky, N., and Mourtzakis, M. 2020. Site-specific skeletal muscle echo intensity and thickness differences in subcutaneous adipose tissue matched older and younger adults. Clin. Physiol. Funct. Imaging: 1–15. doi:10.1111/cpf.12679.

Paris, M., and Mourtzakis, M. 2016. Assessment of skeletal muscle mass in critically ill patients. Curr. Opin. Clin. Nutr. Metab. Care **19**(2): 125–130. doi:10.1097/MCO.0000000000000259.

Paris, M.T., Bell, K.E., Avrutin, E., and Mourtzakis, M. 2021. Older males exhibit reduced anterior upper leg and anterior abdominal muscle thickness compared to younger males when matched for relative appendicular lean tissue. Arch. Gerontol. Geriatr. **96**: 104483. Elsevier. doi:10.1016/J.ARCHGER.2021.104483.

Paris, M.T., Lafleur, B., Dubin, J.A., and Mourtzakis, M. 2017. Development of a bedside viable ultrasound protocol to quantify appendicular lean tissue mass. J. Cachexia. Sarcopenia Muscle **8**(5): 713–726. doi:10.1002/jcsm.12213.

Prado, C., and Heymsfield, S.B. 2014. Lean Tissue Imaging: A New Era for Nutritional Assessment and Intervention. JPEN. J. Parenter. Enteral Nutr. **38**(8): 940–53. doi:10.1177/0148607114550189.

Roberts, H.C., Denison, H.J., Martin, H.J., Patel, H.P., Syddall, H., Cooper, C., and Sayer, A.A. 2011. A review of the measurement of grip strength in clinical and epidemiological studies: Towards a standardised approach. Age Ageing **40**(4): 423–429. doi:10.1093/ageing/afr051.

Sanada, K., Kearns, C.F., Midorikawa, T., and Abe, T. 2006. Prediction and validation of total and regional skeletal muscle mass by ultrasound in Japanese adults. Eur. J. Appl. Physiol. **96**(1): 24–31. doi:10.1007/s00421-005-0061-0.

Stock, M.S., and Thompson, B.J. 2020. Echo intensity as an indicator of skeletal muscle quality: applications, methodology, and future directions. Eur. J. Appl. Physiol. Springer Berlin Heidelberg. doi:10.1007/s00421-020-04556-6.

Strasser, E.M., Draskovits, T., Praschak, M., Quittan, M., and Graf, A. 2013. Association between ultrasound measurements of muscle thickness, pennation angle, echogenicity and skeletal muscle strength in the elderly. Age **35**(6): 2377–2388. doi:10.1007/s11357-013-9517-z.

Takai, Y., Ohta, M., Akagi, R., Kato, E., Wakahara, T., Kawakami, Y., Fukunaga, T., and Kanehisa, H. 2014. Applicability of ultrasound muscle thickness measurements for predicting fat-free mass in elderly population. J. Nutr. Health Aging **18**(6): 579–85. doi:10.1007/s12603-013-0419-7.

Thiebaud, R.S., Loenneke, J.P., Abe, T., Fahs, C.A., Rossow, L.M., Kim, D., Beck, T.W., Bemben, D.A., Larson, R.D., and Bemben, M.G. 2017. Appendicular lean mass and site-specific muscle loss in the extremities correlate with dynamic strength. : 328–331. doi:10.1111/cpf.12292.

Tsukasaki, K., Matsui, Y., Arai, H., Harada, A., Tomida, M., Takemura, M., Otsuka, R., Ando, F., and Shimokata, H. 2020. Association of Muscle Strength and Gait Speed with Cross-Sectional Muscle Area Determined by Mid-Thigh Computed Tomography - A Comparison with Skeletal Muscle Mass Measured by Dual-Energy X-Ray Absorptiometry. J. frailty aging **9**(2): 82–89. doi:10.14283/jfa.2020.16.

Varanoske, A.N., Coker, N.A., Johnson, B.A. DI, Belity, T., and Wells, A.J. 2020. Influence of muscle depth and thickness on ultrasound echo intensity of the vastus lateralis. Acta radiol. **0**(0): 1–10. doi:10.1177/0284185120958405.

Watanabe, Y., Yamada, Y., Fukumoto, Y., Ishihara, T., Yokoyama, K., Yoshida, T., Miyake, M., Yamagata, E., and Kimura, M. 2013. Echo intensity obtained from ultrasonography images reflecting muscle strength in elderly men. Clin. Interv. Aging **8**: 993–998. doi:10.2147/CIA.S47263.

Young, H.-J., Jenkins, N.T., Zhao, Q., and McCully, K.K. 2015. Measurement of intramuscular fat by muscle echo intensity. Muscle and Nerve **52**(6): 963–71. doi:10.1002/elsc.201200179.

Table 1. Participant characteristics

	All (n=32)	Low appendicular lean tissue (n=12)	Normal appendicular lean tissue (n=20)	Unadjusted p-value	Hedges' g (95% CI)
Age, y	75.4 (7.9)	81.9 (6.6)	71.5 (5.8)	<0.001	1.66 (0.84, 2.48)
Height, m	1.73 (0.08)	1.74 (0.07)	1.73 (0.08)	0.789	0.13 (-0.59, 0.84)
Body mass, kg	80.0 (13.3)	72.9 (8.2)	84.2 (14.1)	0.017	-0.90 (-1.65, -0.15)
BMI, kg/m^2	26.5 (4.0)	24.1 (1.8)	28.1 (4.3)	0.004	-1.09 (-1.85, -0.32)
Waist circumference, cm	99.3 (9.5)	95.5 (6.2)	101.5 (10.5)	0.079	-0.64 (-1.37, 0.09)
Appendicular lean tissue index, kg/m^2	7.28 (0.87)	6.48 (0.48)	7.76 (0.68)	<0.001	-2.03 (-2.90, -1.16)
Upper arm lean tissue, kg	1.65 (0.36)	1.36 (0.22)	1.76 (0.35)	0.001	-1.26 (-2.04, -0.48)
Lower arm lean tissue, kg	1.26 (0.19)	1.16 (0.17)	1.33 (0.17)	0.009	-0.97 (-1.73, -0.22)
Upper leg lean tissue, kg	5.50 (0.89)	4.90 (0.68)	5.86 (0.81)	0.002	-1.22 (-2.00, -0.45)
Lower leg lean tissue, kg	2.73 (0.38)	2.50 (0.34)	2.87 (0.34)	0.006	-1.06 (-1.82, -0.30)
Body fat, %	29.6 (4.2)	29.3 (3.3)	29.9 (4.7)	0.704	-0.14 (-0.85, 0.58)

Data are presented as mean (standard deviation [SD]). BMI, body mass index.

Table 2. Strength and physical function characteristics

	All (n=32)	Low appendicular lean tissue (n=12)	Normal appendicular lean tissue (n=20)	Unadjusted p-value	Adjusted p-value	Hedges' g (95% CI)
Knee extensors isometric torque, Nm	168.5 (45.7)	141.9 (39.5)	184.5 (42.4)	0.008	0.048	-1.00 (-1.76, -0.25)
Knee extensors 60 °/sec isokinetic power, W	138.6 (42.1)	113.7 (35.8)	153.6 (39.0)	0.007	0.049	-1.03 (-1.79, -0.27)
Knee extensors 180 °/sec isokinetic power, W	288.8 (87.9)	243.4 (72.6)	316.0 (86.4)	0.021	0.105	-0.87 (-1.61, -0.12)
Knee flexors isometric, Nm	88.6 (23.0)	72.5 (13.0)	98.3 (22.4)	0.001	0.009	-1.29 (-2.07, -0.51)
Grip strength, kg	38.4 (8.9)	34.5 (8.7)	40.7 (8.4)	0.055	0.165	-0.71 (-1.45, 0.03)
Elbow extensors isometric torque, Nm	62.9 (17.1)	54.8 (14.5)	67.8 (17.1)	0.035	0.140	-0.78 (-1.52, -0.04)
Elbow flexors isometric torque, Nm	51.2 (15.4)	40.3 (11.1)	57.7 (14.1)	0.001	0.008	-1.30 (-2.08, -0.51)
Six-minute walk distance, m	540.9 (87.8)	519.1 (103.0)	554.1 (77.1)	0.282	0.282	-1.50 (-2.31, -0.70)
30-second sit to stand, repetitions	15.3 (4.9)	13.6 (4.6)	16.3 (4.9)	0.155	0.310	-0.55 (-1.28, 0.18)

Data are presented as mean (SD). Adjusted p-values were derived using a Holm-Bonferroni correction.

Table 3. Muscle thickness characteristics

	All (n=32)	Low appendicular lean tissue (n=12)	Normal appendicular lean tissue (n=20)	Unadjusted p-value	Adjusted p-value	Hedges' g (95% CI)
Anterior upper arm, cm	3.15 (0.50)	2.78 (0.28)	3.37 (0.47)	<0.001	0.002	-1.4 (-2.19, -0.61)
Posterior upper arm, cm	2.81 (0.74)	2.39 (0.52)	3.06 (0.75)	0.011	0.032	-0.97 (-1.72, -0.21)
Anterior forearm, cm	4.60 (0.50)	4.21 (0.45)	4.84 (0.38)	<0.001	0.002	-1.51 (-2.31, -0.7)
Anterior abdomen, cm	0.87 (0.19)	0.76 (0.18)	0.93 (0.17)	0.012	0.023	-0.95 (-1.71, -0.2)
Anterior upper leg, cm	2.68 (0.67)	2.26 (0.38)	2.94 (0.67)	0.003	0.007	-1.14 (-1.91, -0.37)
Posterior upper leg, cm	4.42 (0.92)	3.79 (0.85)	4.79 (0.76)	0.002	0.006	-1.23 (-2, -0.45)
Anterior lower leg, cm	2.97 (0.28)	3.06 (0.22)	2.82 (0.32)	0.021	0.021	0.81 (0.07, 1.56)
Posterior lower leg, cm	6.16 (0.79)	5.56 (0.71)	6.54 (0.58)	<0.001	0.001	-1.51 (-2.32, -0.71)

Data are presented as mean (SD). Adjusted p-values were derived using a Holm-Bonferroni correction.

Table 4. Muscle echo intensity characteristics

	All (n=32)	Low appendicular lean tissue (n=12)	Normal appendicular lean tissue (n=20)	Unadjusted p-value	Adjusted p-value	Hedges' g (95% CI)
Anterior upper arm, AU	63.5 (11.9)	66.0 (11.8)	62.0 (12.0)	0.371	0.741	0.33 (-0.39, 1.05)
Posterior upper arm, AU	35.3 (9.7)	40.2 (10.9)	32.3 (7.8)	0.023	0.092	0.85 (0.10, 1.6)
Anterior abdomen, AU	58.4 (18.9)	67.5 (21.4)	53.0 (15.3)	0.034	0.101	0.79 (0.05, 1.54)
Anterior upper leg, AU	52.5 (13.9)	62.8 (11.4)	46.3 (11.6)	<0.001	0.003	1.40 (0.60, 2.19)
Anterior lower leg, AU	55.6 (12.2)	63.4 (10.7)	50.9 (10.6)	0.003	0.016	1.15 (0.38, 1.91)
Posterior lower leg, AU	80.1 (17.6)	81.4 (21.9)	79.4 (14.9)	0.761	0.761	0.11 (-0.61, 0.83)

Data are presented as mean (SD). Adjusted p-values were derived using a Holm-Bonferroni correction. AU, arbitrary units.

Table 5. Correlation coefficients between muscle thickness, muscle echo intensity, appendicular lean tissue index, or region-specific lean tissue and maximal muscle torque or power.

	Muscle thickness	Echo intensity	Appendicular lean tissue index	Region-specific lean tissue
Knee extensors isometric torque, Nm	**0.5** (0.18, 0.72)	**-0.41** (-0.66, -0.07)	**0.52** (0.20, 0.73)	**0.70** (0.46, 0.84)
Knee extensors 60 °/sec isokinetic power, W	**0.55** (0.24, 0.75)	**-0.47** (-0.70, -0.14)	**0.57** (0.27, 0.76)	**0.71** (0.48, 0.84)
Knee extensors 180 °/sec isokinetic power, W	**0.62** (0.34, 0.79)	**-0.48** (-0.70, -0.15)	**0.57** (0.27, 0.76)	**0.63** (0.36, 0.80)
Knee flexors isometric, Nm	**0.39** (0.04, 0.65)	**-**	**0.69** (0.44, 0.83)	**0.71*** (0.48, 0.84)
Grip strength, kg	**0.53** (0.22, 0.74)	**-**	**0.63** (0.36, 0.80)	**0.65** (0.38, 0.81)
Elbow extensors isometric torque, Nm	**0.71** (0.48, 0.84)	**-0.59** (-0.77, -0.30)	**0.66** (0.40, 0.82)	**0.83** (0.67, 0.91)
Elbow flexors isometric torque, Nm	**0.58** (0.28, 0.77)	**-0.43** (-0.67, -0.09)	**0.58** (0.28, 0.77)	**0.65** (0.38, 0.81)

Data are presented are correlation coefficient (95% CI). Bold value indicates significant correlation after Holm-Bonferroni correction. * indicates a significantly different correlation coefficient between regional lean tissue or muscle thickness in relation to isometric torque or isokinetic power. Correlation coefficients for muscle thickness and echo intensity were derived between: anterior upper leg and knee extensors (torque and power), posterior upper leg and knee flexors (torque), anterior forearm and grip strength, posterior upper arm and elbow extensors (torque), anterior upper arm and elbow flexors (torque). Correlation coefficients for regional lean tissue were derived between: upper leg lean tissue and knee extensors (torque and power) and flexors (torque), lower arm lean tissue and grip strength, upper arm lean tissue and elbow extensors (torque) and flexors (torque).

Table 6. Multiple linear regression analysis of muscle thickness and echo intensity compared to maximal muscle torque or power.

	Muscle thickness standardized B coefficient	Muscle thickness p-value	Echo intensity coefficient	Echo intensity p-value	Regression coefficient
Knee extensors isometric torque, Nm	0.395	0.06	-0.158	0.45	0.51
Knee extensors 60 °/sec isokinetic power, W	0.420	0.04	-0.203	0.31	0.57
Knee extensors 180 °/sec isokinetic power, W	0.531	0.009	-0.136	0.47	0.63
Elbow extensors isometric torque, Nm	0.566	0.002	-0.231	0.16	0.73
Elbow flexors isometric torque, Nm	0.488	0.006	-0.204	0.23	0.61

Data are presented as standardized B-coefficients. Regressions for muscle thickness and echo intensity were derived between: anterior upper leg and knee extensors (torque and power), posterior upper arm and elbow extensors (torque), anterior upper arm and elbow flexors (torque).

Table 7. Correlation coefficients between muscle thickness, muscle echo intensity, appendicular lean tissue index, or region-specific lean tissue and six-minute walk distance or 30-second sit to stand.

		six-minute walk	30-second sit to stand
Anterior abdominal	thickness, cm	0.12 (-0.23, 0.44)	0.09 (-0.26, 0.42)
	echo intensity, AU	-0.30 (-0.58, 0.05)	-0.47 (-0.70, -0.14)
Anterior upper leg	thickness, cm	0.04 (-0.31, 0.38)	0.1 (-0.25, 0.43)
	echo intensity, AU	-0.17 (-0.48, 0.19)	-0.11 (-0.44, 0.24)
Posterior lower leg	thickness, cm	0.25 (-0.10, 0.55)	-0.06 (-0.40, 0.29)
	echo intensity, AU	-0.03 (-0.37, 0.32)	-0.25 (-0.55, 0.10)
Lean tissue	Appendicular lean tissue index, kg/m^2	0.12 (-0.23, 0.44)	0.03 (-0.32, 0.37)
	Lower body lean tissue, kg	0.29 (-0.06, 0.58)	-0.05 (-0.39, 0.30)

Data are presented are correlation coefficient (95% CI). Bold value indicates significant correlation after Holm-Bonferroni correction. AU, arbitrary units.

Figure 1

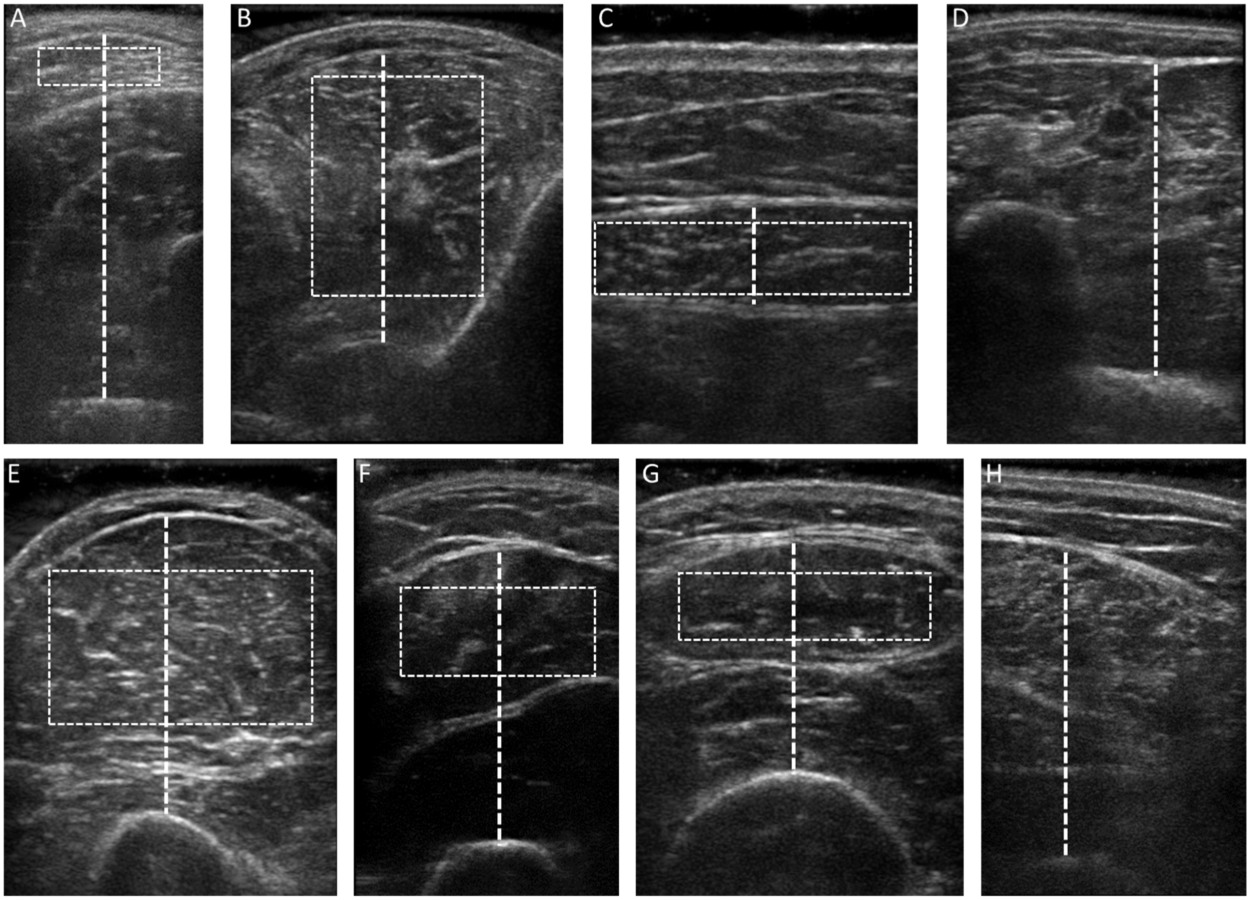

Figure captions

Figure 1. Representative ultrasound images for analysis of skeletal muscle thickness and echo intensity of the A) posterior lower leg, B) anterior lower leg, C) anterior abdominal, D) anterior forearm, E) anterior upper arm, F) posterior upper arm, G) anterior upper leg, H) posterior upper leg.