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The effects of high intensity interval training on muscle size and quality in overweight and obese adults

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Abstract

Objectives—Despite growing popularity of high intensity interval training (HIIT) for improving health and fitness, limited data exist identifying the effects of HIIT on muscle characteristics. The purpose of the current study was to investigate the effects of a 3-week HIIT intervention on muscle size and quality in overweight and obese men and women.

Design—Randomized controlled trial.

Methods—Forty-four overweight and obese men and women (mean $\pm$ SD; age: 35.4 ± 12.3 years; height: 174.9 ± 9.7 cm; weight: 94.6 ± 17.0 kg; %fat: $32.7 \pm 6.5\%$) completed the current study. During baseline and post testing, muscle cross sectional area (mCSA) and echo intensity (EI) were determined from a panoramic scan of the vastus lateralis obtained by B-mode ultrasonography. Body composition variables were measured using dual energy X-ray absorptiometry. Participants were randomized into either a 1:1 work-to-rest ratio HIIT group (SIT; $n = 16$), a 2:1 work-to-rest ratio HIIT group (LIT; $n = 19$), or control (CON; $n = 9$). HIIT participants performed five, 2-min bouts (LIT) or 10, 1-min bouts (SIT) at 85–100% $\text{VO}_{2\text{peak}}$ for 9 sessions over three weeks.

Results—Analysis of covariance demonstrated a significant increase in mCSA for SIT ($p = 0.038$; change () = $-3.17 \pm 3.36 \text{ cm}^2$) compared to CON (= $-0.34 \pm 2.36 \text{ cm}^2$). There was no significant difference in EI across groups ($p = 0.672$).

Conclusions—HIIT may be an effective exercise modality to influence muscle size in overweight and obese individuals. Future studies should investigate muscle characteristics and remodeling in an overweight population following interventions of longer duration and varying work-to-rest protocols.

Keywords

Intermittent exercise; Muscle tissue; Intramuscular fat

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1. Introduction

The high prevalence of overweight and obesity continues to be a public health concern in the United States.¹ Overweight and obesity has been shown to increase the likelihood of developing metabolic syndrome, which is associated with cardiovascular disease, diabetes, and cancer.² High intensity interval training (HIIT) has gained popularity as a safe and efficient exercise method with the potential to influence several health parameters.³ In various populations, HIIT has been shown to increase maximal oxygen consumption,⁴ decrease fat mass, and increase insulin sensitivity.^{5,6} Intracellularly, investigations have observed increases in skeletal muscle oxidative and buffering capacity,⁷ muscle protein synthesis, and mitochondrial biogenesis⁸ as a result of HIIT. Despite the aforementioned data suggesting a potential impact of HIIT on muscle remodeling and growth, there is limited data available, and none, to our knowledge, in an overweight and obese population.

Muscle characteristics, specifically muscle size and quality, have been shown to be related to muscle strength,^{9,10} muscle power, and cardiovascular performance.¹¹ Ultrasonography is becoming a popular tool to determine muscle cross sectional area (mCSA)¹² and muscle quality as measured by echo intensity (EI).^{9,10} Echo intensity, determined by the grayscale analysis of a B-mode ultrasound (US) image, estimates the amount of contractile versus non-contractile tissue, such as adipose and connective tissue, within a muscle.^{13,14} Increased intramuscular fat content may lead to changes in lipid metabolism and has been shown to be related to insulin resistance and the development of type II diabetes.¹⁵ B-mode US has reliably measured mCSA and EI in young, normal weight¹⁶ and overweight and obese adults.¹⁷ Previous studies have investigated the influence of resistance training interventions on muscle size^{12,18} and quality,^{9,18} but to our knowledge no studies have evaluated the effects of HIIT on US mCSA and EI of the VL in an overweight population. Traditional body composition variables such as body fat percentage, lean mass and fat mass are commonly used to observe effects of an intervention, however, many of the devices used to assess the aforementioned measures such as dual-energy X-ray absorptiometry are expensive and immobile. In comparison, the US is an accessible and portable device, therefore determining the relationship of US measures and various body composition variables may increase the application of the US in clinical settings.

Previous studies have utilized HIIT interventions of varying duration (2–24 weeks), interval lengths (8s–4min), and work- to-rest ratios (1:1–2:1); many of which have been shown to be effective in overweight and obese populations.^{5,19} During the initial stages of training, it is expected that muscular adaptations are predominantly oxidative⁴; therefore previous studies investigating the influence of HIIT interventions have primarily focused on fat mass loss, %fat, and weight loss as opposed to lean mass changes.^{3,4,20} However, the increase in muscle protein synthesis reported by Scalzo et al.⁸ following nine cycling HIIT sessions, warrants further investigation of muscular remodeling as a result of HIIT. The purpose of the current study was to investigate the effects of a 3-week HIIT intervention on muscle size and quality in overweight and obese men and women. Exploratory analyses evaluated the relationship between leg fat mass and EI and leg lean mass and mCSA.

2. Methods

Fifty-six overweight men and women volunteered to participate in this study. Physiological outcomes (maximal oxygen consumption, body composition, blood work) have been previously published^{19,21} for this sample of participants of 'low' fitness level (10–20th percentile as defined by the American College of Sports Medicine²²).

Of the 56 participants, 54 individuals were scanned pre and post intervention ($n = 2$ did not return for post testing for reasons unknown). Additionally, $n = 10$ scans did not show the entire fascial border due to insufficient depth of images, therefore, 44 participants were used for analysis in the current study. Descriptive characteristics are presented in Table 1. Inclusion criteria for participation included: BMI between 25–45 kg m⁻², 18–50 years of age, a normal resting 12-lead ECG, willing to maintain their current level of physical activity and physician clearance. Participants were excluded if they were currently participating in HIIT, had untreated hypertension, hyperlipidemia, or a history of cardiopulmonary diseases. Prior to testing, all participants signed an informed consent approved by the University's Institutional Review Board for the protection of human subjects. The content of this study is solely the responsibility of the authors; funding sources had no involvement in data collection, analysis or writing of this report.

The current study evaluated body composition and US assessments before and after a nine-session HIIT intervention. For baseline and post testing, participants arrived to the laboratory at least eight hours fasted. Upon arrival, height was measured using a portable stadiometer (Perspective Enterprises, Portage, MI, USA) and weight was measured using a mechanical scale (Detecto, Webb City, MO, USA). A panoramic ultrasound (US) scan of the vastus lateralis (VL) was performed and then assessed using ImageJ software to quantify echo intensity (EI), muscle cross sectional area (mCSA) and thigh fat thickness (THfat). Additionally, dual-energy X-ray absorptiometry (DXA) was used to determine the combined lean mass of the right and left legs (LegLM) and the combined fat mass of the right and left legs (LegFM). After baseline testing, participants performed a continuous graded exercise test (GXT) on a cycle ergometer to determine peak power output (PPO) for training intensity. Participants were then randomly assigned to one of three groups: control, short interval training (SIT) or long interval training (LIT). Baseline body composition and US testing procedures were repeated following the nine-session intervention.

A panoramic scan of the right vastus lateralis (VL) was performed using a B-mode US (Logiq-e, GE Healthcare, Wisconsin, USA). The ultrasound settings (frequency: 13 Hz, gain: 56) were kept constant to standardize mCSA and EI measures. The depth was set between 4 cm and 5 cm; in the instance an individual had greater subcutaneous fat and the entire VL was not visible at a depth of 5 cm, subject scans were removed from analysis. The depth setting remained consistent within each subject's pre and post testing scans. Prior to each scan, participants were instructed to lay supine with the right leg extended and relaxed on the examination table with a high-density foam pad strapped to the thigh at the midpoint between the femur greater trochanter and femur lateral epicondyle. A wide-band linear array ultrasound transducer probe (GE: 12L-RS) was held perpendicular to the tissue and swept across the skin at equal pressure from the lateral VL border to medial fascia separation. The

same technician performed all scans, and then reviewed the initial quality of images on the US monitor.

Muscle cross sectional area and EI were determined from the panoramic scan of the VL using Image-J software (National Institute of Health, USA, Version 1.37). When analyzing images, scans with evident overlay of successive images that resulted in either detectable shadows on the image or the inability to visualize the full muscle border were removed from mCSA analyses ($n = 1$) and EI analyses ($n = 7$). Echo intensity was determined in the standard histogram function, which uses grayscale analysis of pixels ranging from 0 to 255. Prior to measuring mCSA and EI, each image was calibrated by measuring the number of pixels within a known distance of 1 cm. To measure mCSA and EI, the same technician traced the outline of the VL for each participants' scan along the fascia border as close as possible to capture only the muscle. Test-retest reliability for EI and mCSA measurements taken from a previous study in this laboratory for individuals of similar stature demonstrated an intraclass correlation coefficient (ICC) of 0.74 and 0.87, standard error of the mean (SEM) of 4.58 a.u. and 2.12 cm², and minimal difference (MD) of 12.69 a.u. and 5.89 cm², respectively. Subcutaneous THfat was determined by a linear measure from the epidermal layer to the fascial border of the VL. A correction factor for subcutaneous thigh fat thickness, previously described by Young et al.,²³ was used to account for the influence THfat has on EI measures. Therefore, the following equation was used to determine EI: $y_2 = y_1 + (t \times cf)$, where y_1 = raw EI, t = THfat, $cf=40.5278$, and y_2 = corrected EI.

In order to account for the influence body fluid/hydration may have on mCSA and EI, total body water (TBW) was measured via bioelectrical impedance spectroscopy (SFB7, ImpediMed, Queensland, Australia). Measures of TBW were assessed while the participant lay supine on a table with legs and arms separated by a minimum of 30°. Two electrodes were placed 5 cm apart on the right wrist and hand and two electrodes were placed on the right ankle and foot. Weight, height, age, and sex were entered in the device prior to testing. The average of two trials was recorded as the TBW measurement.

Each subject completed a full body DXA scan (Hologic Inc., Bedford, MA, USA; Apex Software Version 3.3) to determine LegLM and LegFM. Prior to each use, the device was calibrated according to the manufacturer's instructions to ensure valid results. For each scan, birthdate, height, weight, and ethnicity were entered into the software. Participants were asked to remove all metal, thick clothing and heavy plastic to reduce interference. Each subject was placed supine in the center of the scanning table. If subject shoulders were too wide to fit within the scanning area, thumbs were placed under the legs to capture the full width of each subject. Participants were instructed to breathe normally and remain still for the duration of the scan. The same technician performed and analyzed all scans by manually setting the regions of interest. Test-retest reliability for LegLM and LegFM demonstrated ICC of 0.98 and 0.99, SEM of 0.57 kg and 0.32 kg and MD of 1.58 kg and 0.89 kg, respectively.

Participants were randomly assigned to a training group or control group in a 2:2:1 allotment: SIT, LIT, or CON. All training was performed on an electronically braked cycle ergometer (Corival Lode, Gronigen, The Netherlands) under the supervision of trained

research staff. Participants trained three times a week for three weeks for a total of nine training sessions; subjects did not have more than two training sessions on consecutive days each week. Training intensity was established from a graded exercise test as previously described¹⁹; the SIT group performed ten repetitions of 1-min bouts at 90% PPO, and the LIT group performed five repetitions of 2-min bouts at intensities varying between 80–100% PPO; all 9 sessions were matched between groups for work and intensity. Both groups were given 1-min rest periods between each work interval. The HIIT participants reported no adverse events and were 100% compliant.

A univariate analysis of covariance (ANCOVA) was performed to evaluate the change in mCSA between intervention groups (SIT vs. LIT vs. CON) using pre-mCSA as the covariate. A second univariate ANCOVA was performed to evaluate the change in EI between intervention groups using pre-EI as the covariate. Two separate univariate ANCOVAs were performed to evaluate the change in LegLM and LegFM using pre-LegLM and pre-LegFM, respectively as covariate. A Bonferroni adjustment was used to correct p values for pairwise post hoc comparisons. A paired samples t-test was used to evaluate the change in TBW across all groups. Exploratory Pearson Product-Moment correlation analyses were performed to investigate the relationship between LegLM, LegFM, mCSA and EI. An alpha level of 0.05 was set a priori. All analyses were performed using SPSS (Version 21.0 Armonk, NY, USA).

3. Results

For change in mCSA, there was a significant difference between intervention groups ($p = 0.038$). Pairwise comparisons determined there was a significant difference between CON and SIT groups ($p = 0.034$). There was no significant difference between LIT and CON ($p = 0.202$) or SIT ($p > 0.999$). For change in EI, there was no significant difference between intervention groups ($p = 0.672$). There was no significant difference between intervention groups for LegLM ($p = 0.064$) and LegFM ($p = 0.500$). There was no significant difference between pre and post TBW (0.084 ± 2.95 , $p = 0.850$). Pre and post measures for mCSA, EI, LegLM and LegFM are displayed in Table 2. Raw data and adjusted values for individual responses for mCSA for CON, SIT and LIT are presented in Fig. 1.

Pre-intervention LegLM was significantly positively correlated to pre-mCSA ($p = 0.001$, $r = 0.477$); and post-LegLM was significantly positively correlated to post-mCSA ($p < 0.001$, $r = 0.580$). Pre-LegFM was significantly positively correlated to pre-EI ($p < 0.001$, $r = 0.718$); and post-LegFM was significantly positively correlated to post-EI ($p < 0.001$, $r = 0.734$).

4. Discussion

The current study aimed to evaluate the effects of a short duration HIIT intervention on muscle size and composition in overweight individuals. The results indicate that HIIT has the potential to improve mCSA as measured by B-mode US in overweight men and women. Intervals in a one-to-one work to rest ratio (SIT) demonstrated a significant increase in mCSA compared to control, indicating that protocol selection may influence the adaptations and benefits observed from HIIT. In contrast, training had no effect on muscle quality.

Additionally, US variables were correlated with both leg fat and lean mass. This provides support that the US may have utility as a portable tool to track changes in a single muscle and predict overall leg composition changes to an exercise intervention.

High intensity interval training has previously been shown to promote a number of metabolic adaptations.^{4,7} While much is known about aerobic adaptations to HIIT, complete characterization of skeletal muscle remodeling, as a result of this type of training is unclear. The majority of HIIT protocols, including the present study, have utilized the cycling exercise modality which primarily loads the leg musculature. The present study demonstrated a 14% increase in mCSA of the VL after 3 weeks of training in the SIT group. One previous study evaluating men with type 2 diabetes observed a significant 24% increase in mid-thigh mCSA following 8 weeks of high intensity continuous (2 sessions/week; 45 min at 75% $\text{VO}_{2\text{peak}}$) and interval training (1 session/week; 5, 2-min bouts at 85% $\text{VO}_{2\text{peak}}$) on a cycle ergometer.⁵ The longer duration of the training program or the protocol selection of cycling effort may explain the larger increase. Contrary to the current study, Joannis et al.²⁴ performed muscle biopsies of the VL following 18 and 23 sessions of sprint interval training, and did not observe an increase in fiber CSA in overweight or healthy individuals, respectively. However, varying HIIT protocols lasting between 3–15 weeks have resulted in modest increases in total body and trunk lean mass.^{6,19,25} Muscle hypertrophy is dependent upon an increase in the ratio of myofibrillar protein synthesis and breakdown.²⁶ Although the present study did not directly measure muscle protein synthesis, a previous study by Scalzo et al.⁸ demonstrated an increase in mitochondrial biogenesis and muscle protein synthesis in the VL after nine cycling sessions of interval training at a resistance equivalent to 7.5% of body mass for 4–8 bouts of 30 s. Similarly, Di Donato et al.²⁷ demonstrated a significant increase in mitochondrial and myofibrillar protein synthesis 24–28 h postexercise following a higher intensity continuous exercise bout (60% Watt_{max}) compared to a lower intensity bout (30% Watt_{max}). Damas et al.²⁸ observed a significant correlation between myofibrillar protein synthesis and hypertrophy in the early stages of resistance training; at 3 weeks, following 5 resistance training bouts, muscle hypertrophy was no longer correlated with muscle damage, but to protein synthesis. The present study, along with data from the aforementioned studies, supports the need for future investigations to evaluate other cellular mechanistic contributions to increased muscle size with HIIT including both hypertrophic and oxidative changes such as the combination of glycogen content and fluid shifts.²⁹

In the current study, there was no change in EI, which suggests a 3-week high intensity intervention is not sufficient to elicit changes in muscle quality in overweight men and women. It also supports that the changes in mCSA were not a result of muscle damage or inflammation. Muscle swelling as a result of exercise-induced edema has previously been shown to simultaneously increase mCSA and EI 72 h following exercise³⁰ to as long as three weeks following resistance training protocols.²⁸ The lack of change in EI observed in the current study suggests that there was limited acute muscle swelling and inflammation at the time of the measurement. Although to our knowledge, EI responses to HIIT training have not been previously reported, an improvement in muscle quality, as measured by EI, has been shown following resistance training protocols. Specifically, Cadore et al.⁹ found an increase in muscle quality in healthy, college-age individuals following six weeks of resistance training, and Radaelli et al.¹⁸ reported a significant increase in muscle quality

following both low- and high-volume resistance training interventions at 6, 13, and 20 weeks of training in older women. Studies investigating the influence of aerobic exercise on intramuscular fat content in lean and obese insulin-resistant individuals have reported inconsistent results.¹⁵ A variety of factors including the HIIT protocol, the 3-week duration of the present study, ad libitum diet, and the greater infiltration of adipose and connective tissue within the muscle in overweight and obese individuals³¹ may have attenuated changes in muscle quality. Additionally, TBW measured in the current study does not directly measure hydration status; the hydration status and glycogen content of skeletal muscle tissue have the potential to influence EI measures, and therefore further evaluation is warranted. Future studies should investigate whether muscle quality is influenced in overweight individuals following longer duration HIIT interventions.

The significant positive relationship observed between LegFM and EI may support the use of US as a technique for clinicians to detect intramuscular adipose tissue in an overweight population to provide a better understanding of body composition. The significant moderate relationship observed between mCSA and LegLM in the present study, provides initial evidence that US mCSA could be a useful technique to track changes in leg lean mass following an exercise intervention. However, additional research should investigate whether thigh lean mass from DXA has a stronger correlation with mCSA. Additionally, there are limitations of the US that often remain unaddressed. Specifically, it is imperative that the settings of depth and brightness remain consistent, especially if tracking changes. However, high subcutaneous fat thickness and muscle thickness may require changes in depth to gain access to capture the full muscle belly within the image. In the present study, the US depth setting was not sufficient for all participants to observe the entire muscle, and therefore, varied across participants. Adjustments in the depth setting reduces the capability of generating normative values to compare across samples, particularly for EI measures. Data also suggests that training type may influence at what point of the muscle (proximal, medial, distal), and which muscle adapts most favorably, thus influencing at what point of the muscle mCSA should be measured as well as which muscle.³² Furthermore, although EI measures have demonstrated positive correlations to intramuscular adipose tissue,¹⁴ future investigations are needed to continue to describe other components of non-contractile tissue that contribute to changes in EI such as inflammation, skeletal muscle hydration and glycogen content. Additionally, pressure of the probe on the skin may impact tissue deformation and ultimately alter the image. Due to the large amount of subcutaneous fat in the overweight and obese participants, there was increased frequency of the probe losing contact with the skin as the fat undulated with the swiping movement of the probe. The reduced density of the tissue and the curvature of the VL resulted in a shadow in the image or an overlay of images in some cases, similarly described by Noorkoiv et al.³³ Diligently maintaining the US settings, technique, and technician will help attenuate limitations of the US.

5. Conclusions

High intensity interval training may be an effective exercise modality to influence muscle size in overweight and obese individuals. In the current study, a one-to-one work to rest ratio on a cycle ergometer was a safe and well-tolerated HIIT protocol for this population that

elicited an increase in mCSA. The importance of protocol selection in health and body composition benefits should be further evaluated in overweight and obese individuals. The present study found no training or group effect for muscle quality measures. Future studies should investigate muscle size and quality in an overweight population in longer duration HIIT interventions and in protocols varying the work to rest ratio. Additionally, the US is an accessible and portable clinical device, therefore, the correlation of US measures to LegFM and LegLM suggests that future studies should investigate the validity and feasibility of integrating the US into clinical settings to track body composition changes to exercise interventions as well as conditional changes such as aging, weight loss and gain, and injury or illness.

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References

1. Ogden CL, Carroll MD, Kit BK et al. Prevalence of childhood and adult obesity in the United States, 2011–2012. *JAMA* 2014; 311(8):806–814. [PubMed: 24570244]
2. Bradshaw PT, Monda KL, Stevens J. Metabolic syndrome in healthy obese, overweight, and normal weight individuals: the atherosclerosis risk in communities study. *Obesity* 2012; 21(1):203–210.
3. Boutcher SH. High-intensity intermittent exercise and fat loss. *J Obes* 2011; 2011:868305. [PubMed: 21113312]
4. Weston KS, Wisløff U, Coombes JS. High-intensity interval training in patients with lifestyle-induced cardiometabolic disease: a systematic review and meta-analysis. *Br J Sports Med* 2014; 48:1227–1234. [PubMed: 24144531]
5. Boudou P, Sobngwi E, Mauvais-Jarvis F et al. Absence of exercise-induced variations in adiponectin levels despite decreased abdominal adiposity and improved insulin sensitivity in type 2 diabetic men. *Eur J Endocrinol* 2003; 149(5):421–424. [PubMed: 14585088]
6. Trapp E, Heydari M, Freund J et al. The effects of high-intensity intermittent exercise training on fat loss and fasting insulin levels of young women. *Int J Obes* 2008; 32(4):684–691.
7. Gibala MJ, Little JP, van Essen M et al. Short-term sprint interval versus traditional endurance training: similar initial adaptations in human skeletal muscle and exercise performance. *J Physiol* 2006; 575(3):901–911. [PubMed: 16825308]
8. Scalzo RL, Peltonen GL, Binns SE et al. Greater muscle protein synthesis and mitochondrial biogenesis in males compared with females during sprint interval training. *FASEB J* 2014; 28(6):2705–2714. [PubMed: 24599968]
9. Cadore EL, Gonzalez-Izal M, Pallares JG et al. Muscle conduction velocity, strength, neural activity, and morphological changes after eccentric and concentric training. *Scand J Med Sci Sport* 2014; 24(5):e343–e352.
10. Fukumoto Y, Ikezoe T, Yamada Y et al. Skeletal muscle quality assessed from echo intensity is associated with muscle strength of middle-aged and elderly persons. *Eur J Appl Physiol* 2012; 112(4):1519–1525. [PubMed: 21847576]
11. Cadore EL, Izquierdo M, Conceição M et al. Echo intensity is associated with skeletal muscle power and cardiovascular performance in elderly men. *Exp Gerontol* 2012; 47:473–478. [PubMed: 22525196]
12. Ahtiainen JP, Hoffren M, Hulmi JJ et al. Panoramic ultrasonography is a valid method to measure changes in skeletal muscle cross-sectional area. *Eur J Appl Physiol* 2010; 108(2):273–279. [PubMed: 19777252]

13. Pillen S, Tak RO, Zwarts MJ et al. Skeletal muscle ultrasound: correlation between fibrous tissue and echo intensity. *Ultrasound Med Biol* 2009; 35(3):443–446. [PubMed: 19081667]
14. Young HJ, Jenkins NT, Zhao Q, McCully KK. Measurement of intramuscular fat by muscle echo intensity. *Muscle Nerve* 2015; 52(6):963–971. [PubMed: 25787260]
15. Shaw C, Clark J, Wagenmakers AJM. The effect of exercise and nutrition on intramuscular fat metabolism and insulin sensitivity. *Annu Rev Nutr* 2010; 30(1):13–34. [PubMed: 20373917]
16. Palmer TB, Akehi K, Thiele RM et al. Reliability of panoramic ultrasound imaging in simultaneously examining muscle size and quality of the hamstring muscles in young, healthy males and females. *Ultrasound Med Biol* 2015; 41(3):675–684. [PubMed: 25683219]
17. Melvin MN, Smith-Ryan AE, Wingfield HL et al. Evaluation of muscle quality reliability and racial differences in body composition of overweight individuals. *Ultrasound Med Biol* 2014; 40(9):1973–1979. [PubMed: 24912372]
18. Radaelli R, Botton CE, Wilhelm EN et al. Time course of low- and high-volume strength training on neuromuscular adaptations and muscle quality in older women. *Age* 2014; 36(2):881–892. [PubMed: 24414336]
19. Smith-Ryan AE, Melvin MN, Wingfield HL. High-intensity interval training: modulating interval duration in overweight/obese men. *Phys Sportsmed* 2015; 43(2):107–113. [PubMed: 25913937]
20. Fisher G, Brown AW, Bohan Brown M et al. High intensity interval-vs moderate intensity-training for improving cardiometabolic health in overweight or obese males: a randomized controlled trial. *PLoS One* 2015; 10(10):1–15.
21. Smith-Ryan AE, Trexler ET, Wingfield H et al. Effects of high-intensity interval training on cardiometabolic risk factors in overweight/obese women. *J Sports Sci* 2016; 34(21):2038–2046. [PubMed: 26934687]
22. Thompson WR, Gordon NF, Pescatello LS et al. *ACSM's Guidelines for Exercise Testing and Prescription*, 8th ed. Baltimore, MD, Lippincott Williams & Wilkins, 2010.
23. Young HJ, Jenkins NT, Zhao Q et al. Measurement of intramuscular fat by muscle echo intensity. *Muscle Nerve* 2015; 52(6):963–971. [PubMed: 25787260]
24. Joannis S, McKay BR, Nederveen JP et al. Satellite cell activity, without expansion, following non-hypertrophic stimuli. *Am J Physiol Regul Integr Comp Physiol* 2015; 309:R1101–R1111. [PubMed: 26333785]
25. Heydari M, Freund J, Boutcher SH. The effect of high-intensity intermittent exercise on body composition of overweight young males. *J Obes* 2012; 2012:480467. [PubMed: 22720138]
26. Rennie MJ, Wackerhage H, Spangenburg EE et al. Control of the size of the human muscle mass. *Annu Rev Physiol* 2004; 66(9):799–828. [PubMed: 14977422]
27. Di Donato DM, West DWD, Churchward-Venn TA et al. Influence of aerobic exercise intensity on myofibrillar and mitochondrial protein synthesis in young men during early and late postexercise recovery. *Am J Physiol Endocrinol Metab* 2014; 306(9):e1025–e1032. [PubMed: 24595306]
28. Damas F, Phillips SM, Libardi CA et al. Resistance training-induced changes in integrated myofibrillar protein synthesis are related to hypertrophy only after attenuation of muscle damage. *J Physiol* 2016; 18:5209–5222.
29. Fernández-Elías VE, Ortega JF, Nelson RK et al. Relationship between muscle water and glycogen recovery after prolonged exercise in the heat in humans. *Eur J Appl Physiol* 2015; 115(9):1919–1926. [PubMed: 25911631]
30. Radaelli R, Bottaro M, Wilhelm EN et al. Time course of strength and echo intensity recovery after resistance exercise in women. *J Strength Cond Res* 2012; 26(9):2577–2584. [PubMed: 22037095]
31. Goodpaster BH, Theriault R, Watkins SC et al. Intramuscular lipid content is increased in obesity and decreased by weight loss. *Metab Clin Exp* 2000; 49:467–472. [PubMed: 10778870]
32. Earp JE, Newton RU, Cormie P, Blazevich AJ. Inhomogeneous quadriceps femoris hypertrophy in response to strength and power training. *Med Sci Sports Exerc* 2015; 47(11):2389–2397. [PubMed: 25811947]
33. Noorkoiv M, Nosaka K, Blazevich AJ. Assessment of quadriceps muscle cross-sectional area by ultrasound extended-field-of-view imaging. *Eur Appl Physiol* 2010; 109(4):631–639.

Practical implications

- High intensity interval training may be a time efficient and effective method to stimulate muscle size adaptations in overweight individuals.
- A HIIT program utilizing a 1:1 work-to-rest ratio may be the most beneficial for overweight individuals.
- The correlation of US measures to body composition variables may encourage clinicians to integrate the US into clinical practice to track body composition changes due to exercise and diet recommendations, aging, injury or illness.

Fig. 1.

(A) Individual responses of raw data for muscle cross sectional area (mCSA) for short interval training (SIT), control (CON), and long interval training (LIT) groups; (B) Pre and post-mCSA covaried for pre-mCSA (19.88894 cm²) for SIT, CON, and LIT groups.

Descriptive characteristics for long interval training (LIT), short interval training (SIT), and control (CON) groups at baseline.

Table 1:

	N	Age (years)	Ht (cm)	Wt (kg)	BMI (kg/m ²)	%Fat
LIT	19	38.0 ±12.2	176.5 ±9.3	89.7 ±12.3	28.8 ±2.8	32.5 ±6.9
SIT	16	31.4 ±12.0	174.9 ±9.2	97.4 ±14.1	31.8 ± 3.9	32.6 ±6.5
CON	9	37.0 ±12.4	171.6± 11.4	99.7 ± 27.2	33.6 ±7.2	33.4 ±6.4
	44	35.4 ±12.3	174.9 ±9.7	94.6 ±17.0	30.9 ±4.7	32.7 ± 6.5

Mean ±SD. No significant baseline differences.

Table 2:

Pre and post measures of muscle cross sectional area (mCSA), echo intensity (EI), leg fat mass (LegFM) and leg lean mass (LegLM) for long interval training (LIT) groups, short interval training (SIT), and control (CON).

	N	Pre	Post	
mCSA(cm ²)				
LIT	18	16.92 ± 3.97	19.39± 4.53	2.46 ± 3.26
SIT	16	21.93 ±7.04	25.10± 7.87	3.17 ± 3.36 ^a
CON	9	22.18 ±8.58	21.84± 8.37	-0.34 ±2.36
EI (a.u)				
LIT	16	84.71 ± 21.71	81.85 ±22.35	-2.86 ±7.34
SIT	13	78.70 ±21.45	76.41 ± 22.20	-2.28 ± 7.20
CON	8	93.85 ±15.84	93.90 ±18.67	0.05 ± 10.26
LegLM (kg)				
LIT	19	19.06± 4.55	19.28 ±4.53	0.22 ± 0.56
SIT	16	20.35 ± 3.99	20.53 ±4.11	0.18 ± 1.02
CON	9	19.77 ±5.71	19.27 ±5.65	-0.49 ±0.55
LegFM (kg)				
LIT	19	10.04 ± 3.06	9.94 ± 2.93	-0.10± 0.57
SIT	16	10.61 ± 2.75	10.66± 2.54	0.06 ± 0.59
CON	9	10.69± 2.72	10.71 ± 2.40	0.02 ± 0.63

Raw data presented as Mean ±SD, and adjusted change scores (). P-values are based on adjusted baseline scores from the ANCOVA, covaried for pre-mCSA (cm²; 19.88894cm²), pre-EI (a.u.; 84.57609 a.u.), pre-LegLM (kg; 19.6732kg), and pre-LegFM (kg; 10.37975 kg).

^a indicates significant difference from control from the ANCOVA.