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Changes in fat and skeletal muscle with exercise training in obese adolescents: comparison of whole-body MRI and dual energy X-ray absorptiometry

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Abstract

Objective—We examined skeletal muscle (SM) and fat distribution using whole-body MRI in response to aerobic (AE) versus resistance exercise (RE) training in obese adolescents and whether DXA provides similar estimates of fat and SM change as MRI.

Design and Methods—Thirty-nine obese boys (12–18 yr) were randomly assigned to one of three 3-month interventions: AE (*n*=14), RE (*n*=14) or a control (*n*=11).

Results—At baseline, MRI-measured total fat was significantly greater than DXA-measured total fat [Δ=3.1 kg (95% CI: −0.4 to 7.4 kg, $P<0.05$)], wherein underestimation by DXA was greatest in those with the highest total fat. Overall, the changes in total fat were not significantly different between MRI and DXA [Δ= −0.4 kg (95% CI: −3.5 to 2.6 kg, $P>0.05$)], but DXA tended to overestimate MRI fat losses in those with larger fat losses. MRI-measured SM and DXA-measured LBM (lean body mass) were significantly correlated, but as expected the absolute values were different at baseline [Δ= −28.4 kg (95% CI: −35.4 to −21.3 kg, $P<0.05$)]. Further, DXA overestimated MRI gains in SM in those with larger SM gains.

Conclusions—Although DXA and MRI-measured total and regional measures tended to be correlated at baseline and changes with exercise, there were substantial differences in the absolute values derived using DXA versus MRI. Further, there were systemic biases in the estimation between the methods wherein DXA tended to overestimate fat losses and SM gains compared to MRI. Thus, the changes in body composition observed are influenced by the method employed.

Keywords

skeletal muscle; lean body mass; fat; adolescents; DXA; exercise training

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CONFLICT OF INTEREST
All authors have no conflicts of interest to declare.

INTRODUCTION

Magnetic resonance imaging (MRI) provides an accurate assessment of tissue compartments such as skeletal muscle (SM) and various fat depots (e.g., subcutaneous fat, visceral fat and intermuscular fat) *in vivo* and allows for the analysis of separate anatomical regions [1]. Protocols that employ multiple images covering the entire body are considered the reference method for the assessment of whole-body composition in humans. Indeed, the validity of MRI to estimate fat and SM has been compared with dissection in human cadavers and shows strong correlations between cadaver and MRI area measures of SM and fat depot [2]. Several studies in adults examined the changes in total and regional fat distribution in response to exercise and/or diet perturbations in obese men [3, 4] and women [5] using whole-body MRI. To our knowledge, changes in SM and fat distribution using whole-body MRI in response to exercise intervention have not been examined in children and adolescents.

Dual energy X-ray absorptiometry (DXA) has been widely used in obesity research to examine total and regional body composition. Compared with other imaging modalities [e.g., MRI and CT (computed tomography)], DXA is readily available, inexpensive and involves low X- ray exposure by comparison to CT, thereby permitting repeated measurements. However, DXA can only provide overall measures of LBM as it is unable to distinguish SM from other lean tissues [6]. While some studies have shown that appendicular lean soft tissue measured by DXA is able to predict total SM [7, 8], others have questioned the ability of DXA to detect changes in soft tissue with exercise training in older adults [9, 10].

Therefore, the purpose of this study was twofold. First, we examined the changes in regional SM and fat distribution in response to aerobic and resistance training versus a control group using whole-body MRI in obese adolescent boys. Second, we determined whether across these groups, DXA can provide valid estimates of changes in total and regional SM and fat distribution when compared to changes in SM and fat measured by whole-body MRI.

METHODS AND PROCEDURES

Participants

Obese (BMI≥95th percentile) [11] adolescent boys were recruited in the greater Pittsburgh area via posters placed on campus and public transportation, and in the Weight Management and Wellness Center at Children's Hospital of Pittsburgh (CHP). Inclusion criteria included that the subjects be 12–18 years of age, pubertal (Tanner Stages III–V), non-smokers, non-diabetic, and physically inactive (no participation in structured physical activity for past three months except school physical education classes). Exclusion criteria included participation in structured exercise, significant weight change (BMI >2–3 kg/m^2), endocrine and psychiatric disorders, syndromic obesity, and use of chronic medications which influence body composition. A complete medical history, physical examination and pubertal development (according to Tanner criteria based on genital development and pubic hair) were assessed by a certified nurse practitioner. The investigation was approved by the University of Pittsburgh Institutional Review Board. Parental informed consent and child assent were obtained from all participants before participation. The primary purpose of this randomized controlled trial was to examine the effects of aerobic versus resistance exercise alone (e.g., without calorie restriction) on obesity related health outcomes in obese adolescent boys and the metabolic data from this study was published elsewhere [12].

Study design

After completing baseline assessments, subjects were randomly assigned to one of three groups: aerobic exercise, resistance exercise or a non-exercise control group using a completely randomized design and cell sizes of 16 as reported previously [12]. All subjects were asked to follow a weight maintenance diet (55–60% carbohydrate, 15–20% protein, and 20–25% fat) during the study. All exercise sessions were supervised by graduate students and details of exercise training regimen are reported previously [12]. Briefly, the aerobic exercise program required participants to exercise three times per week over the 13-week period, for 60 minutes/session, using treadmills, ellipticals or stationary bikes. The resistance program included a series of 10 whole body exercises, three times per week over the 13-week period for 60 minutes/session. Average (± SD) exercise attendance rate was 99.7 % (± 0.8%) in the aerobic group and 99.0% (± 2.1%) in the resistance group [12].

Anthropometrics

Body weight and height were measured to the nearest 0.1 kg and 0.1 cm using a fixed wall stadiometer (QuickMedical, Issaquah, WA) and a digital scale (Befour Inc., Saukville, WI).

Whole-body magnetic resonance imaging (MRI)

Total fat, SM, and subcutaneous and abdominal fat was determined using a 3.0 Tesla MR system (Trio; Siemens, Erlangen, Germany) at the University of Pittsburgh Magnetic Resonance Research Center. The images were obtained using T1-weighted spin-echo sequence (700-ms repetition time and 5.5-ms echo time) with a 48 × 36 field of view and a 320 × 240 matrix throughout the whole body. As described in detail previously [13, 14], the subjects lay in the magnet in a prone position with their arms placed straight overhead. Using the L4-L5 as the point of origin, transverse images (10 mm image thickness) were obtained every 50 mm to the hand and foot (Figure 1A). Three series of 7 images (e.g., 7 images per series) were obtained from the lower-body and 3 series of 7 images were obtained from the upper-body, resulting in a total of ~41 equidistant images. Once acquired, the MRI data were transferred electronically to a stand-alone computer for analysis using specially designed image analysis software (Tomovision, Montreal, Canada), the procedures for which are fully described elsewhere [13].

Determination of regional SM and fat measures

Total SM and fat volumes were determined using all 41 images. Abdominal fat volumes were calculated using the five images extending from 5 cm below to 15 cm above L4-L5. SM and fat volume in the legs and in the arms was calculated using images extending from the femoral head to the end of the foot and from the humeral head to the end of the hand, respectively (Figure 1A). Intermuscular fat was defined adipose tissue area intertwined between the bundles of skeletal muscle fibers that were visible on the MRI images [14, 15]. Fat and SM volume was converted to mass units (kg) by multiplying the volumes by the assumed constant density for AT (0.92 kg/L) and SM (1.04 kg/L) [16].

Dual-energy X-ray absorptiometry (DXA)

The amount of total and regional fat and lean body mass (a surrogate measure of SM) was determined using Lunar iDXA (GE Healthcare, Madison, WI, USA) and analyzed with software enCORE 2007 version 11.40.004 (GE, Madison, WI, USA). Anatomical landmarks were used to define the legs and arms (Figure 1B). The legs were defined by soft tissue extending from a line drawn through and perpendicular to the axis of the femoral neck and angled with the pelvic brim to the phalange tips and the arms were defined by soft tissue extending from the center of the arm socket to the phalange tips [8]. Quality assurance test was performed according to the manufacturer' guidelines at least 3 times per week and before a subject's test.

Statistical analysis

All analyses were performed using commercially available software (SAS, version 9.3; SAS Institute Inc, Cary, North Carolina). Unless otherwise indicated, data are expressed as mean (± SD). We examined the effect of the exercise intervention using as-treated analyses in participants who had complete baseline and follow-up whole-body MRI and DXA data (n=39). Least squared means difference post hoc tests were used to determine differences between the control and intervention groups. Pearson correlations were conducted assessing the association between MRI and DXA total and regional fat and SM/LBM compartments at baseline and changes with intervention. Bland-Altman analysis [17] was used to compare accordance between whole-body MRI and DXA measurements in evaluating changes in total and regional fat and SM mass. P values of less than 0.05 were accepted to indicate statistical significance.

RESULTS

There were no significant differences between groups for baseline characteristics (Table 1). Some of the physical characteristics were reported previously [12].

Changes in regional fat distribution by whole-body MRI

Compared with controls, significant (P<0.05) reductions in MRI-measured total, subcutaneous and intermuscular fat were observed in both aerobic and resistance exercise groups (Table 1). Accordingly, MRI whole-body SM-to-fat ratio was increased (P<0.05) in both exercise groups. To determine whether regional variation existed in the distribution of fat in response to exercise training, the whole-body was divided into leg, arm and abdominal regions. Within the abdominal region, there were greater reductions in visceral fat than abdominal subcutaneous fat in both exercise training groups (−12.0% versus −8.9% in the aerobic, and −14.4% versus −5.8% in the resistance group).

Changes in regional fat distribution by whole-body DXA

As with MRI, there were significant (P<0.05) reductions in DXA-measured total fat and the total fat to LBM ratio in both aerobic and resistance exercise groups as compared to control

(Table 1). However, changes in regional fat were less consistent with significant reductions in arm and trunk fat in the AE group, and leg fat only in the RE group as compared to control (P<0.05).

Changes in regional SM by whole-body MRI and LBM by DXA

Compared with controls, significant (P<0.05) increase in total SM (kg) as measured by MRI was observed in the resistance exercise group but not in the aerobic exercise group. Inspection of Figure 2 reveals that, in general, the resistance exercise group gained greater SM area (cm^2) per image in the thigh and upper arm regions compared to the aerobic exercise group. Unlike MRI, there were no significant changes in LBM as assessed by DXA.

Comparison between MRI-measured total fat and SM versus DXA-measured total fat and LBM

Collapsed across treatment groups, total fat measured by MRI and DXA were significantly correlated (P<0.05) at baseline (Figure 3A) and changes with intervention (Figure 3B). At baseline, MRI-measured total fat was greater (P<0.05) than DXA-measured total fat wherein there was an increasing underestimation by DXA as compared to MRI with increasing total fat (Figure 3C). The mean change in total fat between MRI and DXA were not significantly different, but there was a systemic bias between the two methods that increased with increasing changes in total fat (Figure 3D).

Total SM measured by MRI and total LBM measured by DXA were significantly correlated at baseline and changes with intervention (Figure 3E+F). However, as expected the absolute differences in MRI-SM and DXA-LBM at baseline were significantly different (Figure 3G). Further, although the two methods similarly assessed changes in SM/LBM (Figure 3H), there was a systematic bias between the methods at both time points such that DXA-LBM overestimated MRI-SM to a greater extent with increasing SM/LBM at baseline and changes therein.

Comparison between MRI-measured leg fat and SM versus DXA-measured leg fat and LBM

At baseline, leg fat measured by MRI and DXA were strongly correlated (Figure 4A). However, there was a small underestimation by DXA as compared to MRI (Figure 4C) that was consistent through the range of leg fat. Change scores with intervention were moderately correlated (Figure 4B), with no overall difference between methods (Figure 4D). However, there was a small systematic bias (R^2=0.17) in that DXA overestimated MRI when there were gains in leg fat and DXA underestimated MRI when there were losses in leg fat.

Leg SM measured by MRI was strongly correlated with leg LBM measured by DXA (Figure 4E) at baseline, but not changes with intervention (Figure 4F). There was a large overestimation of leg SM by MRI as compared to leg LBM by DXA (Figure 4G) that was increased with increasing leg SM/LBM. However, there were no overall difference in changes in leg SM/LBM estimated between methods (Figure 4H). However, there was a slight systematic bias in that DXA measured leg LBM overestimated MRI measures when there was a gain in leg SM and DXA underestimated MRI when there was a loss in leg SM.

Comparison between MRI-measured abdominal fat and SM versus DXA-measured trunk fat and LBM

Abdominal fat measured by MRI and trunk fat measured by DXA were strongly correlated (Figure 5A) at baseline. However, as expected, there was a large overestimation of trunk fat by DXA as compared to abdominal fat by MRI (Figure 5C) that was augmented through the range of abdominal/trunk fat. Change scores with intervention were moderately correlated (Figure 5B), with no overall difference between methods (Figure 5D). However, there was a systematic bias in that DXA trunk fat measures tended to overestimate MRI measured abdominal fat gains and underestimated losses in abdominal fat.

Abdominal SM as assessed by MRI was strongly correlated with DXA-trunk LBM (Figure 5E) at baseline, and weakly with changes with intervention (Figure 5F). There was a large overestimation of baseline MRI-abdominal SM as compared to DXA-trunk LBM that was likely due to differences in the regional borders used (Figure 5G). This difference was increased with increasing abdominal SM/trunk LBM. Further, overall there was an overestimation of changes in MRI abdominal SM by DXA trunk LBM (Figure 4H), and a large systematic bias in that DXA trunk LBM overestimated MRI measured abdominal SM gains and underestimated losses in abdominal SM.

DISCUSSION

Using whole-body MRI, we observed that both aerobic and resistance exercise training without calorie restriction is associated with significant improvements in whole-body composition as reflected by increases in SM to AT ratio and reductions in total and regional fat in previously sedentary, obese adolescent boys. Although DXA-measured changes in total and regional fat and LBM in response to exercise training are strongly correlated with changes in MRI-measured fat and SM, there were substantial differences and systemic biases between the two methods in evaluating body composition in youth. These differences translated into differences in the observed changes in fat and SM/LBM with intervention as assessed by MRI and DXA. This means that the ability to observe significant changes in body composition is influenced by the imaging method employed.

Due to the lack of rigorously controlled studies, the efficacy of regular exercise alone as a treatment strategy to improve whole-body composition has not been clearly established in children and adolescents. A few randomized controlled studies attempted to examine the effect of exercise on visceral fat in obese children [18, 19] and adolescents [20]; however these studies were hampered by age-associated increases in visceral fat [18, 19] and poor compliance to the prescribed exercise regimens [19, 20]. In the current study, we are successful maintaining high exercise compliance rate in both aerobic and resistance exercise groups. Our observation is consistent with previous adult studies demonstrating that engaging in regular exercise alone, in the absence of calorie restriction, is beneficial to reduce both abdominal SAT and visceral fat (kg) in obese women [5] and obese men with and without type 2 diabetes [3, 4]. Our findings of preferential reductions in visceral fat with exercise training are similar to adult studies reporting greater reductions in visceral fat as compared with abdominal SAT in response to aerobic exercise [3, 4, 21], weight loss induced by either diet or exercise [22] or a long-term lifestyle intervention [23].

To our knowledge, this is the first study to examine changes in intermuscular fat in response to aerobic vs. resistance exercise using whole-body MRI in youth. Our finding that regular exercise, independent of exercise modality, is associated with significant reductions in intermuscular fat (kg) is of significance given that adipose tissue within skeletal muscle increases with increasing total adiposity and that intermuscular fat is associated with lower insulin sensitivity in adolescents [24]. Our finding extends previous observations from the STRRIDE trial [25], which examined the effects of differing amounts and intensities of aerobic exercise on intermuscular fat area (cm^2) in overweight/obese dyslipidemic men and women. In that study, 8–9 mo of aerobic exercise alone was associated with significant reductions in thigh-intermuscular fat measured by a single-slice mid-thigh CT in both men and women and that reduction in thigh-intermuscular fat was inversely correlated with changes in both HDL and LDL size in men. Together, these observations reinforce the utility of regular exercise as a strategy to improve skeletal muscle morphology in obese individuals, independent of age.

DXA and MRI are two commonly used tools that use different principles to assess body composition. MRI uses the magnetic differences of atoms to generate cross-sectional images of the body to assess tissue volumes which are converted to mass based on assumed densities [26]. Typically, MRI protocols acquire a series of ~41 non-contiguous images throughout the body as they produce similar results for total and regional fat and SM as the contiguous protocols (~200 images), but require much less acquisition time and image analyses labor [27, 28]. DXA uses the amount of radiation attenuation by the body to estimate fat and LBM within specific predefined areas of interest using proprietary equations. Unlike MRI, DXA cannot differentiate the fat depot types (i.e. visceral versus subcutaneous or intermuscular fat) and is unable to distinguish SM from other types of LBM (i.e. organs, connective tissue, vasculature, etc). As there are many other types of LBM other than SM, it is logical that total and regional DXA LBM is significantly greater than MRI measured SM.

At baseline, DXA significantly underestimated total fat by −3.1 kg and the differences increased in magnitude with increases in total fat. These findings are similar to a previous observation in adults by Kullberg et al. [29] who showed that DXA underestimated total fat by −5.23 kg and −4.7 kg as compared to both whole-body CT and MRI, respectively. In this study, DXA was able to detect significant reductions in total fat, but not changes in LBM with exercise. Although mean changes in fat were similarly estimated by the methods, there was a similar underestimation in fat change by DXA that increased with increasing total fat change. This means that MRI and DXA measures are more analogous at the lower levels of adiposity and fat change and that MRI is more likely to observe larger reductions in fat mass.

Regional changes in fat mass also differed by method of assessment. At baseline, we observed that trunk fat mass by DXA to be significantly larger than MRI abdominal fat and DXA leg fat mass to be smaller than MRI leg fat. One reason is that MRI and DXA use different borders for defining trunk and leg. Using MRI, the abdominal region is defined as 5 cm below L4-L5 extending to 15 cm above using an established method [13], whereas automated DXA software uses the entire trunk and pelvic region. The leg region by MRI extends to the femoral head which includes the gluteal area whereas DXA leg is defined by approximately the inguinal line which excludes some of the gluteal tissue. Given the different region of interest between two measurements, it is intuitive that there would be differences in the absolute trunk and leg measures.

Interestingly, on average changes in abdominal and leg fat were similarly estimated by DXA and MRI although there was a bias that remained in that DXA tended to underestimate larger fat changes. Mean changes in leg LBM was similarly estimated by DXA and MRI, but changes in trunk LBM was overestimated by 0.5 kg. Again, there were biases in that increases in trunk and leg SM were overestimated by DXA as compared to MRI. Thus, DXA appears to be more likely to observe improvements in LBM but less likely to distinguish reductions in fat mass as compared to MRI.

The limitations of this study warrant mention. Although this is the first study in adolescents to compare changes in body composition using whole-body MRI and DXA, our observations are based on pubertal obese adolescent boys. Whether our findings would remain true in girls or pre-pubertal children is unknown. In this study, we did not employ contiguous MRI scans but used a well-accepted MRI protocol to quantify SM and fat. Further, different models of DXA use different technologies and algorithms for assessing body composition, and the degree these observation are true for other DXA machines is unclear. Lastly, the effect of other intervention strategies, such diet weight loss, on the agreement between DXA and MRI changes in measuring fat and SM is unknown and warrants investigations.

In summary, our findings indicate that regular aerobic or resistance exercise over a period of 3 months is associated with significant improvements in whole-body composition in the absence of calorie restriction in obese adolescent boys. However, the ability to observe significant changes in SM and fat mass is influenced by the imaging method employed.

Acknowledgments

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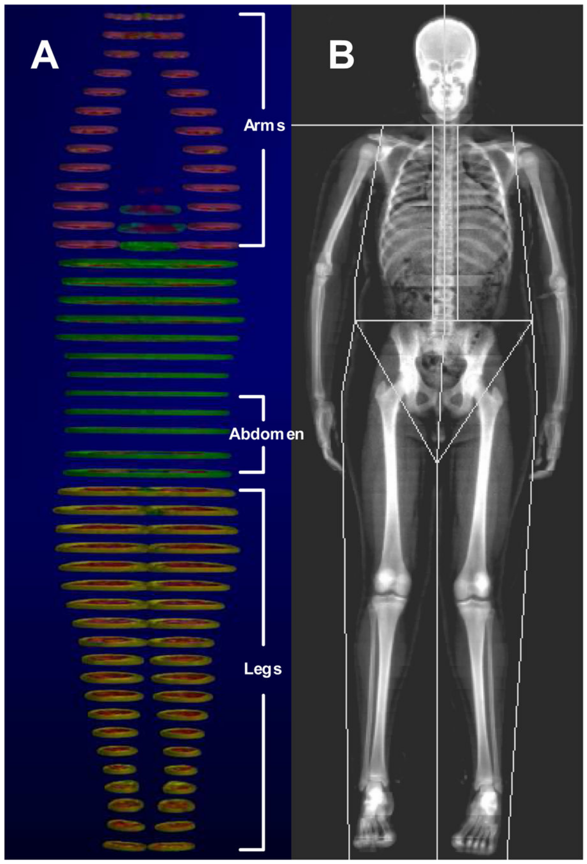

FIGURE 1.
Sample whole-body MRI and DXA scan obtained from a 13 year old African-American boy. The lines on the DXA scan represent automated DXA regions of interest according to software.

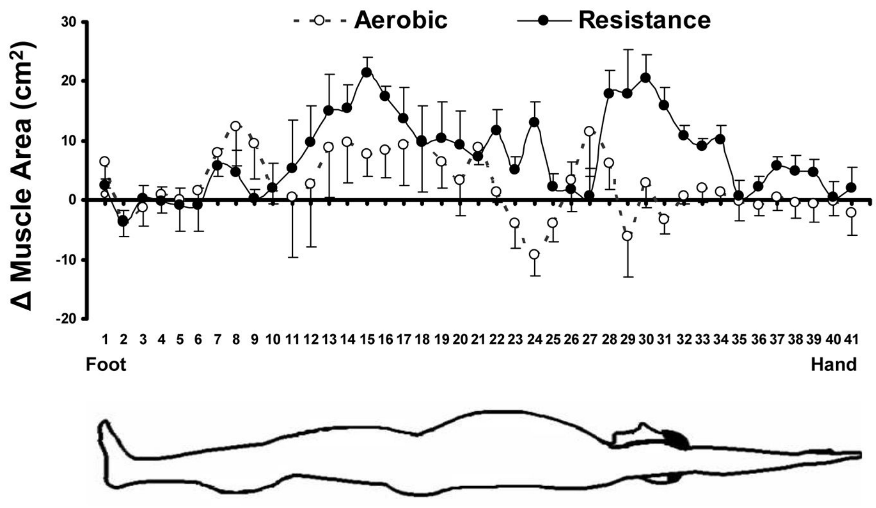

FIGURE 2.

Absolute changes (mean ± SE) in skeletal muscle area (cm^2) in the aerobic and resistance exercise groups.

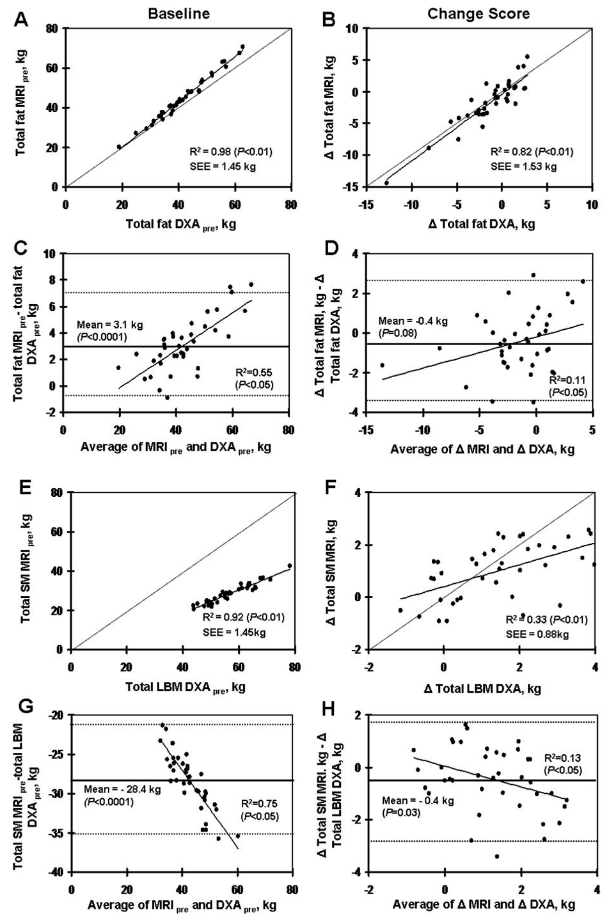

FIGURE 3.

Associations between absolute values of MRI- and DXA- measured total fat and SM/LBM at baseline (A, E) and changes (B, F) with intervention, and the agreement between the measures using Bland-Altman plots (C, D, G, H).

Correlation plots have the line of best fit in black and the line of identity in grey. Bland Altman plots have the mean difference and 95% CI between MRI and DXA measures indicated by the parallel solid black line and dotted lines. Significant p-values indicate significant over- or under-estimation of MRI by DXA. Line of identity and significant r-squared values indicate a systematic difference between the measures.

MRI = magnetic resonance imaging; DXA = dual-energy absorptiometry; SM = skeletal muscle; LBM = lean body mass.

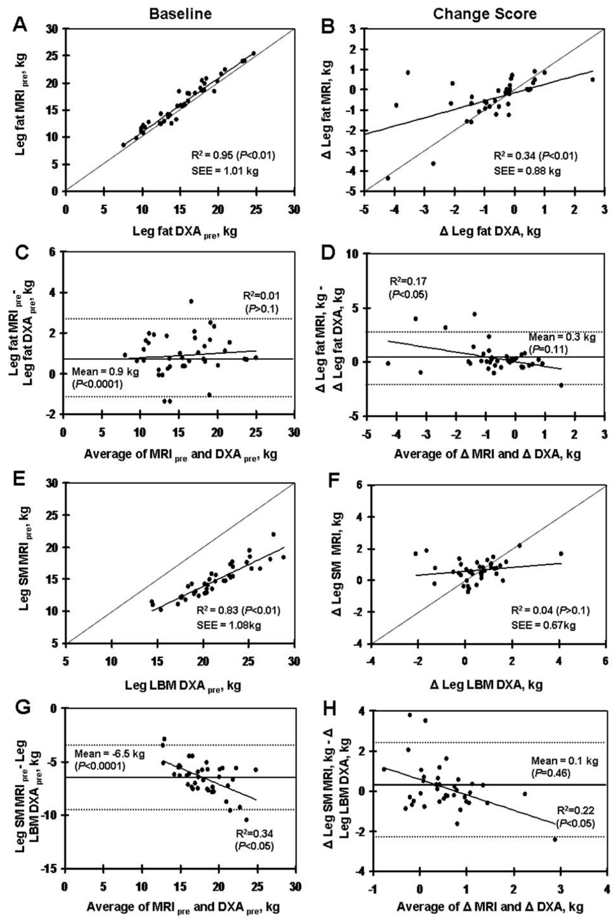

FIGURE 4.

Associations between absolute values of MRI- and DXA- measured leg fat and SM/LBM at baseline (A, E) and changes (B, F) with intervention, and the agreement between the measures using Bland-Altman plots (C, D, G, H). Correlation plots have the line of best fit in black and the line of identity in grey. Bland Altman plots have the mean difference and 95% CI between MRI and DXA measures indicated by the parallel solid black line and dotted lines. Significant p-values indicate significant over- or under-estimation of MRI by DXA. Line of identity and significant r-squared values indicate a systematic difference between the measures.

MRI = magnetic resonance imaging; DXA = dual-energy absorptiometry; SM = skeletal muscle; LBM = lean body mass.

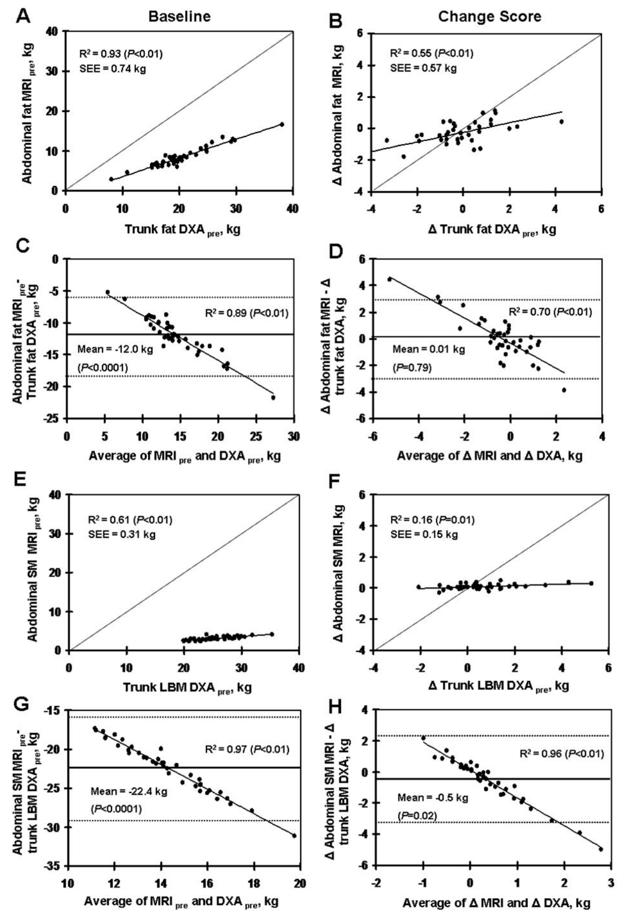

FIGURE 5.

Associations between absolute values of MRI- and DXA- measured abdominal fat and SM/LBM at baseline (A, E) and changes (B, F) with intervention, and the agreement between the measures using Bland-Altman plots (C, D, G, H).

Correlation plots have the line of best fit in black and the line of identity in grey. Bland Altman plots have the mean difference and 95% CI between MRI and DXA measures indicated by the parallel solid black line and dotted lines. Significant p-values indicate significant over- or under-estimation of MRI by DXA. Line of identity and significant r-squared values indicate a systematic difference between the measures.

MRI = magnetic resonance imaging; DXA = dual-energy absorptiometry; SM = skeletal muscle; LBM = lean body mass.

TABLE 1

Subject characteristics and changes in fat, skeletal muscle and lean body mass distribution by whole-body MRI and DXA

	Control (n=11)		**Aerobic Exercise (n=14)**		**Resistance Exercise (n=14)**	
	Baseline	**Δ**	**Baseline**	**Δ**	**Baseline**	**Δ**
Age, years	14.9 ± 1.5		15.1 ± 1.7		14.8 ± 1.5	
Body weight, kg	99.0 ± 15.5	2.9 ± 2.3	107.7 ± 17.1	−1.4 ± 3.9 *	98.7 ± 11.2	−0.01 ± 2.6 *
CRF, ml/kg/min	30.9 ± 4.1	−0.2 ± 3.5	29.7 ± 4.6	9.4 ± 4.2 *	30.7 ± 4.8	7.9 ± 2.5 *
Total fat (MRI), kg	42.3 ± 13.3	1.6 ± 2.1	46.9 ± 11.6	−3.5 ± 3.9 *	43.4 ± 9.0	−2.5 ± 2.5 *
Total fat (DXA), kg	39.6 ± 11.5	1.2 ± 1.4	43.4 ±10.2	−2.6 ± 3.4 *	40.5 ± 7.8	−1.9 ± 2.7 *
Leg fat (MRI), kg	16.0 ± 5.3	0.3 ± 0.5	16.6 ± 4.1	−0.8 ± 1.2 *	16.1 ± 3.8	−0.8 ± 1.1 *
Leg fat (DXA), kg	15.0 ± 5.3	0.03 ± 1.3	15.6 ± 4.0	−1.0 ± 1.5	15.3 ± 3.6	−1.3 ± 1.6 *
Arm fat (MRI), kg	4.8 ± 1.6	0.4 ± 0.6	5.1 ± 1.1	−0.2 ± 0.7 *	5.0 ± 1.1	−0.1 ± 0.6 *
Arm fat (DXA), kg	4.3 ± 1.3	0.2 ± 0.5	4.3 ± 1.1	−0.2 ± 0.5 *	4.4 ± 1.1	−0.01 ± 0.5
Abdominal fat (MRI), kg	7.7 ± 2.9	0.5 ± 0.4	9.4 ± 2.8	−0.9 ± 0.9 *	8.1 ± 2.3	−0.6 ± 0.5 *
Trunk fat (DXA), kg	19.2 ± 5.6	0.9 ± 1.4	22.3 ± 6.3	−1.4 ± 2.3 *	19.6 ± 4.4	−0.6 ± 1.8
Total SM (MRI), kg	27.2 ± 5.2	0.6 ± 1.2	31.0 ± 4.8	0.8 ± 1.0	27.2 ± 4.0	1.6 ± 0.8 *
Total LBM (DXA), kg	55.9 ± 8.4	1.4 ± 1.4	60.6 ± 8.2	0.7 ± 1.2	54.2 ± 6.5	2.2 ± 1.4
Leg SM (MRI), kg	14.1 ± 2.6	0.4 ± 0.8	16.0 ± 2.6	0.7 ± 0.8	14.0 ± 2.3	0.8 ± 0.5
Leg LBM (DXA), kg	20.8 ± 3.5	0.03 ± 1.3	23.0 ± 3.6	−1.0 ± 1.5	19.9 ± 2.8	−1.3 ± 1.6
Arm SM (MRI), kg	4.1 ± 0.8	0.1 ± 0.4	4.9 ± 0.9	0.03 ± 0.3	4.0 ± 0.8	0.4 ± 0.5
Arm LBM (DXA), kg	6.3 ± 1.2	0.2 ± 0.5	7.0 ± 1.5	−0.2 ± 0.5	6.1 ± 1.0	−0.01 ± 0.5
Abdominal SM (MRI), kg	2.9 ± 0.5	0.1 ± 0.2	3.4 ± 0.5	0.01 ± 0.1	3.0 ± 0.3	0.2 ± 0.2
Trunk LBM (DXA), kg	25.0 ± 4.1	0.9 ± 1.4	26.7 ± 3.7	−1.4 ± 2.3	24.6 ± 2.9	−0.6 ± 1.8
SM to fat ratio (MRI)	0.71 ± 0.26	−0.02 ± 0.07	0.69 ± 0.14	0.07 ± 0.05 *	0.66 ± 0.20	0.09 ± 0.06 *
LBM to fat ratio (DXA)	1.52 ± 0.48	−0.01 ± 0.10	1.45 ± 0.30	0.10 ± 0.07 *	1.39 ± 0.32	0.15 ± 0.14 *
Total subcutaneous fat (MRI), kg	36.1 ± 11.9	0.9 ± 1.1	39.9 ± 10.4	−2.7 ± 3.4 *	37.6 ± 8.3	−2.4 ± 2.3 *
IMAT (MRI), kg	3.7 ± 1.2	0.3 ± 0.5	4.1 ± 1.2	−0.5 ± 0.5 *	3.3 ± 0.7	−0.2 ± 0.3 *

Data are mean ± SD. = Posttreatment – Pretreatment.

MRI, magnetic resonance imaging; DXA, dual-energy absorptiometry; CRF, cardiorespiratory fitness; IMAT, intermuscular adipose tissue; SM, skeletal muscle; FM, fat mass; LBM, lean body mass.

*Changes are significantly different from the control group ($P<0.05$).