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THE MUSCLE STRENGTH AND SIZE RESPONSE TO UPPER ARM, UNILATERAL RESISTANCE TRAINING AMONG ADULTS WHO ARE OVERWEIGHT AND OBESE

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ABSTRACT. Pescatello, L.S., B.K. Kelsey, T.B. Price, R.L. Seip, T.J. Angelopoulos, P.M. Clarkson, P.M. Gordon, N.M. Moyna, P.S. Visich, R.F. Zoeller, H.A. Gordish-Dressman, S.M. Bilbie, P.D. Thompson, and E.P. Hoffman. The muscle strength and size response to upper arm, unilateral resistance training among adults who are overweight and obese. *J. Strength Cond. Res. 21(2):307–313. 2007.*—Overweight and obesity result in musculoskeletal impairments that limit exercise capacity. We examined if the muscle strength and size response to resistance training (RT) differed among 687 young (mean ± *SEM*, 24.2 ± 0.2 years) overweight and obese (OW) compared to normal weight (NW) adults as denoted by the body mass index (BMI). Subjects were 449 NW (22.0 ± 0.1 $\text{kg}\cdot\text{m}^{-2}$, 23.4 ± 0.3 years) and 238 OW (29.2 ± 0.2 $\text{kg}\cdot\text{m}^{-2}$, 25.6 ± 0.4 years) men ($n = 285$) and women ($n = 402$) who underwent 12 weeks (2 $\text{d}\cdot\text{wk}^{-1}$) of RT of the nondominant arm. Maximum voluntary contraction (MVC) and 1 repetition maximum (1RM) assessed peak elbow flexor strength. Magnetic resonance imaging measured the biceps muscle cross sectional area (CSA). Multiple dependent variable analysis of covariance tested if muscle strength and size differed among BMI groups pre-, post-, and pre-to-post–RT. Overweight and obese had greater MVC, 1RM, and CSA than NW pre- and post-RT ($p < 0.001$). Maximum voluntary contraction and 1RM gains were not different between BMI groups pre- to post-RT ($p \geq 0.05$). When adjusted for baseline values, NW had greater relative MVC (21.2 ± 1.0 vs. 17.4 ± 1.4%) and 1RM (54.3 ± 1.5 vs. 49.0 ± 2.0%) increases than OW ($p < 0.05$). Normal weight also had greater allometric MVC (0.48 ± 0.02 $\text{kg}\cdot\text{kg}^{-0.67}$ vs. 0.40 ± 0.03 $\text{kg}\cdot\text{kg}^{-0.67}$) and 1RM (0.25 ± 0.00 vs. 0.22 ± 0.01 $\text{kg}\cdot\text{kg}^{-0.67}$) gains than OW ($p < 0.05$). CSA gains were greater among OW than NW (3.6 ± 0.2 vs. 3.2 ± 0.1 cm^2) ($p < 0.001$); however, relative CSA increases were not different between BMI groups (19.4 ± 0.5 vs. 18.4 ± 0.7%) ($p \geq 0.05$). Despite similar relative muscle size increases, relative and allometic strength gains were less among OW than NW. These findings indicate the short-term relative and allometric muscle strength response to RT may be attenuated among adults who are overweight and obese.

KEY WORDS. adiposity, exercise, magnetic resonance imaging, weight training

INTRODUCTION

Habitual exercise participation is an essential strategy to prevent unhealthy weight gain and optimize physical function (2, 3, 30). People who are overweight and obese experience numerous health benefits from exercise training programs even in the absence of significant amounts of weight loss or improvements in cardiopulmonary physical fitness (2, 30). Yet, there is considerable variability in the extent to which these adaptations occur due to many factors that include genetics (9, 27, 29), age (25, 28), gender (17, 24, 25, 28), and baseline levels (17).

People with overweight and obesity have alterations in skeletal muscle structure and function compared to those who are normal weight that could also contribute to variability in the exercise response. These alterations include a lower percentage of type I and a higher percentage of type II muscle fibers, impaired muscle oxidative capacity, a diminished ability to alter fuel utilization between carbohydrate and lipid under conditions of metabolic demand, and increased intramuscular lipid accumulation (6, 10, 26). In addition, excess adipose tissue releases a variety of neurohormones and cytokines that blunt insulin-stimulated glucose uptake by the muscle (5). These adiposity-associated structural and metabolic skeletal muscle alterations have been postulated to contribute to the impaired exercise capacity that is sometimes reported in people with overweight and obesity (2, 19, 21, 26).

Minimal work has been done to examine the influence of overweight and/or obesity on the skeletal muscle response to resistance training (RT). Hulens et al. (18) examined peripheral muscle strength among a sample of young women, 80 of whom were normal weight and 173 who were obese. The women with obesity possessed greater absolute isokinetic trunk and lower body muscle strength than the normal weight women; however, when the strength measures were normalized for body mass by the allometric method, the women who were obese were found to have less muscle strength than the lean women. Whether the lean and obese women would have responded differently to a resistance training (RT) intervention is not known because this study was not designed to examine this question. Blake et al. (7) investigated the muscle strength response of sedentary, middle-aged women, 43 of whom were normal weight and 46 who were obese, to a 14 week physical fitness training program that included cardiovascular, resistance, and flexibility exercises. They found the women gained similar amounts of absolute (i.e., unadjusted) and relative (i.e, adjusted for baseline values) grip strength after the exercise regimen, regardless of body mass classification. Van Etten et al.

TABLE 1. Physical characteristics (mean ± *SEM*) of the total sample and by body mass group and gender.

Characteristic	Total sample (n = 687)	Normal weight (n = 449)	Normal weight men (n = 166)	Normal weight women (n = 283)	Overweight and obese (n = 238)	Overweight and obese men (n = 118)	Overweight and obese women (n = 120)
Age	24.2 ± 0.2	23.4 ± 0.3	23.7 ± 0.4	23.1 ± 0.3	25.6 ± 0.4‡	25.6 ± 0.5	25.6 ± 0.5
Body mass (kg)	70.1 ± 0.6	64.1 ± 0.5	69.0 ± 0.8	59.3 ± 0.6‖	85.1 ± 0.6‡	90.5 ± 0.9	79.8 ± 0.9‖
Height (m)	1.70 ± 0.00	1.71 ± 0.00	1.77 ± 0.00	1.65 ± 0.00‖	1.71 ± 0.00	1.77 ± 0.00	1.65 ± 0.00‖
BMI* (kg·m^{-2})	24.5 ± 0.2	22.0 ± 0.1	22.2 ± 0.2	21.8 ± 0.2§	29.2 ± 0.2‡	29.0 ± 0.3	29.5 ± 0.3
Non-dominant biceps skinfold (mm)	10.7 ± 0.2	8.3 ± 0.3	6.4 ± 0.4	10.1 ± 0.3‖	14.2 ± 0.4‡	11.1 ± 0.5	17.4 ± 0.5‖
Non-dominant triceps skinfold (mm)	18.6 ± 0.3	15.4 ± 0.3	12.0 ± 0.5	18.7 ± 0.4‖	22.9 ± 0.4‡	18.2 ± 0.6	27.6 ± 0.6‖

* BMI = body mass index.
† $p < 0.05$ normal weight vs. overweight and obese.
‡ $p < 0.001$ normal weight vs. overweight and obese groups.
§ $p < 0.05$ men vs. women within a body mass group.
‖ $p < 0.001$ men vs. women within a body mass group.

(32) studied muscle strength changes from a 12 week progressive, total body RT program in sedentary, middle-aged men, 10 of whom were normal weight and 11 who were overweight. These authors also found absolute and relative strength increases were not different between the body mass groups pre- to post-RT. However, the small number of subjects in these exercise training studies raises the possibility that the statistical power was not sufficient to detect a difference in the muscle strength response among the body mass groups.

Due to limited and inconclusive evidence, we undertook a study to examine if the muscle strength and size response to a 12 week upper arm, unilateral RT program differed among a large sample ($n = 687$) of young adults who are overweight and obese compared to normal weight adults. Because excess weight is associated with musculoskeletal structural and functional impairments (2, 5, 6, 10, 19, 21, 26, 28), we hypothesized that the muscle strength and size gains resulting from a short-term RT would be attenuated in adults who were overweight and obese compared to those who were normal weight.

METHODS

Experimental Approach to the Problem

This study was undertaken by the Exercise and Genetics Collaborative Research Group as part of the multicenter trial, Functional Single Nucleotide Polymorphisms Associated with Human Muscle Size and Strength (FAMuSS). The FAMuSS methods have been described in detail elsewhere (9, 17, 27, 29). After obtaining informed consent, subjects were oriented to all study procedures. Anthropometrics, isometric (maximum voluntary contraction [MVC]) and dynamic strength (1 repetition maximum [1RM]) of the elbow flexors, and cross-sectional area (CSA) of the upper arm with magnetic resonance imaging (MRI) were measured in 285 men and 402 women before and after 12 weeks of supervised, progressive RT of the nondominant arm (i.e., the hand with which the subject did not write). Of these 687 subjects, 65.4% were normal weight as denoted by a body mass index (BMI) between 18.5 and <25 kg·m^{-2}, and 34.6% were overweight and obese with a BMI ≥25 kg·m^{-2}. To ensure adequate measurement validity and reliability within and among sites, standardized testing protocols were developed and biannual investigator training was performed. In addition, identical equipment was purchased for each site, and research personnel conducted quarterly conference calls to review protocols and discuss other relevant study issues.

Subjects

Potential subjects were apparently healthy men and women between 18 and 39 years. Volunteers were screened for exclusion criteria which included a history of RT during the prior year, regular use of the upper body during occupational labor or leisure activity, dietary protein supplementation during the prior 3 months, alcohol consumption in excess of 14 drinks per week, heart conditions, diabetes mellitus, pregnancy, metallic implants, or claustrophobia. Additionally, potential subjects were excluded for self-reported use of antihypertensive or dyslipidemic medications, anabolic steroids, corticosteriods, Depo-Provera contraceptive injection, Rhinocort nasal inhaler, lithium, and chronic use of nonsteroidal anti-inflammatory medications. Subjects were asked to maintain their normal dietary intake for the duration of the study. Prior to participation each volunteer signed an informed consent approved by the institutional review boards of the nine institutions involved with FAMuSS.

The study sample ($n = 687$) had a mean age of 24.2 ± 0.2 yr (± *SEM*) and was composed of 449 normal weight (22.2 ± 0.2 kg·m^{-2}) and 238 overweight and obese (29.2 ± 0.2 kg·m^{-2}, $n = 169$, BMI ≥25 to <30 kg·m^{-2} and $n = 69$, BMI ≥ 30 kg·m^{-2}, respectively) men ($n = 285$) and women ($n = 402$) (Table 1). The adults with overweight and obesity were older, weighed more, and had greater BMI and nondominant biceps and triceps skinfolds than the subjects who were normal weight ($p < 0.001$). The men who were normal weight were taller, weighed more and had a greater BMI than the women in this BMI group; however, the women who were normal weight had greater biceps and triceps skinfolds than the men in this body mass group ($p < 0.05$). The men with overweight and obesity were taller and weighed more than the women in this body mass group; whereas the women with overweight and obesity had greater biceps and triceps skinfolds than the men in this BMI group ($p < 0.001$). The sample was mostly Caucasian (79.1%) with 8.7% Asian, 4.7% Hispanic, 3.8% African American, and 3.7% other. The attrition rate was greater among the adults with overweight and obesity than those with normal weight, 25.5 versus 9.7% not finishing the study, respectively ($p < 0.001$).

Experimental Procedures

Anthropometric Assessment. Subjects removed shoes, heavy clothing and pocket contents prior to weighing. Body weight was measured on a standard balance beam scale (Model 338 Eye-Level Physician Scale; Detectoscale, Webb City, MO) and recorded in pounds. Height was measured with a nonstretchable fiberglass tape measure affixed to the wall. Subjects stood erect with heels against the wall and chin perpendicular to the body. The subject's height was judged to be the location at which the top of his or her head intersected the tape and was recorded in inches. Height and weight were used to calculate BMI. Average BMI did not differ among the eight RT sites ($p \geq 0.05$), indicating similar proportions of subjects who were normal weight and overweight and obese among RT sites. In addition to pre- and post-RT, body weight was taken every 3 weeks of study involvement in order to monitor weight stability defined as ±5.0 lb of pre-RT weight. Weight maintenance throughout the study was used as an indicator that volunteers were adhering to their usual dietary patterns.

Skinfold measurements of the nondominant arm biceps and triceps were taken with Lange skinfold calipers (Model QM200; Beta Technology Inc., Cambridge, MA) in triplicate to the nearest 0.1 mm and averaged. The biceps skinfold was taken at the point of maximal upper arm circumference and the triceps skinfold on the back of the upper arm midway between the shoulder and elbow. The same investigator from each site took anthropometric measurements on the same subjects pre- and post-RT.

Isometric Strength Assessment. All wrist jewelry was removed prior to testing. The MVC of the nondominant elbow flexor was measured using a custom-made preacher bench and strain gauge (Model 32628CTL; Lafayette Instrument Company, Lafayette, IN). Pre-RT MVC was assessed on 3 days spaced 24–48 hr apart; and post-RT MVC on 2 days spaced 24–48 hr apart and within 48 hr of the last RT session. The same investigator measured MVC with verbal encouragement in a given subject pre- and post-RT after calibrating the strain gauge and using a fixed seat height and a goniometer to maintain the elbow joint angle of 90°. On each testing day, subjects underwent 3 trials within 5 $\text{ft}\cdot\text{lb}^{-1}$ of each other. If a trial exceeded the 5 $\text{ft}\cdot\text{lb}^{-1}$ range, additional trials were conducted up to a maximum of 6 trials. After 6 trials, the 3 closest values were chosen, averaged and recorded as MVC. Pre-RT MVC was determined to be the average of testing days 2 and 3, and post-RT MVC was the average of both testing days. The inter-site within subject pre-RT MVC coefficient of variation was calculated on pre-RT testing days 2 and 3 and found to be 7.4%, indicating acceptable reliability of this measurement among sites.

Dynamic Strength Assessment. 1RM of the nondominant elbow flexor was measured with subjects seated on a standard preacher curl bench (Yukon International Inc., Cleveland, OH) holding a Powerblock (Powerblocks; Intellbell, Inc., Owatonna, MN) before the first RT session and 48 hr after the last RT session. Powerblocks are hand-held weights similar to dumbbells that can be adjusted in increments of 2.50 and 5.00 lb to total up to 50 lb. If smaller increments were needed, weight was added in 1.25 lb increments using Platemates (Benoit Built Inc., Boothbay Harbor, ME). After a progressive warm up with interspersed rest periods, study investigators verbally instructed subjects to perform 1 full range of motion repetition, extending the elbow to 180°, and curling the weight back up to the shoulder with the weight at 100% of estimated maximum. If the lift was unsuccessful, a 3 min rest was taken and the weight decreased by 2.5 lb. If the lift was successful, a 3 min rest was taken and the weight increased by 2.5 lb. The procedure was repeated until subjects failed to complete a full range of motion lift. Maximum weight lifted was recorded in pounds as the greatest amount of weight successfully lifted 1 time. Weights were selected so that the 1RM was completed in 3–5 attempts and verbal encouragement was provided during each 1RM attempt. As with MVC, the same investigator measured 1RM for a subject pre- and post-RT.

MRI Muscle Size Assessment. The CSA of the nondominant biceps brachii was measured using MRI with 1.5T (tesla) systems. The MRI were taken prior to the first RT session and within 48 to 96 hr after the last RT session. Prior to entering the MRI magnet, a radiographic bead (Beekley Spots; Beekley Corp., Bristol, CT) was placed at the maximum circumference or the point of measure (POM) of the upper arm. The POM was determined with the subject's arm abducted 90° at the shoulder, flexed 90° at the elbow, hand open, and biceps maximally contracted. The same investigator visually located the POM for a subject pre- and post-RT.

The MRI consisted of 15 axial slices comprising 24 cm of the upper arm. Subjects were supine on the scanning bed, with the arm aligned to the isocenter of the magnet. The hand was supinated and taped in position on the scanner bed, and the POM centered to the alignment light of the MRI. Coronal and sagittal scout images were produced to locate the long axis of the humerus and to align the 8–9th axial slices with the POM. Fifteen spoiled gradient images were generated {time to echo = 1.9 ms, time to repeat = 200 ms, flow artifact suppression, 30° flip angle} with POM as the center point. Axial imaging began at the superior portion of the upper arm and proceeded distally toward the elbow joint. Each image slice was 16 mm thick with a 0 mm inter-slice gap, 256 × 192 matrix resolution, 22 cm × 22 cm field of view, number of experiments = 6.

Magnetic resonance images from each site were saved via magnetic optical disk or CD-ROM in a DICOM format and sent to the central imaging facility for analysis. The same investigator analyzed MRI images using a custom designed program created to function within Matlab (The Math Works, Inc., Natick, MA), software that enabled the analyst to assign regions of interest in an image by tracing region borders with a mouse. Once the region of interest was defined, the program reported the number of pixels contained in the selected region of interest. The CSA was then determined by multiplying the number of pixels within the defined area by the preset CSA value of 0.01 cm^2, determined from the MRI matrix and field of view. The MRI standardization between sites was accomplished by comparing the radiographic bead's measured CSA with the MRI-determined CSA.

To assign the slice to be assessed, the analyst identified the slice immediately following the axilla and then counted down slice-by-slice to the slice showing the POM. In the rare instance that the number of slices between the axilla and POM differed pre- and post-RT, readily apparent discernable irregularities in the contour of the muscle and shape of the arm pre-RT were compared with slices adjacent to the post-RT POM until an identical anatomical match was found. The ninth axial slice was measured for maximum biceps CSA for most subjects. The pre-CSA was subtracted from the post-CSA yielding the RT response for that arm. Interobserver reliability was ±3.5%, and intra-observer reliability for the entire process of image acquisition and analysis was calculated to be a correlation coefficient of 0.99. As an additional quality control measure to validate the CSA calculation, data from a subset of 70 subjects were analyzed with volumetric analysis. The CSA (cm^2) of 11 successive slices was determined over 17.6 cm of the scanned length of the upper arm. Each CSA was multiplied by the known slice thickness (1.6 cm) to yield a slice volume (cm^3). Slice volumes were then summed over the length of the biceps. Comparison of the relative % from baseline training-induced change in volume versus CSA within the subgroup of 70 subjects revealed no significant differences between the two methods ($p \geq 0.05$).

Resistance Training Program. All RT was performed with the nondominant arm. We chose an upper arm, unilateral RT program to minimize the confounding effects of usual activities of daily living on the muscle strength and size response to RT (29). In addition, the RT intervention was designed to maximize muscle strength and size gains (3). Prior to each session, subjects warmed up with 2 sets of 12 repetitions of the biceps preacher curl and the seated overhead triceps extension. The initial weight was set at 65% of the subject's biceps preacher curl 1RM. All workouts were supervised, performed with Powerblocks and lasted 45 to 60 min. A session consisted of 5 exercises in the following order: biceps preacher curl, seated overhead triceps extension, biceps concentration curl, triceps kickback, and standing biceps curl with a 2 min rest period between each set. Training was periodized so that visits 1 through 8 required 3 sets of 12 repetitions at 65– 75% 1RM; visits 9–18, 3 sets of 8 repetitions at 75 to 82% 1RM; and visits 19–24, 3 sets of 6 repetitions at 83 to 90% 1RM.

Data Management. Data from all investigational sites were manually entered into the master database website (Microsoft SQL Database) maintained by staff at Children's National Medical Center, Washington, DC. Each site was assigned a username and password to maintain security and confidentiality.

Statistical Analyses

Descriptive statistics were generated on all study variables. Independent variables were gender and body mass classification via BMI as normal weight (BMI 18.5 to <25 $kg \cdot m^{-2}$) and overweight and obese (BMI ≥ 25 $kg \cdot m^{-2}$). Dependent variables were MVC, 1RM and CSA. Bivariate correlations revealed age (negatively) and relative body mass change ([postmass − premass]/premass × 100%) (positively) related to muscle strength and size ($p \leq 0.05$). Multiple dependent variable analysis of covariance (MANCOVA) with age and % body mass change as covariates tested for differences in physical characteristics between gender and BMI groups. Chi-square tested the difference in program attrition rates, i.e., drop outs, between the BMI groups.

The muscle strength data were analyzed with no correction (absolute), corrected for prestrength baseline values (relative) ([poststrength − prestrength]/prestrength × 100%}, and normalized for body mass with the allometric method (strength [kg] × body weight $[kg]^{-0.67}$) (20, 31). The CSA was analyzed with no correction (absolute) and corrected for initial values (relative). Consequently, 3 separate MANCOVA with age and % body mass change as covariates and gender as a fixed factor were performed for MVC, 1RM, and CSA, respectively, to test if muscle strength and size differed between BMI groups pre-RT and post-RT; and if absolute, relative and allometric muscle strength and size changes differed between BMI groups pre- to post-RT.

Because of its fairly strong correlation of BMI with total body fat content and relative ease of use in the general nonathletic population (13, 30), we used BMI to categorize the body mass status of our sample. Originally the hypothesis was tested on subjects categorized into 3 BMI groups, normal weight (18.5 and <25 $kg \cdot m^{-2}$, $n = 449$), overweight (≥ 25 and <30 $kg \cdot m^{-2}$, $n = 169$) and obese (≥ 30 $kg \cdot m^{-2}$, $n = 69$). There were no differences in the primary outcomes between the subjects who were overweight and obese so that these body mass categories were combined into one, i.e., overweight and obese, and results are reported for 2 BMI groups, normal weight compared to overweight and obese.

The FAMuSS findings regarding gender effects are reported elsewhere (17). In this study no gender by BMI interactions were found for absolute, relative, and allometric muscle strength and size pre-, post- and pre-to-post–RT. For these reasons, the findings are presented for the total sample and not by gender except for descriptive purposes. All statistical analyses were performed with SPSS (version 13.0 for Windows; SPSS, Inc., Chicago, IL) with $p \leq 0.05$ established as the level of statistical significance and data are reported as the mean ± *SEM*.

RESULTS

Anthropometrics

Body mass (absolute 0.3 ± 0.1 kg, relative 0.5%) and BMI (0.1 ± 0.0 $kg \cdot m^{-2}$) increased slightly, and nondominant biceps (−0.4 ± 0.2 mm, −1.0%) and triceps (−0.6 ± 0.2 mm, −0.8%) skinfolds decreased in the total sample pre- to post-RT ($p < 0.001$). The increase in relative body mass pre- to post-RT tended to be greater for the normal weight (0.8%) than the overweight and obese (0.3%) subjects ($p = 0.067$).

Isometric Strength

The subjects who were overweight and obese had greater MVC than those who were normal weight pre- and post-RT (Table 2) ($p < 0.001$); whereas allometric MVC was not different between BMI groups pre- and post-RT ($p \geq 0.05$). Absolute (unadjusted) and relative (adjusted for baseline values) MVC increased among the total sample and the normal weight and overweight and obese groups pre- to post- RT (Table 3) ($p < 0.001$). Absolute MVC gains were not different among the BMI groups pre- to post- RT (Table 3) ($p \geq 0.05$). In contrast, the subjects who were normal weight had greater relative and allometric MVC increases than those who were overweight and obese before versus after RT ($p < 0.05$).

Dynamic Strength

The subjects who were overweight and obese had greater 1RM than those who were normal weight pre- and post-RT (Table 2) ($p < 0.001$). Allometric 1RM was not different between the BMI groups pre-RT ($p > 0.05$), but was greater for participants who were normal weight than overweight and obese post-RT ($p \leq 0.05$). Absolute (unadjusted) and relative (adjusted for baseline values) 1RM increased among the total sample and the subjects who

TABLE 2. Muscle strength and size measures (mean ± *SEM*) of the total sample and by body mass group pre- and postresistance training.*

Measure	Total sample (n = 687)		Normal weight (n = 449)		Overweight and obese (n = 238)	
	Pre	Post	Pre	Post	Pre	Post
MVC (kg)	46.5 ± 0.6	54.3 ± 0.7	42.2 ± 0.7	50.6 ± 0.8	50.4 ± 1.0‡	58.1 ± 1.1§
Allometric MVC ($\text{kg}\cdot\text{kg}^{-0.67}$)	2.58 ± 0.03	3.02 ± 0.04	2.58 ± 0.04	3.01 ± 0.04	2.58 ± 0.06	2.99 ± 0.06
1RM (kg)	9.2 ± 0.1	13.3 ± 0.1	8.3 ± 0.1	12.4 ± 0.1	10.1 ± 0.2‡	14.2 ± 0.2‖
Allometric 1RM ($\text{kg}\cdot\text{kg}^{-0.67}$)	0.51 ± 0.00	0.74 ± 0.01	0.51 ± 0.01	0.76 ± 0.01	0.51 ± 0.01	0.73 ± 0.01§
CSA	18.0 ± 0.2	21.4 ± 0.2	16.4 ± 0.2	19.6 ± 0.3	19.5 ± 0.3‡	23.1 ± 0.4‖
(cm^2)	(n = 548)		(n = 359)		(n = 189)	

* Covariates included age and relative body mass change, and gender as a fixed factor. MVC = maximum voluntary contraction; 1RM = one repetition maximum; CSA = biceps cross sectional area.

† All muscle strength and size measures increased pre- to post-RT in the total sample, and among the body mass groups, $p < 0.001$ (see Table 3).

‡ $p < 0.001$, normal weight vs. overweight and obese groups preresistance training.

§ $p < 0.05$, normal weight vs. overweight and obese groups preresistance training.

‖ $p < 0.001$, normal weight vs. overweight and obese groups postresistance training.

TABLE 3. Muscle strength and size changes (mean ± *SEM* with 95% confidence interval) of the total sample and by body mass group pre- to postresistance training.*

	Total sample (n = 687)			Normal weight (n = 449)			Overweight and obese (n = 238)		
Measure	Absolute (kg)	Relative (%)	Allometric ($\text{kg}\cdot\text{kg}^{-0.67}$)	Absolute (kg)	Relative (%)	Allometric ($\text{kg}\cdot\text{kg}^{-0.67}$)	Absolute (kg)	Relative (%)	Allometric ($\text{kg}\cdot\text{kg}^{-0.67}$)
MVC	7.8 ± 0.3	19.3 ± 0.9	0.44 ± 0.02	7.9 ± 0.4	21.2 ± 1.0	0.48 ± 0.02	7.7 ± 0.5	17.4 ± 1.4†	0.40 ± 0.03†
(kg)	(7.2, 8.4)	(17.6, 21.0)	(0.40, 0.48)	(7.2, 8.6)	(19.2, 23.1)	(0.44, 0.52)	(6.7, 8.7)	(14.6, 20.3)	(0.34, 0.46)
1RM	4.1 ± 0.1	51.6 ± 1.2	0.23 ± 0.00	4.0 ± 0.1	54.3 ± 1.5	0.25 ± 0.00	4.2 ± 0.1	49.0 ± 2.0†	0.22 ± 0.01‡
(kg)	(4.0, 4.2)	(49.1, 54.1)	(0.22, 0.24)	(3.8, 4.2)	(51.3, 57.3)	(0.24, 0.26)	(3.9, 4.4)	(45.0, 53.0)	(0.20, 0.23)
CSA	3.4 ± 0.1	18.9 ± 0.4		3.2 ± 0.1	19.4 ± 0.5		3.6 ± 0.2§	18.4 ± 0.7	
(cm^2)	(3.2, 3.5)	(18.1, 19.8)		(3.0, 3.3)	(18.4, 20.4)		(3.4, 3.9)	(17.1, 19.8)	
	(n = 548)			(n = 359)			(n = 189)		

* Covariates included age and relative body mass change, and gender was a fixed factor. MVC = maximum voluntary contraction; 1RM = one repetition maximum; CSA = biceps cross sectional area. All muscle strength and size measures increased pre- to post-RT in the total sample and body mass groups, $p < 0.001$.

† $p < 0.05$, normal weight vs. overweight and obese groups.

‡ $p < 0.001$, normal weight vs. overweight and obese groups.

§ $p < 0.01$, normal weight vs. overweight and obese groups.

were normal weight and overweight and obese pre- to post-RT (Table 3) ($p < 0.001$). Absolute 1RM increases were not different between BMI groups pre- to post-RT (Table 3) ($p \geq 0.05$); whereas the subjects who were normal weight had greater relative and allometric 1RM gains than those who were overweight and obese before compared to after RT ($p < 0.05$).

Muscle Size

The subjects who were overweight and obese had greater biceps CSA than those who were normal weight pre- and post-RT (Table 2) ($p < 0.001$). Absolute (unadjusted) and relative (adjusted for baseline values) biceps CSA increased among the total sample and the subjects who were normal weight and overweight and obese pre- to post-RT (Table 3) ($p < 0.001$). Absolute biceps CSA increases were greater among the subjects who were overweight and obese ($p < 0.01$); however, relative biceps CSA gains were not different between the BMI groups pre- to post-RT (Table 3) ($p \geq 0.05$).

DISCUSSION

We sought to determine if the muscle strength and size response to a supervised upper arm, unilateral RT intervention differed among a large cohort ($n = 687$) of healthy, young adults who are overweight and obese compared to normal weight adults. The major finding of this study was that the absolute MVC and 1RM elbow flexor muscle strength gains were not different between the BMI groups pre- to post-RT; but when corrected for baseline values or body mass, adjusted MVC and 1RM peak elbow flexor strength gains were 4% (i.e., relative) to 17% (i.e., allometric) less in the subjects who were overweight and obese than those who were normal weight (Table 3). Furthermore, the subjects who were overweight and obese had greater absolute biceps size increases than the subjects who were normal weight, but these differences were no longer evident when correction was made for baseline values.

These findings are consistent with our hypothesis and suggest that the peak muscle strength gains to a short-term upper arm, unilateral RT program when adjusted for baseline values and body mass are less in young adults who are overweight and obese compared to their normal weight counterparts. This attenuation of relative and allometric muscle strength gain in the young adults who are overweight and obese compared to those who are normal weight occurred despite similar relative gains in muscle size and decreases in skinfold thickness. We further analyzed our muscle strength data per unit of biceps CSA and found no difference between the BMI groups pre-, post- and pre-to-post–RT (data not shown) ($p \geq 0.05$). Thus, differences in muscle quality did not provide insight into possible reasons for the diminished short-term relative and allometric muscle strength response to RT that we observed in the subjects who were overweight and obese.

Our findings conflict with those of Abe et al.(1), Blake et al. (7), and Van Etten et al. (32) who reported no difference in the absolute and relative muscle strength response to a total body RT intervention in samples consisting of small numbers of middle-aged men and women who were overweight and obese. However, our results are consistent with the conclusions of Hulens et al. (18) that women who were obese had less peripheral muscle strength than women who were normal weight when allometric scaling was applied; and with Falk et al. (11) who found overweight attenuated the increase in lower body muscle strength to a 3 year RT school-based program in young boys. Furthermore, our results are in accord with reports that excess body mass reduces submaximal and maximal aerobic capacity (19, 28) and impairs the ability to perform activities of daily living (16, 21, 28, 34).

Discrepancies between our findings and those of Abe et al. (1), Blake et al. (7), and Van Etten et al. (32) may be due to differences in the RT intervention. We purposely isolated the nondominant arm for RT to minimize variability in the training response due to activities of daily living (29), but this decision may have prevented the more systemic adaptations that result from a whole body RT program to occur as employed in these other studies (1, 3, 7, 24, 32). Nonetheless, the large sample size of this study allowed us to statistically account for important confounding factors in the muscle strength and size response to RT (i.e., age, gender, and body mass change); and to have the statistical power needed to detect differences in the muscle strength and size responses between the BMI groups that these other studies were underpowered to detect (1, 7, 32).

The mechanisms by which overweight and obesity would attenuate the muscle strength response to RT are not well established. Possibilities include candidate genes involved in the etiology of being overweight, the regulation of glucose and lipid metabolism, and alterations in muscle structure and function as well as their interactions (4, 8, 26). Although not directly measured in this study, excess adiposity is associated with microvascular (10) and metabolic alterations (5, 6, 10, 26) and intramuscular lipid accumulation (6, 10, 26) that could limit the muscle strength gains resulting from a RT program. Hyperproduction of proinflamatory cytokines (e.g., tumor necrosis factor alpha [TNF-α], Interleukin 6 [IL-6], and C-reactive protein) due to overweight and obesity impairs glucose disposal in skeletal muscle via defects in insulin signaling and glucose transporter protein (GLUT-4) trafficking (10, 12), suppresses lipoprotein lipase expression (23), and decreases protein synthesis in response to RT (14). Collectively, these adiposity-associated structural and metabolic derangements could have hindered the muscle strength response to RT that we observed among the overweight and obese subjects in this study.

Alternatively, Hansen et al. (15) found increased amounts of circulating growth hormone were positively related to gains in muscle strength and size to RT among young, untrained men who were normal weight. Kanaley (22) and Veldhuis et al. (33) reported lower serum growth hormone levels at rest and in response to RT in adults who were obese compared to adults who were normal weight. Consequently, the diminished muscle strength response to RT may have been due to lower levels of growth hormone in the subjects who were overweight and obese than those who were normal weight in our study. Clearly, further investigation is needed to determine how genetics and the structural, metabolic, and hormonal alterations that may result from overweight and obesity could account for our findings.

This study is subject to several limitations. The use of an RT program of the nondominant arm allowed us to isolate the muscle strength and size adaptations that resulted from the RT intervention per se. However, the type of RT program typically prescribed for health and fitness among healthy adults is a whole body workout (3). It is possible that the elbow flexor muscle strength and size response would be different with a total body than an upper arm, unilateral RT intervention. This seems unlikely because the magnitude of the biceps size increases we found with upper body training is consistent with reports in the literature regarding total body RT programs (7, 32).

Our measure of adiposity was BMI, a valid indicator of overall adiposity (13, 30), but BMI does not indicate how fat and muscle were distributed or how these compartments may have changed with RT. The upper body skinfold measures showed a small loss of subcutaneous fat as a result of the RT program, but no difference in the amount of fat loss between BMI groups. Subjects remained weight stable for the study duration, an indication that they adhered to their normal dietary patterns. Thus, the muscle strength impairments we observed in the subjects who were overweight and obese do not appear to be related to differential losses or shifts in adipose tissue. Nonetheless, the biceps CSA assessments did not account for intramuscular lipid accumulation, a possible explanation for the lack of a difference in muscle quality that we found between the BMI groups. Despite these limitations, this study has several strengths that make it unique and its contributions noteworthy. These include a large sample size, a well controlled RT intervention, the determination of biceps CSA with MRI, and direct comparison of subjects who were overweight and obese to those who were normal weight.

In conclusion, our findings suggest the relative and allometric muscle strength response to a short-term upper arm, unilateral RT program may be attenuated in young adults who are overweight and obese. These alterations occurred despite similar relative increases in muscle size in the normal weight and overweight and obese groups. Whether this apparent disadvantage in the relative and allometric muscle strength adaptations to a short-term RT intervention among persons who are overweight and obese would persist following a long-term, whole body RT program is not known.

PRACTICAL APPLICATIONS

Our results suggest that exercise prescriptions may need to be adjusted so that overweight and obese adults maximize the relative and allometric muscle strength gains they experience from RT. A simple adjustment may be participation in a more long-term, less rigorous, and more progressive whole body RT program. Weight loss achieved either with exercise, diet or both has been shown to reverse some of the metabolic derangements associated with overweight and obesity (2, 30). Whether modest, intentional weight loss would have improved the relative and allometric muscle strength response to RT among the subjects who were overweight and obese is not known. More subjects who were overweight and obese than normal weight did not complete the RT program. A possible reason for this observation is that the difficulty of performing the RT exercises was greater for the subjects who were overweight and obese than those who were normal weight, although we did not measure perception of effort during the supervised RT program. Clearly, additional investigation is warranted to validate our findings, and determine what adjustments if any may need to be made in the exercise prescriptions of people who are overweight and obese to maximize the benefits that they experience from RT.

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