Subcutaneous Fat Alterations Resulting from an Upper-Body Resistance Training Program

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ABSTRACT

KOSTEK, M. A., L. S. PESCATELLO, R. L. SEIP, T. J. ANGELOPOULOS, P. M. CLARKSON, P. M. GORDON, N. M. MOYNA, P. S. VISICH, R. F. ZOELLER, P. D. THOMPSON, E. P. HOFFMAN, and T. B. PRICE. Subcutaneous Fat Alterations Resulting from an Upper-Body Resistance Training Program. *Med. Sci. Sports Exerc.*, Vol. 39, No. 7, pp. 1177–1185, 2007. **Purpose:** It is believed spot reduction, the exercise-induced localized loss of subcutaneous fat, does not occur as a result of an exercise program; however, evidence as a whole has been inconsistent. To reexamine this concept, we compared subcutaneous fat measurements before and after resistance training among 104 subjects (45 men, 59 women). **Methods:** Subjects participated in 12 wk of supervised resistance training of their nondominant arm. Magnetic resonance imaging and skinfold calipers examined subcutaneous fat in the nondominant (trained) and dominant (untrained) arms before and after resistance training. Repeated-measures ANCOVA tested for subcutaneous fat differences within and between arms before, after, and from before to after resistance training by gender and measurement technique, with BMI and age as covariates. Simple linear regression compared subcutaneous fat changes before and after resistance training as assessed by MRI and skinfold. **Results:** Subcutaneous fat, measured by skinfold, decreased in the trained arm and not the untrained arm in the men ($P < 0.01$); it was similar in the total sample and in the women ($P > 0.05$). MRI determinations of subcutaneous fat changes were not different between arms in the total sample and by gender ($P > 0.05$). **Conclusion:** Subcutaneous fat changes resulting from resistance training varied by gender and assessment technique. Skinfold findings indicate that spot reduction occurred in men but not in women. In contrast, MRI found a generalized subcutaneous fat loss independent of gender, supporting the notion that spot reduction does not occur as a result of resistance training. MRI, sensitive to changes along the entire upper arm, detected greater variation in resistance training responses, preventing significant differences between trained and untrained arms. Variation in upper-arm resistance training response was not evident from a single skinfold measurement at the belly of the muscle. **Key Words:** SPOT REDUCTION, MAGNETIC RESONANCE IMAGING, SKINFOLD MEASUREMENT, GENDER, EXERCISE

APPLIED SCIENCES

The term *spot reduction* refers to the localized loss of subcutaneous fat as a result of exercising that particular part of the body. Despite the commonly held belief that spot reduction does not occur as a result of exercise training (19), the literature conflicts on this issue. The majority of investigations ($N = 5$) examining spot reduction ($N = 8$) have concluded that it does not occur (2,9,11,20,21). In contrast, Mohr (12), Olsen and Edelstein (16), and Noland and Kearney (15) report that spot reduction occurred as a result of exercise training. These investigators (12,15,16) used samples ranging between 32 and 56 subjects. Sample sizes ranged between 10 and 22 subjects for those reporting a generalized loss of subcutaneous fat (2,9,11,20,21) or those reporting that spot reduction did not occur as a result of exercise training, suggesting that the sample sizes in these studies may not have been sufficient to detect significant changes in subcutaneous fat. The specific area of the body examined also differed greatly among these studies and included subcutaneous fat over the triceps (16,20), forearms (2), thigh (11), and abdomen (9,12,15,21). Another factor accounting for the discrepancies among studies examining

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the concept of spot reduction is that the exercise modality used to train subjects (i.e., tennis, calisthenics, sit-ups, and resistance training (2,9,11,20,21)) varied considerably.

Treuth et al. (25,26) found that subcutaneous fat did not change in a sample of adult men (26) and women (25) when assessed by skinfold before and after 16 wk of resistance training, whereas subcutaneous fat decreased as a result of resistance training when assessed by magnetic resonance imaging (MRI) (26), computer x-ray tomography (CT) (25), or dual x-ray absorptiometry (DEXA) (26). Treuth et al. (25,26) conclude that decreases in subcutaneous fat resulting from resistance training are only detectable using imaging techniques such as MRI, CT, or DEXA, and not with anthropometric assessments such as skinfold (26).

The majority of spot reduction investigations have used skinfolds as a measurement technique for assessing subcutaneous fat (2,11,12,15,16,20). Though Treuth et al. (25,26) were not examining spot reduction, their findings raise the possibility that skinfold is not a valid technique for measuring local subcutaneous fat changes resulting from exercise training. Because of this possibility, and because of conflicting evidence in the literature, the purpose of the study was to reexamine the concept of spot reduction by comparing pre- to postresistance training subcutaneous fat changes as assessed by skinfold and MRI among a large sample of men and women. We hypothesized that subcutaneous fat as measured by MRI would be significantly reduced in the trained arm versus the untrained arm after resistance training, and that there would be no difference in subcutaneous fat changes as assessed by skinfold between the trained and untrained arms. Thus, spot reduction would be detected by MRI but not by skinfold, indicating that MRI and skinfold determinations of subcutaneous fat changes resulting from resistance training are not comparable.

METHODS

Overview. This study was part of a larger multicenter study, the Functional Single Nucleotide Polymorphisms Associated with Human Muscle Size and Strength (FAMuSS). FAMuSS was conducted by the Exercise and Genetics Collaborative Research Group consisting of researchers from the University of Connecticut, Dublin City University, University of Massachusetts, Central Michigan University, University of Central Florida, Florida Atlantic University, West Virginia University, Yale University, Hartford Hospital, and the Children's National Medical Center. The experimental design of FAMuSS has been described (1,7,18,23). The institutional review boards from the 10 institutions involved with FAMuSS approved the study protocol.

Potential study volunteers were recruited from the eight resistance training sites via strategic flyer placement and inhouse listserv and radio announcements. The mean number of subjects trained at the eight sites was 14, with a range of 10–18 individuals per site. Dynamic strength of the elbow flexors, cross-sectional area, and volume of the upper-arm musculature and subcutaneous fat were measured before and after 12 wk of elbow flexor (biceps) and extensor (triceps) resistance training of the nondominant (trained) arm in all subjects. Pre- and postresistance training measurements included body weight (in pounds, using a standard balance beam scale), height (in inches), body mass index (BMI; in kilograms per squared meters), trained and untrained arm circumferences (using a Gulick retractable measuring tape), subcutaneous fat in the trained and untrained arms (measured via Lange skinfold calipers; Cambridge Scientific Industries) over the biceps and triceps muscles of the trained and untrained arms, and one-repetition maximum (1RM) of the biceps of trained and untrained arm. Cross-sectional area and volumetric measurements of the upper-arm musculature and subcutaneous fat were obtained using MRI. Figure 1 summarizes the study protocol.

Subjects. All individuals gave written informed consent. For this study, 104 subjects aged 18–40 yr were randomly selected from the larger pool of more than 1000 from FAMuSS. Potential volunteers were excluded from study participation if they

1. used medications known to affect skeletal muscle such as corticosteroids, antihypertensive or hyperlipidemic medications, anabolic steroids, diuretics, arthritis medications (Vioxx, Celecrex), Depo-Provera contraceptive injection, clenbuterol, Rhinocort nasal inhaler, lithium, and chronic use of nonsteroidal antiinflammatory drugs;
2. had chronic medical conditions such as diabetes mellitus;
3. had metal implants in arms, eyes, head, brain, neck, or heart;
4. had performed any regular activity that required repetitive use of the arms within the prior year;
5. consumed an average of more than two alcoholic drinks daily;
6. used dietary supplements reported to build muscle size/strength or to cause weight gain such as protein supplements, creatine, or androgenic precursors; or
7. had gained or lost more than 2.2 kg within 3 months of study participation.

1RM strength testing. The dynamic strength of the elbow flexor muscles of the trained and untrained arm was assessed by 1RM on a standard preacher curl bench (Yukon International Inc., Cleveland, OH) holding a dumbbell (Powerblocks, Intellbell, Inc., Owatonna, MN). Powerblocks are handheld weights resembling dumbbells, adjustable in increments of 1.1 and 2.2 kg. If needed, additional weight could also be added in 0.6-kg increments using Platemates (Benoit Built Inc., Boothbay Harbor, ME). Each subject performed two warm-up sets with increasing weight. The arm not being tested rested on the lap with the hand in a pronated position. Study investigators then verbally

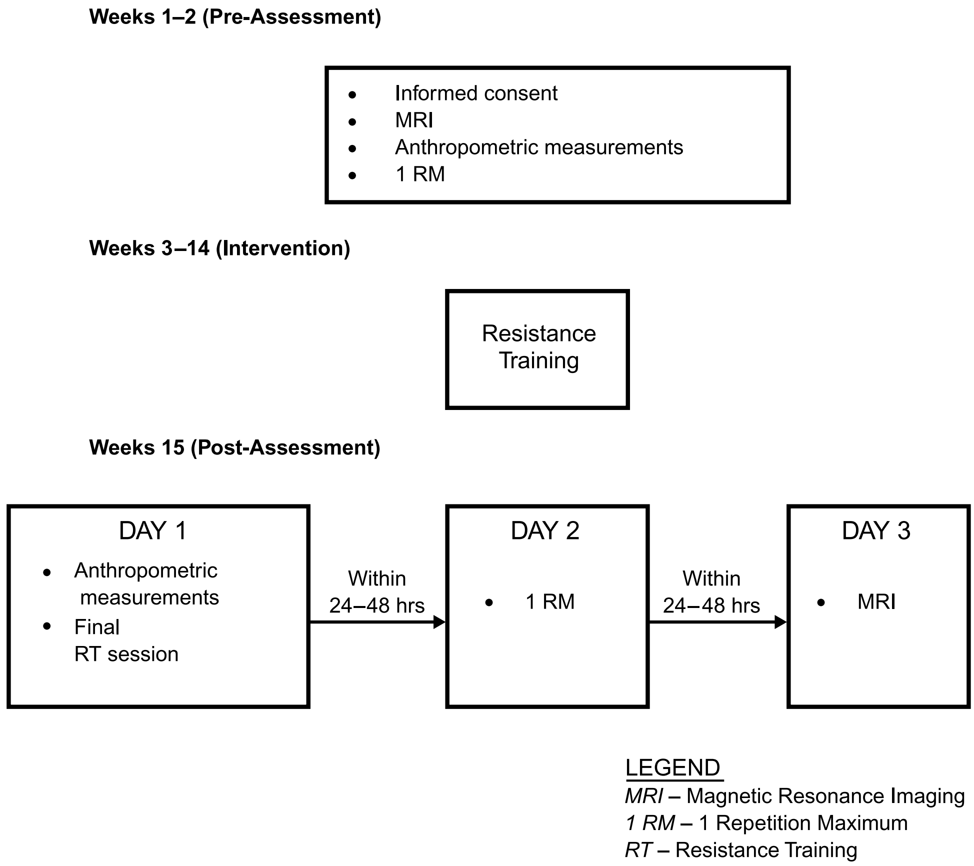

FIGURE 1—Research timeline.

instructed subjects to perform one 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 was decreased slightly. If the lift was successful, a 3-min rest was taken, and the weight was increased. The procedure was repeated until subjects failed to complete a full range-of-motion lift. Weights were chosen so that the 1RM could be determined in three to five attempts. Maximum weight lifted was recorded in kilograms as the greatest amount of weight successfully lifted one time. Study investigators gave verbal encouragement to each subject during each 1RM attempt. Pre- and postresistance training 1RM tests were administered by the same investigator.

Resistance training sessions. Subjects underwent 12 wk of gradually progressive, supervised resistance training of their nondominant arm. Subjects performed two workouts per week, each separated by a minimum of 48 h. The exercises consisted of the biceps preacher curl, overhead triceps extension, biceps concentration curl, triceps kickback, and standing biceps curl. Each resistance training session began with a warm-up series consisting of two sets of 12 repetitions of the biceps preacher curl and overhead triceps extension. Each warm-up set was followed by a 3-min rest. The weight for the first and second warm-up sets of the biceps preacher curl was 25 and 50% of the subject's 1RM, respectively. The warm-up weight for the warm-up sets of the overhead triceps extension was 25% of the subject's 1RM.

After the warm-up series, subjects performed three sets of 12 repetitions at 65–75% of their 1RM of each of the five aforementioned exercises. Each contraction was 4 s: 2 s for the concentric phase, and 2 s for the eccentric phase. Each set was followed by a 2-min rest. At week 5, the number of repetitions was decreased to eight, and then to six at week 10. Consequently, the exercise intensity at weeks 5 and 10 increased to 75–82 and 83–90% 1RM, respectively. Experienced investigators supervised the training sessions and adjusted the weight accordingly. Each session lasted approximately 45–60 min. Both the biceps and triceps muscles were exercised to ensure that upper-arm strength was balanced.

Magnetic resonance imaging. MRI images were taken before the subject's first resistance training session and within 48–96 h after the subject's final resistance training session. Before entering the MR magnet, a radiographic bead (Beekley Spots, Beekley Corp., Bristol, CT) was placed at the maximum circumference, or the point of measure of the right and left upper arm of each subject. The point of measure was determined with subject's arm abducted 90° at the shoulder, flexed 90° at the elbow, and the biceps maximally contracted. The same investigator visually located the point of measure and attached the bead before and after resistance training.

Subjects had their trained and untrained arms scanned separately in the supine position, with the arm of interest at their side and the center of the arm as close to the magnetic isocenter of the scanner as possible. The hand was supinated and taped in place on the scanner bed surface, and the point of measure was centered to the alignment light of the MRI. A coronal scout image was obtained to locate the long axis of the humerus, followed by a sagittal scout image to align the eighth slice of the axial/oblique image with the point of measure. These axial/oblique image slices (i.e., perpendicular to the humerus) were arranged so that the middle or eighth slice was at the point of measure with the others stacking above toward the shoulder and below toward the elbow, for a total length of 24 cm. Fifteen serial fast spoiled gradient images of each arm were then obtained (time to echo (TE) = 1.9 ms, time to repeat (TR) = 200 ms, flow artifact suppression, 30° flip angle), beginning from the shoulder of the arm and proceeding distally to the elbow. Individual image slices were 16-mm thick, with a 0-mm interslice gap, 256 × 192 matrix resolution, 22 × 22 cm field of view, and number of acquisitions (NEX) of six. MRI was performed at multiple sites with all units operating at 1.5 T. Images from each site were saved via magnetic optical disk and sent to Hartford Hospital for analysis.

MRI measurements of the upper arm. A pre- and postresistance training set of magnetic resonance images, each consisting of 15 slices (16 mm), was acquired from the trained and untrained arms of each subject, for a total of four sets. Each set encompassed the volume of the upper arm. Each individual slice contained a single image. The images, once acquired and converted to CD, were traced on a computer screen using a standard mouse and pointer by two different observers, one from Hartford Hospital and one from the University of Connecticut. Observers used a custom-designed program created to function within Matlab (The Math Works, Inc., Natick, MA). This program enabled the observers to assign regions of interest in an image set by tracing region borders with a mouse.

Three regions were traced on each image. The first encompassed the entire circumference of the arm (arm), the second encompassed the lean tissue (lean), and the third encompassed the cortical bone and marrow of the humerus (bone). The program reported the number of pixels in each region of interest. Pixels were then converted to squared centimeters by multiplying the number of pixels within the defined area by a preset value of 0.01, determined from the MRI matrix and field of view. A cross-sectional area determination consisted of measurements from a single image represented in squared centimeters. A volumetric measurement was the sum of cross-sectional area measurements represented in milliliters. Subcutaneous fat and muscle volumetric measurements of each arm were calculated using the following equations, where C = 0.01 (conversion from pixels to squared centimeters) and trained = slice thickness (1.6 cm):

$$\text{Subcutaneous fat volume (mL)} = \Sigma(\text{arm} - \text{lean}) \times C \times \text{trained}$$
$$\text{Muscle volume (mL)} = \Sigma(\text{lean} - \text{bone}) \times C \times \text{trained}$$

The observer from Hartford Hospital analyzed the single image containing the point of measure (typically the eighth axial slice) of each set of slices (i.e., before and after resistance training of trained and untrained arms) for each subject. To ensure that the slice containing the point of measure after resistance training was taken from the same section of the arm as the pre-resistance training slice, the analyst identified the slice that immediately followed the axilla as the anatomical marker that was noted as the first image to show separation between the arm and trunk. The analyst then counted down slice-by-slice to the slice showing the point of measure. In the rare instance that the number of slices between the axilla and point of measure differed before and after resistance training, readily apparent irregularities in the contour of the muscle and shape of the arm before resistance training were compared with slices adjacent to the postresistance training point of measure, until an identical anatomical match was found.

Beginning with the axilla, the observer from the University of Connecticut analyzed 9–11 slices in each of the four sets of each subject (this includes the eighth slice in each set). Accordingly, the slices occurring at the lower extremes of each set encompassed the elbow joint, where subcutaneous fat was difficult to discern. The slices containing the elbow joint were readily obvious by the increasing diameter of the humerus as it widens into the distal epiphysis and the scarcity of lean tissue surrounding the olecranon process. Thus, the slice preceding the first slice that contained the elbow joint was the final slice included in the volumetric analysis. Volumetric analyses included an equal number of pre and post slices and encompassed the area of the arm between the axilla and the elbow joint. The subjects' blinded data were then sent to the observer from the University of Connecticut, who determined pre and post subcutaneous fat and muscle volume of the upper arms of each subject. The fully analyzed data were then sent back to the observer from Hartford Hospital, who compared his analysis of the middle slice of each subject with that of the observer from the University of Connecticut and calculated interobserver reliability to be 3.5%.

The observer from the University of Connecticut randomly selected a single slice from 10 different subjects and reanalyzed each slice once per week for a 4-wk period. Thus, each of the 10 chosen slices was analyzed five times. The coefficient of variation for these 10 subjects for each region of interest—that is, the arm, lean, and bone—was 0.8, 1.0, and 4.0%, respectively. All data reported in this study were from the analysis done by the observer from the University of Connecticut. MRI standardization between sites was accomplished by comparing the radiographic bead's measured cross-sectional area with the MRI-determined cross-sectional area.

Skinfold measurements. Double-thickness subcutaneous fat measurements over the biceps and triceps muscles of each arm of each subject were taken with Lange skinfold calipers (Cambridge Scientific Industries) before and after resistance training. The exact location of the biceps skinfold measurement on the arm was determined with the same aforementioned methods as described for the point of measure. Triceps skinfolds were taken midway between the acromion and olecranon processes along the posterior midline of each arm. Skinfolds were pinched between the thumb and forefinger 1 cm above the skinfold site. Calipers were applied perpendicular to the skinfold between the base and the crest of the fold, approximately 1 cm away from the thumb and forefinger. All measurements were taken in triplicate, alternating between the trained and untrained arms to allow sufficient time for the fat fold to return to normal suppleness. The average of the three measurements was recorded. The same investigator performed pre- and postresistance training anthropometric and point-of-measure determinations. The coefficient of variation for all skinfold measurements was 3.8%. Triceps skinfold data are not shown because they did not demonstrate any significant within- or between-arm differences.

Data administration. Data from all investigative sites were compiled in a master database maintained by a statistical consultant at the Children's National Medical Center, Washington, DC. Each investigative site was able to access the database and manually enter data via a secure intranet using a confidential username and password.

Quality control. Strategies to alleviate variability within and between sites included protocol and methodology reviews at biannual staff meetings, periodic site visitations to ensure protocol adherence, use of common standard operating procedures by all sites, and frequent contact between the investigators through regular conference calls. Additionally, identical testing and workout equipment were issued to each site.

Statistical analysis. Descriptive statistics and frequencies were calculated on all study variables. The analyses included only those who completed all of the resistance training sessions. We performed a power calculation using the mean and standard deviation of the subcutaneous fat volume change of the trained (mean ± SD, −23.6 ± 46.4 mL) and untrained (−28.4 ± 38.0 mL) arms of the first 18 subjects analyzed, to determine the sample size needed to detect significant differences in volumetric subcutaneous fat changes between the trained and untrained arms from before to after resistance training. With $\alpha = 0.05$ and $\beta = 0.80$, we estimated that a sample of 101 subjects would be necessary to detect spot reduction, if it actually occurred.

Repeated-measures ANCOVA tested for significant pre- and postresistance training differences within and between trained and untrained arms, with BMI and age as covariates and gender as a fixed factor. In these analyses, dependent variables included pre- and postresistance training measurements of subcutaneous fat volume, subcutaneous fat cross-sectional area, skinfold thickness, muscle volume, and muscle cross-sectional area, which were represented in absolute (no correction) and relative (postresistance training − preresistance training/preresistance training × 100) terms. Cross-sectional area data mirrored MRI volume data, so only MRI volume data are reported.

Simple linear regression compared MRI- and skinfold-determined subcutaneous fat changes from before to after resistance training. In these analyses, variables tested included absolute and relative (percent of baseline values) pre- to postresistance training measurements of subcutaneous fat volume and skinfold in the trained and untrained arms. Additionally, simple linear regression compared absolute muscle cross-sectional area and subcutaneous fat cross-sectional area in the trained and untrained arms. Statistical significance was set at the $P < 0.05$ level, with all data reported as means ± SEM. All statistical analyses were performed using SPSS 13.0 for Windows.

RESULTS

Subject characteristics. The sample (N = 104) consisted of 45 men and 59 women, most of whom were Caucasian (94%), with an average age (± SD) of 24.1 ± 5.1 yr and BMI of 24.2 ± 4.1 $kg \cdot m^{-2}$. Average age (23.8 ± 4.7 vs 24.4 ± 5.4 yr) and BMI (24.8 ± 3.4 vs 23.8 ± 4.6 $kg \cdot m^{-2}$) were not different between the men and women, respectively ($P > 0.05$). Body weight remained stable throughout the 12-wk resistance training program ($P > 0.05$). The physical characteristics of this sample were similar to those of the larger FAMuSS cohort (1,7,18).

Subcutaneous fat determinations by skinfold. Table 1 displays the biceps skinfold findings among the total sample and by gender. The women had greater skinfold measurements in the trained and untrained arms from pre- and postresistance training compared with the men ($P < 0.01$). Absolute and relative skinfolds decreased in the trained arm from pre- and postresistance training among the men ($P < 0.01$), whereas the absolute and relative skinfold change in the trained arm was not different in the total sample or in the women from pre- and postresistance training ($P > 0.05$). Skinfold did not change in the untrained arm pre- and postresistance training among the total sample, the men, or the women ($P > 0.05$). The absolute and relative skinfold change in the trained arm was greater than in the untrained arm in the men ($P < 0.05$), but not in the total sample or in the women ($P > 0.05$). Relative skinfold in the trained arm decreased significantly more in the men compared with the women ($P < 0.05$). No significant within- or between-arm differences were found with the triceps skinfold data from pre- and postresistance training (data not shown).

Subcutaneous fat determinations by MRI. Table 2 contains the subcutaneous fat volume determinations made

TABLE 1. Adjusted mean (± SD) subcutaneous fat (mm) pre-, post-, and pre- to postresistance training by skinfold in the trained (trained) and untrained (untrained) arms among the total sample and by gender.

	Total Sample (*N* = 90)	Men (*N* = 38)	Women (*N* = 52)
Trained arm, pre	10.1 ± 5.9	8.4 ± 5.0	11.4 ± 6.1§
Trained arm, post	9.1 ± 6.3	7.0 ± 5.6	10.6 ± 6.4§
Trained arm, post − pre (absolute Δ)	−1.1 ± 2.8	−1.3 ± 2.3*	−0.8 ± 3.1
Trained arm, post − pre (relative Δ) (%)	−9.4 ± 28.1	−16.0 ± 26.7*	−4.6 ± 28.5
Untrained arm pre	9.8 ± 6.1	7.9 ± 5.6	11.2 ± 6.2§
Untrained arm post	9.4 ± 6.2	7.7 ± 5.4	10.7 ± 6.5§
Untrained arm, post − pre (absolute Δ)	−0.5 ± 2.0	−0.3 ± 1.9	−0.6 ± 2.1
Untrained arm, post − pre (relative Δ) (%)	−2.8 ± 26.1	0.3 ± 34.7	−0.5 ± 17.3
Trained Δ − untrained Δ (absolute)	−0.6 ± 2.7	−1.0 ± 2.4‡	−0.3 ± 2.9
Trained Δ − untrained Δ (relative) (%)	−6.6 ± 29.8	−16.2 ± 28.5†	0.5 ± 29.0¶

SCF, subcutaneous fat; RT, resistance training; SF, skinfold; Δ, change. § Men vs women, $P < 0.01$; * pre- vs post-RT, $P < 0.01$; ‡ T vs UT, $P < 0.05$; † T vs UT, $P < 0.01$; ¶ men vs women, $P < 0.05$.

by MRI among the total sample and by gender. Women had greater subcutaneous fat volume in the trained and untrained arms pre- and postresistance training compared with the men ($P < 0.01$). Subcutaneous fat did not change over time and was not different between the trained and untrained arms in the total sample; however, there was a significant gender effect ($P < 0.05$). Absolute and relative subcutaneous fat volume decreased in the trained arm in the men, whereas only absolute subcutaneous fat decreased in the women ($P < 0.05$). Absolute subcutaneous fat volume decreased in the untrained arm from pre- and postresistance training among the men and women ($P < 0.05$), whereas relative subcutaneous fat volume decreased only in men. The absolute and relative subcutaneous fat volume changes were not different between the trained and untrained arms pre- and postresistance training in the men and women ($P > 0.05$).

TABLE 2. Adjusted mean (± SD) subcutaneous fat volume (mL) pre-, post-, and pre- to postresistance training by MRI in the trained and untrained arms among the total sample and by gender.

	Total Sample (*N* = 104)	Men (*N* = 45)	Women (*N* = 59)
Trained arm, pre	422.9 ± 140.4	326.5 ± 139.9	519.5 ± 139.8§
Trained arm, post	406.3 ± 142.2	311.0 ± 141.7	501.6 ± 141.5§
Trained arm, post − pre (absolute Δ)	−16.9 ± 45.4	−16.1 ± 36.8*	−17.5 ± 51.3*
Trained arm, post − pre (relative Δ) (%)	−3.5 ± 12.3	−4.0 ± 12.2*	−3.2 ± 12.5
Untrained arm pre	427.6 ± 134.5	315.9 ± 134.1	519.3 ± 133.9§
Untrained arm post	414.1 ± 129.4	324.1 ± 129.0	504.1 ± 128.8§
Untrained arm, post − pre (absolute Δ)	−13.7 ± 46.6	−11.9 ± 38.4**	−15.1 ± 52.3*
Untrained arm, post − pre (relative Δ) (%)	−2.2 ± 12.9	−1.9 ± 14.7	−2.4 ± 11.5
Trained Δ − untrained Δ (absolute)	−3.2 ± 38.0	−4.2 ± 41.2	−2.4 ± 35.7
Trained Δ − untrained Δ (relative) (%)	−1.0 ± 12.1	−2.1 ± 16.6	−0.7 ± 7.1

SCF, subcutaneous fat; RT, resistance training; MRI, magnetic resonance imaging, Δ, change. § Men vs women, $P < 0.01$; * pre- vs post-RT, $P < 0.01$; ** pre- vs post-RT, $P < 0.05$.

TABLE 3. Adjusted mean (± SD) muscle volume (mL) pre-, post-, and pre- to postresistance by MRI in the trained (T) and untrained (UT) arms among the total sample and by gender.

	Total Sample (*N* = 104)	Men (*N* = 45)	Women (*N* = 59)
Trained arm, pre	577.7 ± 166.8	692.2 ± 177.6	490.4 ± 86.7§
Trained arm, post	652.2 ± 189.3	785.3 ± 198.4	550.6 ± 97.5§
Trained arm, post − pre (absolute Δ)	74.4 ± 69.0	93.0 ± 84.8*	60.3 ± 50.3¶
Trained arm, post − pre (relative Δ) (%)	13.4 ± 10.6	14.3 ± 11.7*	12.8 ± 10.0
Untrained arm, pre	592.0 ± 168.0	711.9 ± 170.2	500.8 ± 80.8§
Untrained arm, post	592.8 ± 162.7	708.5 ± 170.2	504.6 ± 82.2§
Untrained arm, post − pre (absolute Δ)	0.7 ± 36.5	−3.2 ± 40.6	3.7 ± 33.1
Untrained arm, post − pre (relative Δ) (%)	0.5 ± 6.1	0.0 ± 5.6	1.0 ± 6.9
Trained Δ − untrained Δ (absolute)	73.7 ± 75.1	89.1 ± 96.2†	57.4 ± 56.5§
Trained Δ − untrained Δ (relative) (%)	12.9 ± 11.3	14.3 ± 12.0†	11.8 ± 10.7

RT, resistance training; MRI, magnetic resonance imaging; Δ, change. § Men vs women, $P < 0.01$; * pre- vs post-RT, $P < 0.01$; ¶ men vs women, $P < 0.05$; † T vs UT, $P < 0.01$.

Muscle determinations by MRI. Table 3 displays the muscle volume determinations pre- and postresistance training among the total sample and by gender. Men had greater muscle volume in the trained and untrained arms pre- and postresistance training compared with the women ($P < 0.01$). Absolute and relative muscle volume increased in the trained arm from pre- and postresistance training among the men ($P < 0.01$) but not in the total sample or among the women ($P > 0.05$). However, the absolute and relative change in muscle volume in the untrained arm did not differ pre- and postresistance training among the total sample of men and women ($P > 0.05$). The absolute increases in muscle volume were greater for men than women pre- and postresistance ($P < 0.05$); however, the relative increases in muscle volume were not different between men and women ($P > 0.05$). The absolute and relative muscle volume increase was greater in the trained than in the untrained arm pre- and postresistance training in the men ($P < 0.01$) but not in the total sample or among the women ($P > 0.05$).

Comparison of subcutaneous fat determinations made by MRI and skinfold. There were no significant correlations between subcutaneous fat cross-sectional area and skinfold changes in the trained or untrained arms in the total sample, men, or women ($P > 0.05$). Table 4 contains the absolute subcutaneous fat volume and skinfold determinations in trained and untrained arms pre- and postresistance training in the total sample of men and women.

TABLE 4. Correlation between absolute subcutaneous fat volume change and skinfold thickness change in the trained (T) and untrained (UT) arms in the total sample, men, and women.

Group	Arm	Pearson *r*	*P* Value
Total sample	T	−0.231	0.028
Total sample	UT	0.118	0.267
Men	T	−0.090	0.591
Men	UT	0.242	0.142
Women	T	−0.286	0.040
Women	UT	0.053	0.707

Simple linear regression of absolute subcutaneous fat volume pre- and postresistance training as determined by MRI and absolute skinfold change pre- and postresistance training in the trained arm revealed a weak, negative correlation in the total sample and in the women ($P < 0.05$). In contrast, no significant correlation between absolute subcutaneous fat volume pre- and postresistance training as determined by MRI and absolute skinfold change pre- and postresistance training in the trained arm was found in the men ($P > 0.05$). There were no significant correlations between subcutaneous fat and skinfold determinations pre- and postresistance training in the untrained arm in the total sample, in men, or in women ($P > 0.05$).

Comparison of muscle and subcutaneous fat cross-sectional area by MRI. There was no significant correlation between absolute subcutaneous fat cross-sectional area and absolute muscle cross-sectional area pre- and postresistance training in the trained arm in the total sample, in men, or in women ($P > 0.05$). The men, however, showed a weak, negative correlation that approached significance ($P = 0.06$, $r^2 = 0.08$). There was no significant correlation between relative subcutaneous fat cross-sectional area and relative muscle cross-sectional area pre- and postresistance training in the trained arm in the total sample, in men, or in women ($P > 0.05$).

DISCUSSION

To revisit the concept of spot reduction, we compared subcutaneous fat changes above the biceps in the trained and untrained arms after a 12-wk resistance training intervention among healthy young men and women. Contrary to our hypothesis, the major finding of this study was that spot reduction did not occur in the total sample, in men, or in women when assessed by MRI. When assessed by skinfold, absolute (i.e., unadjusted) and relative (i.e., corrected for baseline values) subcutaneous fat decreased in the trained but not the untrained arm in the men, but it was not different in the women or in the total sample pre- and postresistance training ($P > 0.05$). Accordingly, the absolute and relative subcutaneous fat decreases in the trained arm with skinfold were greater than the untrained arm in the men, indicating that spot reduction occurred as a result of resistance training in the men but not in the women.

Reasons for these findings become apparent when subcutaneous fat measurements between the two techniques are compared. Simple linear regression revealed no significant correlations between pre- and postresistance training subcutaneous fat determinations with MRI and skinfold (Table 4). Tothill and Stewart (24) found a modest, positive correlation between skinfold and MRI determinations of subcutaneous fat in the midthighs of eight men and two women ($r^2 = 0.17$, SEE = 2.2, $P = 0.040$). These authors conclude that the agreement between the two measurement techniques was poor. Hayes et al. (5) compared MRI measurements of subcutaneous fat thickness at 12 anatomical sites with those of skinfold calipers at the same sites. Hayes et al. (5) found a strong positive correlation ($r = 0.880$, $P < 0.001$) when the overall means from all 12 subcutaneous fat sites were compared between MRI and skinfold. However, when the 12 subcutaneous fat sites were compared individually between the two techniques, the correlation was much weaker ($r = 0.205$, $P < 0.001$). Hayes et al. (5) conclude that the subcutaneous fat measurements made with MRI were not reproducible with those made by skinfold calipers. Our findings are consistent with those of Tothill and Stewart (24) and Hayes et al. (5) in that MRI and skinfold site measurements of subcutaneous fat did not agree.

A reason that skin calipers but not MRI detected spot reduction may be that the muscle growth compressed the extracellular space between fat cells in the upper arm (11). The total amount of subcutaneous fat in the trained arm may remain the same after resistance training but occupy less space because of muscle hypertrophy; therefore, it would result in a decrease in subcutaneous fat as assessed by skinfold, as we have reported. Krotkeiwski et al. (11) report a similar finding in the trained leg compared with the untrained leg after 5 wk of resistance training. In the trained leg, subcutaneous fat decreased when assessed by skinfold, and the muscle increased. The actual size of the adipocytes in the trained area was unchanged, as verified by measurements of fat-cell weight via fat biopsy. Fat biopsies were not taken in our study, so we can only speculate that adipocyte cell size did not change.

A possible explanation that MRI did not detect spot reduction, as skinfold calipers did, is that MRI was sensitive to variations in muscle and subcutaneous fat responses from resistance training along the entire upper arm, whereas skinfold calipers measured subcutaneous fat change only at the belly of the muscle. Absolute pre-resistance training subcutaneous fat volume in the trained arm (coefficient of variation = 48.3%) showed the least variation compared with absolute pre-resistance training skinfolds (coefficient of variation = 60.0%) in men. However, when comparing pre- versus post-subcutaneous fat variations in the trained arm among the two techniques in men, subcutaneous fat volume (coefficient of variation = 228.8%) as assessed by MRI was more variable than when assessed by skinfold (coefficient of variation = 172.7%). The larger variations in muscle and subcutaneous fat responses to resistance training as determined by MRI in the trained arm in men is the most likely reason that MRI did not detect a pre- versus postresistance training difference in subcutaneous fat between the trained and untrained arms, as skinfold measurements did.

It is possible that skinfold calipers do not detect spot reduction in all resistance training studies because of variations in the intensity of the resistance training program among studies. Muscle size is most effectively increased with progressively heavy loads (10). Treuth et al. (26)

report subcutaneous fat decreases with MRI in 13 adult men (26) and with CT in 14 adult women (25), but not with skinfold calipers. Additionally, Hakkinen et al. (4) found that subcutaneous fat did not change in a mixed-gender sample of 42 adult men and women after a 6-month resistance training program (4). In contrast, Wilmore (27), with a mixed-gender sample of 73 men and women, Staron (22), with 13 adult women, Hagerman (3), with 78 adult men, and Olson (16) all have reported decreases in subcutaneous fat resulting from resistance training, as measured by skinfold calipers. The exercise intensities in the studies finding subcutaneous fat decreases range from 70 to 80% 1RM (22) and from 85 to 90% 1RM (3), with Wilmore (27) and Olson (16) not reporting intensity but stating that each set was performed to maximal exhaustion. In contrast, intensity ranged from 50 to 67% 1RM in the Treuth studies (25,26), from 50 to 80% 1RM in the Hakkinen study (4), and was 50% 1RM in the Roby study (20). The intensity in our study ranged between 65 and 75% 1RM, progressing to 83–90% 1RM. A possible reason that skinfold did not decrease in all resistance training studies (4,20,25,26) is that loads were not heavy enough to bring about a large-enough increase in muscle hypertrophy to affect skinfold by subcutaneous fat compression.

Spot reduction is the localized loss of subcutaneous fat, resulting from exercising that specific part of the body; however, regions of the body (e.g., legs, arms, or trunk) differ in their propensity to store and mobilize subcutaneous fat (6,8). Exercise-induced regional fat mobilization also differs between men and women (14) and is likely attributable to gender-specific hormone differences. These regional subcutaneous fat differences could account for the differences in spot reduction that we found between men and women.

This study was subject to a number of limitations. Skinfold measurements were only taken over the biceps and triceps. Abdominal subcutaneous fat may be preferentially used as a result of physical exercise (13,14,17,28); thus, is not known whether subcutaneous fat decreased in other regions of the body in addition to the trained arm. It is possible that our sample size was too small to detect subcutaneous fat changes resulting from resistance training, as determined by MRI. However, power estimates indicate that our sample size was sufficient to detect spot reduction if it did actually occur. Future research examining subcutaneous fat changes resulting from exercise training should involve whole-body resistance training protocols and other subcutaneous fat assessments, such as fat biopsies, to account for any subcutaneous fat compression. Nonetheless, the strengths of this study are its large sample of men and women and its inclusion of MRI and skinfold to assess subcutaneous fat changes.

In conclusion, spot reduction did not occur in the total sample, in men, in or women as determined by MRI. The conclusion that spot reduction as detected with skinfold calipers occurred in men is problematic, because of the inherent limitations of skinfold calipers for detecting skinfold changes resulting from resistance training. Skin calipers measure only at the belly of the muscle; thus, subtle volumetric changes in the upper arm from resistance training may go undetected. Because MRI measures changes within the entire circumference of the upper-arm segment, it is better suited for examining subcutaneous fat changes that result from resistance training. Comparisons of subcutaneous fat measurements made by MRI and skinfold reveal that skinfold calipers are not suitable for assessing local subcutaneous fat changes that result from resistance training. Thus, the findings from this study support the current belief that spot reduction does not occur as a result of resistance training.

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APPLIED SCIENCES

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