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Bradley A. Ruple

Christopher G. Vann

Casey L. Sexton

Shelby C. Osburn

Morgan A. Smith

See next page for additional authors

Authors

Bradley A. Ruple, Christopher G. Vann, Casey L. Sexton, Shelby C. Osburn, Morgan A. Smith, Joshua S. Godwin, Petey W. Mumford, Matt S. Stock, Michael D. Roberts, and Kaelin C. Young

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SHORT COMMUNICATION

Peripheral quantitative computed tomography is a valid imaging technique for tracking changes in skeletal muscle cross-sectional area

Bradley A. Ruple[1] | Christopher G. Vann[2] | Casey L. Sexton[1] | Shelby C. Osburn[1] | Morgan A. Smith[1] | Joshua S. Godwin[1] | Petey W. Mumford[3] | Matt S. Stock[4] | Michael D. Roberts[1,5] | Kaelin C. Young[1,6]

[1]School of Kinesiology, Auburn University, Auburn, Alabama, USA

[2]Duke Molecular Physiology Institute, Duke University School of Medicine, Duke University, Durham, North Carolina, USA

[3]Department of Kinesiology, Lindenwood University, St. Charles, Missouri, USA

[4]School of Kinesiology and Physical Therapy, University of Central Florida, Orlando, Florida, USA

[5]Edward Via College of Osteopathic Medicine, Auburn, Alabama, USA

[6]College of Osteopathic Medicine, Pacific Northwest University of Health Sciences, Yakima, Washington, USA

Correspondence

Kaelin C. Young, Molecular and Applied Sciences Laboratory-Auburn University, Professor and Division Chief of Physiology, College of Osteopathic Medicine, Pacific Northwest University of Health Sciences, 200 University Pkwy, Yakima, WA 98901, USA.
Email: kyoung@pnwu.edu

Michael D. Roberts, School of Kinesiology, Director, Molecular and Applied Sciences Laboratory, Auburn University, Auburn, AL, USA.
Email: mdr0024@auburn.edu

Abstract

Peripheral quantitative computed tomography (pQCT) has recently expanded to quantifying skeletal muscle, however its validity to determine muscle cross-sectional area (mCSA) compared to magnetic resonance imaging (MRI) is unknown. Eleven male participants (age: 22 ± 3 y) underwent pQCT and MRI dual-leg mid-thigh imaging before (PRE) and after (POST) 6 weeks of resistance training for quantification of mid-thigh mCSA and change in mCSA. mCSA agreement at both time points and absolute change in mCSA across time was assessed using Bland-Altman plots for mean bias and 95% limits of agreement (LOA), as well as Lin's concordance correlation coefficients (CCC). Both pQCT and MRI mCSA increased following 6 weeks of resistance training ($\Delta mCSA_{pQCT}$: 6.7 ± 5.4 cm^2, $p < 0.001$; $\Delta mCSA_{MRI}$: 6.0 ± 6.4 cm^2, $p < 0.001$). Importantly, the change in mCSA was not different between methods ($p = 0.39$). Bland-Altman analysis revealed a small mean bias (1.10 cm^2, LOA: −6.09, 8.29 cm^2) where pQCT tended to overestimate mCSA relative to MRI when comparing images at a single time point. Concordance between pQCT and MRI mCSA at PRE and POST was excellent yielding a CCC of 0.982. For detecting changes in mCSA, Bland-Altman analysis revealed excellent agreement between pQCT and MRI (mean bias: −0.73 cm^2, LOA: −8.37, 6.91 cm^2). Finally, there was excellent concordance between pQCT and MRI mCSA change scores (CCC = 0.779). Relative to MRI, pQCT imaging is a valid technique for measuring both mid-thigh mCSA at a single time point and mCSA changes following a resistance training intervention.

KEYWORDS

magnetic resonance imaging, muscle cross-sectional area, peripheral quantitative computed tomography, skeletal muscle

1 | INTRODUCTION

The accurate and precise measurement of skeletal muscle size is crucial for determining if an intervention is effective at inducing muscle hypertrophy. Likewise, monitoring the rate of skeletal muscle atrophy due to aging, disease, or period of disuse is also critical for researchers and practitioners. Therefore, it is imperative that imaging techniques aimed at quantifying changes in skeletal muscle size are both valid and reliable (Haun et al., 2019). For example, magnetic resonance imaging (MRI), long considered the gold standard in soft-tissue imaging (Erlandson et al., 2016), is noninvasive and does not involve the use of radiation. MRI is commonly praised for its ability to contrast muscle and adipose compartments with high resolution. However, obtaining MRI images is costly, requires specialized training for acquisition as well as image processing, and is quite limited in availability outside of a clinical setting. In addition, there is a long list of contraindications that may prevent acquiring images from certain populations (Dill, 2008).

Peripheral quantitative computed tomography (pQCT) was originally designed for the acquisition and quantification of volumetric bone mineral content, density, and structural characteristics of the limbs (Wong & Manske, 2020; Wong, 2016). More recently, pQCT has been utilized to capture and quantify soft tissue measurements such as muscle cross-sectional area (mCSA), muscle density, as well as subcutaneous and intermuscular adipose tissue area (DeFreitas et al., 2010; Rowe et al., 2019). While pQCT resembles full bore computed tomography (CT), pQCT technology has some inherent differences. Both techniques use X-ray attenuation to produce a cross-sectional image, but pQCT has the advantage of being more portable, is affordable for research and clinical laboratories, and exposes the patient to a significantly lower dose of radiation (< 1.5 μSv per scan) (Braun et al., 1998; Erlandson et al., 2016; Genant et al., 1996). However, there is a lack of validation with respect to the accuracy of the pQCT to determine mCSA changes over time. To our knowledge, there is only one study that has directly compared pQCT-derived mid-thigh mCSA to MRI-derived mid-thigh mCSA (Sherk et al., 2011). Sherk and colleagues reported excellent concordance in mid-thigh mCSA between pQCT and MRI, provided that a strong smoothing filter was applied to the pQCT images (Sherk et al., 2011). While these data are encouraging for measurements taken at a single time point, the accuracy of the pQCT to detect and quantify changes in mCSA over time has yet to be determined. With pQCT becoming increasingly more utilized for assessing skeletal muscle morphological adaptations (Candow et al., 2021; Figueiredo et al., 2021; Lamb et al., 2020; May et al., 2022; Mitchell et al., 1985; Reidy et al., 2018; Sexton et al., 2021; Smith et al., 2023), we sought to evaluate the longitudinal agreement between pQCT and MRI in detecting resistance training-induced increases in mid-thigh mCSA in participants undergoing a 6-week resistance training programme.

2 | METHODS

2.1 | Participant characteristics

The data from this study was collected as a secondary investigation from a previous study that was reviewed and approved by the Institutional Review Board at Auburn University (IRB approval #: 19-245 MR 1907). The study examined skeletal muscle hypertrophy from 6 weeks of either high-load low-volume (HL) or low-load high-volume (HV) unilateral lower-body resistance training (Vann et al., 2022). Inclusion criteria consisted of being free of cardiometabolic diseases and free of any conditions that prevented the collection of a skeletal muscle biopsy. All participants provided written consent before the start of the study and all standards set by the Declaration of Helsinki were followed.

Fifteen previously resistance-trained college-aged men volunteered for the original training study (Vann et al., 2022). However, only 11 of these participants (22 ± 3 years old; 182.3 ± 9.0 cm; 86.8 ± 12.6 kg) were included in the current analyses due to insufficient MRI image quality of four participants precluding accurate segmentation. Training status was determined by two criteria: (i) a self-reported training age greater than 1 year (note, self-reported resistance training experience was 6 ± 3 years); and (ii) a one-repetition maximum (1RM) barbell back squat that exceeded one and one-half times the individual's body mass, estimated from a 3RM test (relative squat strength to body mass ratio was 1.9 ± 0.4). Participants were asked to continue their normal diet and stop all training outside of the study. Notably, the original study only reported MRI outcomes and did not include any of the pQCT data discussed herein.

2.2 | Experimental protocol

A detailed description of the study protocol has been published previously (Vann et al., 2022). Briefly, participants performed resistance training 3 days per week for 6 weeks. Before (PRE) and 3 days following (POST) the last resistance training bout, participants submitted a urine sample (~5 mL) to assess urine specific gravity (USG) using a handheld refractometer (ATAGO). USG in all participants was between 1.005 and 1.020 indicating sufficient hydration (American College of Sports et al., 2007) and mean USG was not different between pre and post time points (PRE: 1.016 ± 0.006 vs. POST: 1.016 ± 0.004, $p = 0.45$). Height and body mass were attained using a digital column scale (Seca 769), and values were recorded to the nearest 0.5 cm and 0.1 kg, respectively. Mid-thigh mCSA of both the left and right leg were assessed by pQCT and MRI. Participants arrived at the lab for testing following, at minimum, a 4-h fast and care was taken to schedule participants during a similar time of day for both testing sessions (± 2 h of PRE). Finally, seven ($n = 14$ thighs) of the participants underwent back-to-back (position-reposition) mid-thigh MRI scans at PRE so that test–retest reliability statistics could be computed for MRI mid-thigh mCSA. It should be

noted that only seven participants were included due to the financial constraints associated with performing MRI scans.

2.3 | Resistance training programme

A more detailed description of the resistance training programme has been published (Vann et al., 2022). Briefly, both of the participant's legs were randomly assigned to perform either HL or HV training. The training programme consisted of training three times a week, for 6 weeks, including unilateral leg press and knee extension exercises, barbell bench press, barbell row and barbell stiff-legged deadlifts. Compound full-body exercises were performed for three sets of 10 repetitions at 70% of 1RM throughout the training programme, whereas the unilateral lower-body exercises followed a progressive overload paradigm specific to HL or HV training.

2.4 | Peripheral quantitative computed tomography

pQCT imaging and analysis was performed as previously described by our laboratory (Ruple et al., 2021). Briefly, transverse images of both the right and left mid-thigh were acquired using a pQCT scanner (Stratec XCT 3000; Stratec Medical). Mid-thigh was determined by measuring the total distance from the mid-inguinal crease in a straight line to the proximal patella, with the knee and hip flexed at 90°, a mark was made using a permanent marker at 50% of the total length. Images were acquired using a single 2.4 mm slice thickness, a voxel size of 0.4 mm and scanning speed of 20 mm s^{-1}. All images were analysed for total mCSA (cm^2) using the pQCT BoneJ plugin (Rantalainen et al., 2011) freely available through ImageJ analysis software (NIH). Figure 1 depicts both a raw (a) and segmented (b) image of the mid-thigh captured by pQCT. Test–retest reliability using intraclass correlation coefficient$_{3,1}$ ($ICC_{3,1}$), standard error of the measurement (SEM), and minimal difference to be considered real (MD) was previously determined for mCSA on ten participants scanned approximately 24 h apart resulting in an ICC of 0.99, SEM of 0.84 cm^2, and MD of 2.32 cm^2. All scans were captured and analysed by the same investigator (K.C.Y.).

2.5 | Magnetic resonance imaging

Participants were shuttled to the Auburn University MRI Research Center to undergo dual-leg mid-thigh MRI scans. All measurements were performed on a 3 T VARIO system (Siemens, Erlangen, Germany). Briefly, upon arrival, participants were placed in a supine

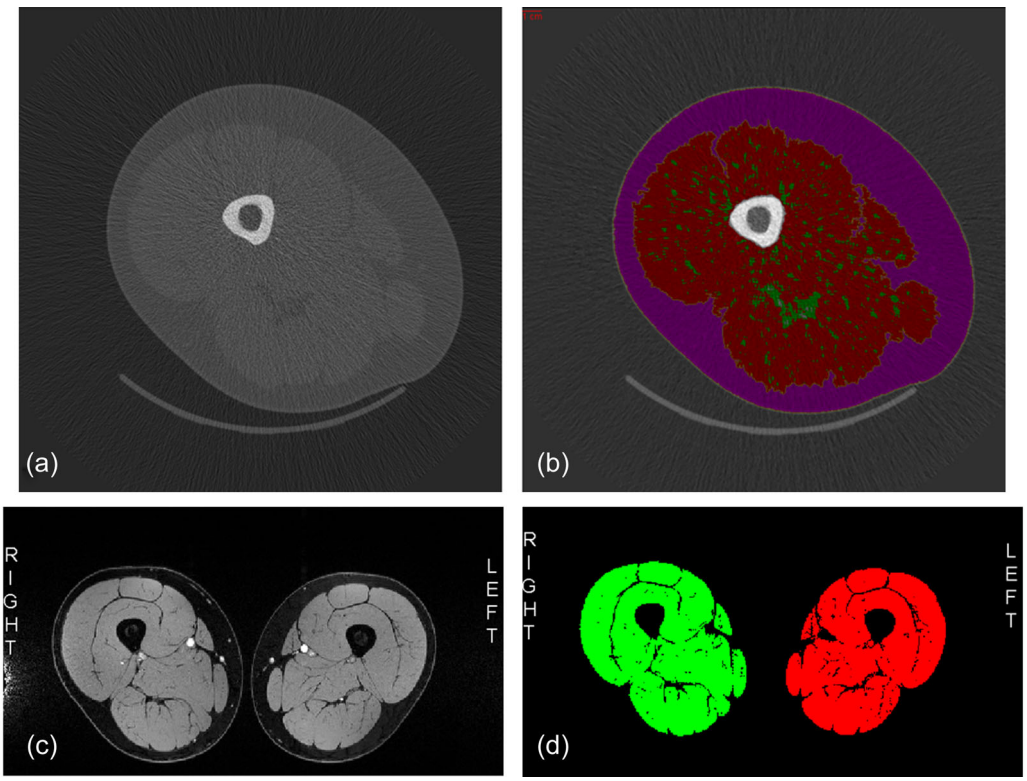

FIGURE 1 (a) Representative raw peripheral quantitative computed tomography (pQCT) image of the mid-thigh. (b) Segmented image of the mid-thigh. Purple indicates subcutaneous adipose area, red indicates skeletal muscle area, and green indicates inter/intramuscular adipose area. (c) Representative raw magnetic resonance imaging (MRI) image of the mid-thigh. (d) Segmented image of the mid-thigh representing skeletal muscle area only in red and green.

position for 10 min to allow for body fluid stabilization. A volume coil was used for radiofrequency transmission and body and spine array coils placed around the legs were used for signal receive. A 3D gradient echo sequence (3D fast low-angle shot) was used to acquire fat-suppressed images with the following parameters: TR/TE = 10/4.92 ms; flip angle = 10°; bandwidth = 510 Hz/pixel, in-plane resolution 1 mm × 1 mm and slice thickness = 2.2 mm. An axial 3D 35.2 mm thick slab (a6 partitions) was placed to image both thighs with the thickness dimension carefully centered on the participant's mid-thigh mark. To estimate test–retest reliability (Weir, 2005) of these MRI methods, a subset ($n = 7$) of participants underwent a second scan at baseline following their first scan. Participants were removed from the magnet's gantry, allowed to stand, and then repositioned back into the gantry for a second image to be captured. Following the conclusion of the study and collection of the post-training scans, all MRI images were first corrected for signal inhomogeneity using the multiplicative intrinsic component optimization method for MRI bias field estimation (Li et al., 2014). Corrected images were then analysed for mCSA using sliceOmatic software (v. 5.0, TomoVision; Magog) by applying signal intensity thresholding to segment skeletal muscle from other tissue types. Depiction of both a raw (c) and analysed MRI image (d) is presented in Figure 1. All MRI images were analysed by the same investigator (K.C.Y).

2.6 | Statistical analysis

Statistical analyses were performed using SPSS v. 25.0 (IBM SPSS Statistics Software). Changes in mCSA from pre- to post-training for both MRI and pQCT were evaluated using a paired samples *t*-test. For validity testing and agreement between methods, paired samples *t*-tests were run to compare mean mCSA at pre- and post-time points as well as on the mean change in mCSA across time. Bland and Altman plots with the calculation of mean bias and 95% limits of agreement were calculated using MRI-determined mid-thigh mCSA as the criterion measure. Furthermore, Lin's concordance correlation coefficients (CCC) were run between pQCT and MRI-derived mid-thigh mCSA at both pre- and post-timepoints (combined) as well as on mCSA change scores (Lin, 1989). A CCC value of 1 is indicative of perfect agreement, values between 0.7 and 0.99 were considered excellent, values between 0.5 and 0.69 were moderate and <0.5 were considered poor (Scott et al., 2017). All data in tables and figures are presented as mean ± standard deviation, and statistical significance was set at $p < 0.05$.

3 | RESULTS

3.1 | General training adaptations

Physical characteristics and general training adaptations are displayed in Table 1. Briefly, 11 participants completed 6 weeks of resistance training. Due to the different unilateral training paradigms for each leg, both the right and left leg for each participant was analysed individually resulting in a sample size of $n = 22$. Following training, mid-thigh mCSA significantly increased when measured by both pQCT and MRI (Figure 2). mCSA measured by pQCT significantly increased from 195.0 ± 20.3 to 201.7 ± 20.2 cm^2 ($p < 0.001$) while MRI-measured mCSA significantly increased from 194.3 ± 19.9 to 200.2 ± 19.5 cm^2 ($p < 0.001$), respectively. Importantly, the mean ΔmCSA between methods was not different ($p = 0.39$).

3.2 | Test–retest reliability of MRI mid-thigh mCSA

Seven participants ($n = 14$ thighs) were included for calculation of reliability statistics for MRI mid-thigh mCSA. There was no difference in mCSA between the first and second set of MRI scans at baseline (202.0 ± 22.9 vs. 202.6 ± 23.8 cm^2, $p = 0.35$). Test–retest reliability was excellent, resulting in an ICC of 0.997, SEM of 1.2 cm^2, and MD of 3.2 cm^2.

3.3 | Agreement in mid-thigh mCSA between pQCT and MRI

There was no significant difference in mCSA between pQCT and MRI at PRE (195.0 ± 20.3 vs. 194.3 ± 19.9 cm^2, $p = 0.31$) or POST (201.7 ± 20.2 vs. 200.2 ± 19.5 cm^2, $p = 0.10$), respectively. Figure 3 displays the agreement between pQCT and MRI mid-thigh mCSA at the PRE and POST time points combined. When examining the concordance of PRE and POST measurements combined, there was excellent concordance between methods (CCC = 0.982). Bland-Altman analysis of the combined PRE and POST mCSA values revealed good agreement (mean bias: 1.10 cm^2, 95% LOA: −6.09, 8.29 cm^2) between methods with pQCT tending to overestimate mCSA relative to MRI. Figure 4 displays the agreement between pQCT and MRI in detecting changes in mCSA following the intervention. Excellent concordance between pQCT and MRI was also found for mCSA change scores (CCC = 0.779). Moreover, the Bland-Altman plot of the change scores revealed good agreement

TABLE 1 Participant characteristics.

Variable	Pre	Post
Age (years)	22 ± 3	…
Height (m)	1.8 ± 0.1	…
Mass (kg)	86.8 ± 12.6	87.7 ± 12.7
Lean mass (kg)	67.5 ± 6.5	68.1 ± 6.1*
Fat mass (kg)	16.4 ± 7.2	16.4 ± 7.6
Leg press 1RM (kg)	118.6 ± 43.3	172.1 ± 53.6*
Leg Ext 1RM (kg)	89.1 ± 16.0	113.5 ± 12.1*

Note: All data are presented as mean ± standard deviation values.
*Indicates increase from PRE to POST ($p < 0.05$).

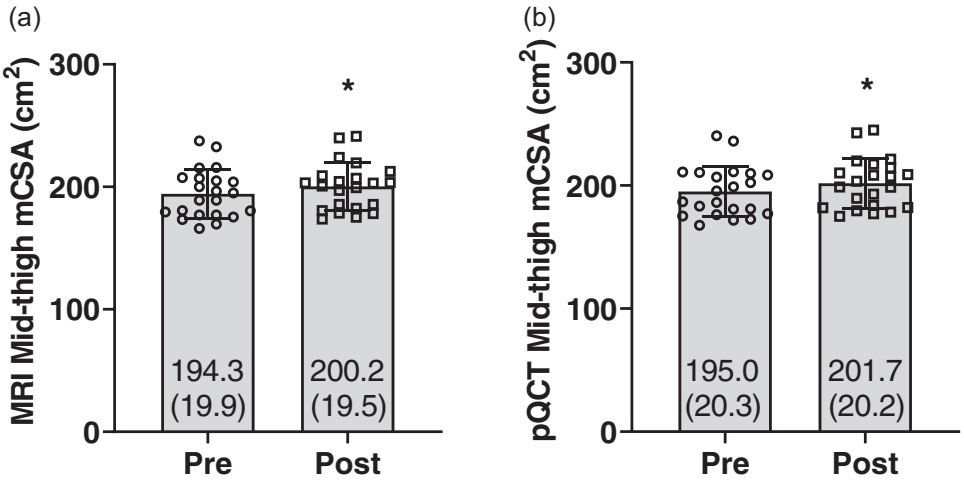

FIGURE 2 Resistance-training induced changes in mid-thigh muscle cross-sectional area (mCSA) from (a) magnetic resonance imaging (MRI) and (b) peripheral quantitative computed tomography (pQCT). All data are reported as mean (standard deviation). *Significant increase from PRE ($p < 0.05$).

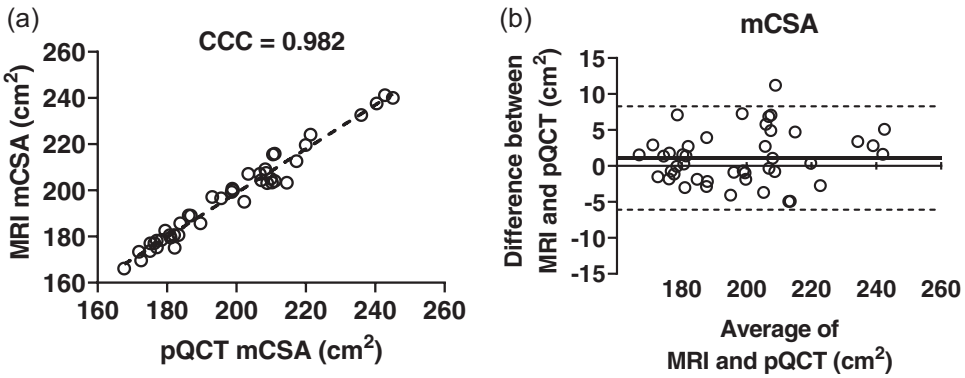

FIGURE 3 (a) Scatterplot showing the relationship between mid-thigh $mCSA_{MRI}$ and $mCSA_{pQCT}$ from the combined legs at PRE and POST ($n = 44$). (b) Bland-Altman plot of the agreement between mid-thigh $mCSA_{MRI}$ and $mCSA_{pQCT}$ from the combined PRE and POST data points ($n = 44$). Dotted horizontal lines represent the upper and lower limits of agreement, and the solid horizontal line represents the mean bias of pQCT compared to MRI. Points in between the dotted lines represent agreement between imaging techniques, while the points outside the dotted lines represent poor agreement. CCC, concordance correlation coefficients; mCSA, muscle cross-sectional area; MRI, magnetic resonance imaging; pQCT, peripheral quantitative computed tomography.

between methods with minimal systematic bias (mean bias: −0.73 cm^2, 95% LOA: −8.37, 6.91 cm^2).

4 | DISCUSSION

This study aimed to examine: (i) the agreement between pQCT and MRI in determining mCSA of the mid-thigh; and (ii) the agreement between pQCT and MRI in detecting changes in mCSA of the mid-thigh following a resistance training intervention. To our knowledge, this is the first investigation to show that pQCT is a valid imaging technique for detecting changes in mid-thigh mCSA relative to MRI. Our findings show excellent agreement between pQCT and MRI regarding quantification of mid-thigh mCSA when compared at a single time point, as well as tracking changes in muscle size (i.e., from PRE to POST). For this reason, in healthy populations, the pQCT is a valid alternative for quantifying mCSA and detecting changes in mCSA following resistance training.

While there has been little research directly comparing pQCT and MRI for mCSA quantification, there has been prior research comparing mCSA attained by full-bore CT to MRI. Mitsiopoulos et al. compared adipose-free leg mCSA values between full-bore CT and MRI, reporting high correlation between the measures ($r = 0.97$, SEE 3.9 cm^2) (Mitsiopoulos et al., 1985). While encouraging, they studied adipose-free cadaveric specimens and thus their model was limited to data from a single time point and does not account for beam attenuation from adipose tissue. Similarly, Engstrom et al. found mid-thigh mCSA measured by CT to be highly correlated with MRI measurements ($r = 0.99$) in cadaveric specimens. However, they also found that CT measurements had a tendency to overestimate mCSA

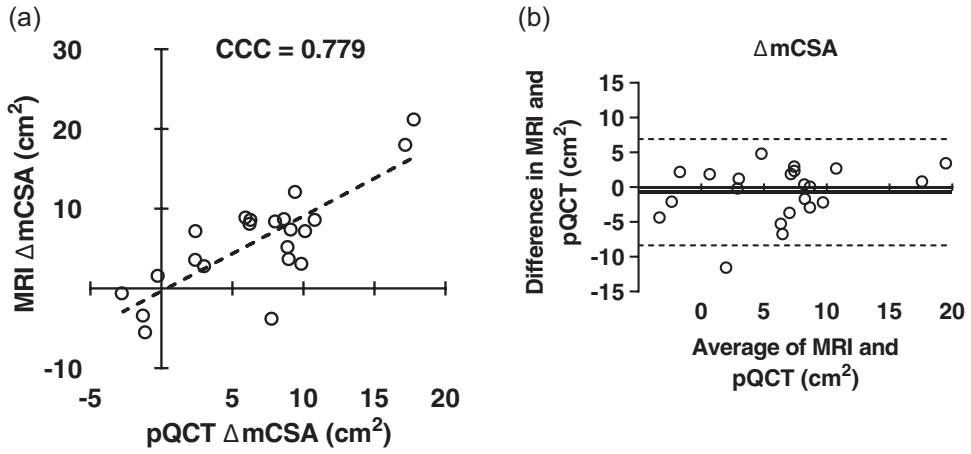

FIGURE 4 (a) Scatterplot showing the relationship between mid-thigh $\Delta mCSA_{MRI}$ and $\Delta mCSA_{pQCT}$ from both legs ($n = 22$). (b) Bland-Altman plot of the agreement between mid-thigh $\Delta mCSA_{MRI}$ and $\Delta mCSA_{pQCT}$ from both legs ($n = 22$). Dotted horizontal lines represent the upper and lower limits of agreement, and the solid horizontal line represents the mean bias of pQCT compared to MRI. Points in between the dotted lines represent agreement between imaging techniques, while the points outside the dotted lines represent poor agreement. CCC, concordance correlation coefficients; mCSA, muscle cross-sectional area; MRI, magnetic resonance imaging; pQCT, peripheral quantitative computed tomography.

by about 10-20% compared to MRI (Engstrom et al., 1991). Interestingly, our data also show that pQCT measurements tended to over-estimate mid-thigh mCSA compared to MRI, albeit at a much lower magnitude (mean bias: 1.10 cm^2, 0.52%). The discrepancy in the magnitude of overestimation between our work and Engstrom et al. is possibly due to the analysis method employed. Engstrom's group determined overall mCSA of the thigh by analysing mCSA of the individual muscles within the thigh. Furthermore, the mCSA's were hand drawn, enlarged and then digitized. Additionally, our analysis includes the segmentation of intra- and inter-muscular adipose tissue area whereas Engstrom's does not. While our data support the previous findings that full-bore CT is a valid imaging tool for measuring mid-thigh mCSA, there are inherent differences between CT and pQCT that may limit the utility of these comparisons. pQCT uses a much lower dose of radiation to capture images (<1.5 μSv per scan) (Braun et al., 1998; Erlandson et al., 2016; Genant et al., 1996). While this inherently decreases the radiation exposure for the patient, it does so at the expense of image resolution with full-bore CT producing higher resolution images for analysis.

To our knowledge, only one study has specifically compared mCSA measurements of the mid-thigh from the pQCT to MRI. Sherk et al. reported strong agreement (mean Diff = −3.1%, CCC = 0.97) between MRI and pQCT-derived mCSA, but only after a strong smoothing filter was applied to reduce noise (scatter) in the raw pQCT image (Sherk et al., 2011). While our single timepoint data support these findings (CCC = 0.982), there are differences between studies that warrant discussion. The MRI image analysis employed by Sherk et al. neglected to segment inter- and intramuscular adipose tissue from skeletal muscle and therefore likely led to an inflated MRI-measured mCSA (Sherk et al., 2011). We posit that this led to the discrepancy between our findings and theirs' in which we found pQCT to slightly overestimate mCSA (mean bias: 1.10 cm^2, 0.52%) whereas Sherk et al. reported a systematic underestimation (−3.1%) of pQCT-measured mCSA compared to MRI. Furthermore, the pQCT analysis parameters differed between studies. Sherk et al. analysed images using the pQCT manufacturer-provided software, which allows users to modify analysis parameters including density thresholds for segmenting tissues, as well as smoothing filters aimed at reducing noise in the image (Sherk et al., 2011). As part of the aim of their study, Sherk and colleagues employed three different filter parameters (no filter, weak filter, and strong smoothing filter) to determine which level of filtering best agreed with MRI image data. They found that only using a strong filter produced mCSA data that agreed well with MRI (Sherk et al., 2011). The present study chose not to use manufacturer-provided software and instead opted to analyse our images in ImageJ using the pQCT BoneJ plugin (Rantalainen et al., 2011). While some thresholding parameters used in the BoneJ plugin are different than those employed by Sherk et al., both analyses used strong smoothing filters to reduce the noise in the image, which seems necessary to produce strong agreement with MRI. Finally, Sherk and colleagues only compared pQCT mid-thigh mCSA to MRI at a single time point, which does not provide the crucial information on the validity of pQCT to accurately detect changes in skeletal muscle size.

While MRI is widely considered the gold standard for skeletal muscle imaging due to its high resolution and high soft tissue contrast, it does have several drawbacks that preclude musculoskeletal researchers from its widespread use. MRI is costly, can be difficult to access, and requires specialized training in both acquisition and analysis of images. Additionally, MRI contraindications such as pacemakers, implanted defibrillators, or metal foreign bodies further limit the inclusion of certain populations (Dill, 2008). Particularly concerning, and pertinent to its use in research, is the lack of

standardized methods for segmenting tissues for size quantification. Alternatively, pQCT is relatively financially attainable for an academic research lab and technicians can be trained in its use within hours. With respect to the analysis of pQCT images for mCSA, the user has a couple of options available to them. Specifically, the manufacturer-provided guidelines and software can be used to segment tissues or one can simply upload their raw images into ImageJ (NIH) and utilize the pQCT BoneJ plugin (Rantalainen et al., 2011) which is freely available. The latter method of analysis was the one used herein, and based on the data presented, this segmentation method agrees well with MRI and provides a standardized method for researchers using pQCT for skeletal muscle quantification. Another advantage of pQCT compared to MRI is that it can be moved and made portable if the need arises. However, pQCT is not without its own limitations. Unfortunately, pQCT exposes subjects to a small dose of radiation (<1.5 μSv per scan) (Braun et al., 1998; Erlandson et al., 2016; Genant et al., 1996). This can be problematic as radiation exposure for research purposes is restricted in some jurisdictions. Another limitation is the size of a participant's thigh relative to the size of the pQCT gantry. There is a size limit within the gantry which will limit the applicability of some populations to be studied (e.g., obese/morbid obese, some types of athletes). Moreover, larger thighs, regardless of tissue type, yield lower resolution images due to noise in the image. Finally, because the radiation dose used is quite low, the pQCT image produced does not have nearly the resolution and contrast provided by MRI. This can be an issue for researchers studying changes in individual muscle groups.

The current study is the first to validate pQCT regarding measuring changes in skeletal muscle size over time. Herein, we contend that pQCT agrees strongly with MRI in detecting muscle size changes following a resistance training intervention. This is an encouraging finding, especially since other whole-muscle imaging techniques commonly used to quantify changes in skeletal muscle size (i.e., dual energy x-ray absorptiometry, B-mode ultrasonography) tend not to strongly agree/correlate with MRI (Ruple et al., 2022). Moreover, we have previously found pQCT test–retest reproducibility for mid-thigh mCSA to be slightly better than MRI (MD: 2.3 vs. 3.2 cm^2, respectively), further lending to its utility in tracking changes in skeletal muscle size and quality.

4.1 | Limitations

The current study examined a hypertrophic stimulus; therefore, it is unknown as to whether the pQCT can precisely track muscle atrophy or tissue composition changes from extended periods of disuse, aging, or in diseased populations. In addition, the data presented were collected in well-trained, college-aged males, and may not be applicable in populations with thicker subcutaneous adipose, as thicker adipose tissue may yield lower resolution images due to an increase in pQCT beam attenuation. Another limitation worth mentioning was the method used for determining test–retest reliability for MRI imaging. Ideally, we would have used a greater n-size but were limited due to the cost of the MRI scans. Lastly, for both the pQCT and the MRI, there is no accepted standardized protocol for imaging or analysing skeletal muscle parameters, thus complicating adequate comparisons (Erlandson et al., 2016). Hence, this is a broader issue that needs to be addressed in the field.

5 | CONCLUSION

Our findings of strong agreement between pQCT and MRI for assessing mid-thigh mCSA, as well as for detecting changes in muscle size following a period of resistance training, suggest that the pQCT is a valid and attractive imaging technique for measuring changes in skeletal muscle size and quality.

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CONFLICT OF INTEREST STATEMENT

M.D.R. and K.C.Y. have received laboratory funds from various industry sources in the form of fixed-priced contracts or laboratory gifts. M.D.R. has also been financially compensated from various industry entities for consultation work regarding scientific presentations and/or various scientific writing endeavours in accordance with Auburn University's Research Compliance and Ethics Guidelines. In relation to the current data, however, the authors declare that no conflicts of interest exist.

DATA AVAILABILITY STATEMENT

Raw data files can be obtained upon reasonable request by emailing the corresponding/senior author (kyoung@pnwu.edu).

ORCID

Bradley A. Ruple http://orcid.org/0009-0001-7277-0771
Matt S. Stock http://orcid.org/0000-0003-1156-1084

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