Influence of diet and exercise on skeletal muscle and visceral adipose tissue in men

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Ross, Robert, John Rissanen, Heather Pedwell, Jennifer Clifford, and Peter Shragge. Influence of diet and exercise on skeletal muscle and visceral adipose tissue in men. J. Appl. Physiol. 81(6):2445–2455, 1996.—The effects of diet only (DO) and diet combined with either aerobic (DA) or resistance (DR) exercise on subcutaneous adipose tissue (SAT), visceral adipose tissue (VAT), lean tissue (LT), and skeletal muscle (SM) tissue were evaluated in 33 obese men (DO, n = 11; DA, n = 11; DR, n = 11). All tissues were measured by using a whole body multislice magnetic resonance imaging (MRI) model. Within each group, significant reductions were observed for body weight, SAT, and VAT (P < 0.05). The reductions in body weight (~10%) and SAT (~25%) and VAT volume (~35%) were not different between groups (P > 0.05). For all treatments, the relative reduction in VAT was greater than in SAT (P < 0.05). For the DA and DR groups only, the reduction in abdominal SAT (~27%) was greater (P < 0.05) than that observed for the gluteal-femoral region (~20%). Conversely, the reduction in VAT was uniform throughout the abdomen regardless of treatment (P > 0.05). MRI-LT and MRI-SM decreased both in the upper and lower body regions for the DO group alone (P < 0.05). Peak O2 uptake (liters) was significantly improved (~14%) in the DA group as was muscular strength (~20%) in the DR group (P < 0.01). These findings indicate that DA and DR result in a greater preservation of MRI-SM, mobilization of SAT from the abdominal region, by comparison with the gluteal-femoral region, and improved functional capacity when compared with DO in obese men.

obesity; magnetic resonance imaging; lean tissue; weight loss

THE RELATIONSHIP BETWEEN OBESITY and cardiovascular disease was clarified in the mid-1980s with the publication of several prospective studies indicating that, in both genders, body fat distribution was a strong predictor of cardiovascular disease and non-insulin-dependent diabetes (NIDDM; 13, 24, 25, 32). These observations stimulated cross-sectional research that confirmed that upper body or abdominal obesity, as characterized by the waist-to-hip circumference ratio (WHR), was more closely related to the metabolic disturbances than was obesity per se (6).

Another advance in our understanding of the health risks associated with obesity occurred in the 1980s and early 1990s when, with the use of computerized tomography (CT), the clinical importance of intra-abdominal or visceral adipose tissue (VAT) accumulation was identified (45). It is now apparent that VAT is an independent correlate of alterations in plasma glucose, insulin, lipid, and lipoprotein concentrations (11, 15). These observations indicate that if weight reduction is to control the health risks associated with obesity, both abdominal obesity and VAT should be reduced. This is particularly true for men because, matched for age, body mass index (BMI), and WHR, men are characterized by greater quantities of VAT (27, 41) and are at greater health risk compared with women (25, 51). Furthermore, strategies designed to reduce adiposity in men or women would ideally do so concurrently with a preservation of lean tissues (LT), in particular skeletal muscle (SM), because the preservation of LT contributes to the maintenance of resting energy expenditure and daily energy requirements (49).

Few studies have investigated the effects of diet- or exercise-induced weight loss on adipose tissue (AT) distribution in men (26, 36). To our knowledge, only two studies have described the effects of weight loss on VAT in men (8, 44). Furthermore, absent from the literature are studies that have considered the combined effects of diet- and exercise-induced weight loss on either VAT or SM in men.

A recent study reported that, in women, the combination of diet and exercise results in a greater reduction of AT and preservation of LT and SM compared with diet only (DO) (38). The purpose of this study was to assess the influence of DO and the combination of diet and either aerobic (DA) or resistance exercise (DR) on whole body and regional subcutaneous AT (SAT), VAT, and SM tissue in men.

METHODS

Subjects

Subjects were recruited from the general public through the local media and randomly assigned to the various treatment groups. Inclusion criteria required that the men were upper body obese (BMI > 27; WHR > 0.95 (derived by using the umbilical waist circumference)); were weight stable (±2 kg) for 6 mo before the beginning of the study; took no medication known to affect the study variables; and consumed an average fewer than two alcoholic beverages per day.

Thirty-three subjects complied with the study requirements, 11 each in the DO group, DA group, and the DR group, respectively. The descriptive characteristics for all groups are given in Table 1. The groups were not significantly different with respect to age, BMI, WHR, and total LT or AT (P > 0.05). All subjects were informed and provided written consent before participation in this study, which was conducted in accordance with the ethical guidelines of Queen's University (Kingston, ON).

Tissue Measurement by Magnetic Resonance Imaging (MRI)

Magnetic resonance (MR) images were obtained with a General Electric Signa Advantage 1.5-tesla scanner using software version 5.4.2. (Wisconsin). As illustrated in Fig. 1, a T1-weighted spin-echo sequence with a 210-ms repetition time; 10.2 ms echo time; 10-mm slice thickness; matrix, 256 x 192; number of excitations, 2; field of view, 400 x 400 mm; and a 256 x 192 pixel matrix size.
time and 17-ms echo time was used to acquire the MRI data. The abdominal protocol was used to acquire three sets of seven images. Two sets extended from L4-L5 to the upper thorax region and one extended from L4-L5 to the approximate level of the femoral head. The other three acquisitions were obtained by using the appendicular protocol. The total time required to obtain all MR data (41 images) for each subject was 25 min. During this time, the subjects lay in the magnet in a prone position. All image data were transferred onto a stand-alone Indigo2 computer (Silicon Graphics, Mountain View, CA) for analysis using software developed in our laboratory.

Calculation of LT and AT Area and Volume

The model used to segment the various tissues is illustrated in Fig. 2. The threshold selected for AT and LT was based on the analysis of a sample of typical images and their respective gray-level histograms (step 1). Each slice was reviewed by using an interactive slice-editor program, which allowed for verification and, where necessary, correction of the segmentation result (step 2). The operation was facilitated by superimposing the original gray-level image on the binary segmented image by using a transparency mode (step 3). In Fig. 2, step 4 provides a completed example of an axial image that has been segmented and the various tissues are identified by using separate color codes.

To calculate tissue area, the areas (cm²) of the respective tissue regions in each slice were computed automatically by summing the given tissues’ pixels and multiplying by the pixel surface area. The volume (cm³) of the respective tissues (i.e., AT or LT) in each slice was calculated by multiplying the tissue area (cm²) by the slice thickness (10 mm). Whole body AT and LT volume was calculated by adding the volumes of truncated pyramids as follows

\[
V = \sum_{i=1}^{N} A_i t + \frac{h}{3} \sum_{i=1}^{N} A_{i-1} + A_i + \sqrt{(A_{i-1} A_i)}
\]

where \(V\) is the total tissue volume, \(A\) is the tissue area, \(t\) is slice thickness, \(h\) is the distance between consecutive slices.

Table 1. Descriptive characteristics

<table>
<thead>
<tr>
<th>Descriptive characteristics</th>
<th>DO (n = 11)</th>
<th>DA (n = 11)</th>
<th>DR (n = 11)</th>
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<tbody>
<tr>
<td>Anthropometric</td>
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<tr>
<td>Age, yr</td>
<td>46.8 ± 7.6</td>
<td>47.6 ± 6.4</td>
<td>39.0 ± 12.9</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>31.6 ± 2.7</td>
<td>32.6 ± 3.6</td>
<td>33.5 ± 4.1</td>
</tr>
<tr>
<td>WC, cm</td>
<td>110.7 ± 7.8</td>
<td>114.4 ± 7.9</td>
<td>117.9 ± 10.3</td>
</tr>
<tr>
<td>WHR</td>
<td>0.99 ± 0.04</td>
<td>1.00 ± 0.05</td>
<td>1.02 ± 0.05</td>
</tr>
<tr>
<td>MRI</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SAT, liters</td>
<td>27.8 ± 7.1</td>
<td>27.1 ± 6.6</td>
<td>32.8 ± 8.6</td>
</tr>
<tr>
<td>VAT, liters</td>
<td>4.6 ± 1.6</td>
<td>4.6 ± 1.4</td>
<td>3.9 ± 2.3</td>
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<tr>
<td>LT, liters</td>
<td>57.7 ± 5.6</td>
<td>58.4 ± 6.2</td>
<td>61.4 ± 6.7</td>
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<tr>
<td>SM, liters</td>
<td>33.5 ± 4.1</td>
<td>33.2 ± 4.3</td>
<td>35.2 ± 4.8</td>
</tr>
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</table>

Values are means ± SD; \(n\) = no. of subjects. DO, diet alone; DA, diet + aerobic exercise; DR, diet + resistance exercise; BMI, body mass index; WC, waist circumference (umbilicus); WHR, waist-to-hip ratio derived by using umbilicus WC; MRI, magnetic resonance imaging; SAT, subcutaneous adipose tissue; VAT, visceral adipose tissue; LT, lean tissue; SM, skeletal muscle; male subjects showed no between-group differences for any of variables shown (\(P > 0.05\)).
and N is the number of slices. Whole body volume was calculated by using all 41 slices. To determine whether regional differences existed with respect to the effects of either treatment on MRI-LT, the whole body was divided into upper (21 images) and lower (20 images) body regions by using L4-L5 as the dividing point (Fig. 1). Intra-abdominal LT volume was derived by using four abdominal images extending from L4-L5 to three above. Leg SM was calculated by using the MR images extending from the foot to the femoral head; thus leg-SM includes a portion of the gluteal SM. Although not anatomically landmarked, the femoral head was visible for all subjects both pre- and posttreatment. Regional effects of weight loss on SAT were determined by comparing the leg and abdominal regions (Fig. 1).

Reliability

For MRI-LT measurements, a previous study reported the results obtained when duplicate (same day) MR images obtained on 19 female subjects at the L4-L5 level were compared (39). The correlation coefficient obtained between the two measurements was 0.94 (P < 0.001). The difference between the two mean values was 1.0 ± 5.1% (P > 0.10). The repeatability of whole body LT volume (liters) measurements was assessed from repeated measurements on two obese male subjects. For each subject a complete data set was acquired (41 images) on two separate occasions during the same day. The mean difference between tests 1 and 2 for MRI-LT (liters) was <2%. The MRI-LT calculations were determined by a
single individual and thus represent the intrinsidual error associated with repeated LT volume calculations. Previous studies have reported that for total AT volume (liters), the mean difference between tests 1 and 2 was 2.6%, with a range of 0.9 to 4.3% (37).

Anthropometric Variables

Subjects' body weight was measured while they were wearing underclothes on a balance scale calibrated to 0.1 kg. Barefoot standing height was measured to the nearest 0.1 cm by using a wall-mounted stadiometer. Circumference measurements were obtained at the following sites with the subjects in a standing position: biceps, forearm, chest, hip, proximal thigh, calf, and waist at the umbilicus and last rib levels by using the procedures described in the "Anthropometric Standardization Reference Manual" (29). All circumference measurements were obtained by the same investigator pre- and posttreatment. Body fat distribution by anthropometry was estimated by using a WHR derived by using the umbilicus (Table 1) and last rib (Table 2) waist circumferences.

Diet and Exercise Regimens

Dietary protocol. Basal energy requirements were estimated by using the Harris-Benedict equation (18) multiplied by a factor of 1.5. With the use of this method it has been reported that the difference between the estimated and actual energy requirements in healthy subjects is ~8% (30). A weight-maintenance diet at the prescribed energy intake was followed for 1 wk. For 16 wk after the baseline period, the weight-maintenance energy intake was reduced by 4.19 MJ/day (1,000 kcal/day). After completion of the 16-wk treatment period, the energy intake required to maintain weight was recalculated by deriving the average daily energy intake obtained from the dietary records and adding to that number the energy value associated with the weight loss (assuming 32.2 MJ/kg, 3,500 kcal/lb.). The derived value was prescribed and followed for 1 wk. Subjects were required to limit the contribution of fat to the total energy intake to 30%. The foods consumed were self-selected, and no supplements were prescribed. Food diaries were recorded daily for the duration of the 18-wk study and were analyzed weekly by using standard food tables (22a) to ensure adherence to the dietary protocol and that proper nutrition was maintained. All subjects were asked to attend weekly group meeting sessions to provide dietary counsel and develop individual success strategies.

Aerobic exercise protocol. In addition to the energy-reduced diet, 11 men performed aerobic exercise 5 days/wk. The initial duration of exercise was ~15 min and progressed to a maximum duration of 60 min according to individual capabilities. Exercise intensity (heart rate) was monitored each session by using an automated heart rate monitor (Polar USA, Stamford, CT). The mode of exercise was determined by the subjects and varied among stationary cycling, walking on a motorized treadmill, and stair stepping. All exercise sessions were by appointment and supervised by a physical educator.

Resistance training protocol. In addition to the energy-reduced diet, 11 men performed resistance weight-training exercises 3 days/wk by using Nautilus (Nautilus, Deland, FL) weight-training equipment. For each training session, the following eight exercises were performed: leg extension, leg flexion, supravelvolver (latissimus dorsi), chest press and cross (horizontal flexion of the shoulder joint), shoulder press, triceps extension, and biceps curl. Subjects performed between 8 and 12 repetitions to the point of failure (volitional fatigue) for all exercises during each training session. The weight lifted was increased as soon as 12 repetitions with a given weight were attained by a quantity (i.e., 1 plate) that permitted ~8 repetitions to be performed. For each exercise, the subjects performed the concentric contraction phase in 2 s and the eccentric contraction in 4 s. Substantial strength increases [one repetition maximum (RM)] on the order of 30–45% have been demonstrated by using this training protocol with Nautilus equipment in both men and women (7). In addition to the eight resistance exercises, sit-ups (curl ups) for the abdominal muscles were also performed each session. All exercise sessions were by appointment and supervised. For all sessions, the exercise supervisor provided verbal encouragement in attempts to ensure proper form and that physiological failure was attained for each exercise. The quantification of strength gains was derived by using the following equation: \[(a - b)/a \times 100\], where a equals the number of weight plates lifted (between 8 and 12 repetitions) at the beginning of week 4, and b equals the number of weight plates lifted at the completion of the program (i.e., 16 wk). Week 4 was chosen as the initial week in an attempt to represent changes in muscle strength that were due to adaptations in SM per se, thereby omitting initial increases attributed to neuromuscular factors. With the use of a Nautilus training protocol similar to ours, Braith et al. (7) have demonstrated that there is a linear relationship between the 7–10 RM and the 1 RM both pre- and posttraining. Increases in upper body strength were calculated by using the chest press and supervelvolver exercises, whereas lower body strength was derived by using the leg extension and leg curl exercises.

Table 2. Effects of diet and exercise on selected anthropometric and whole body MRI variables

<table>
<thead>
<tr>
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<th>DO (n = 11)</th>
<th>DA (n = 11)</th>
<th>DR (n = 11)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Abs</td>
<td>%</td>
<td>Abs</td>
</tr>
<tr>
<td>Anthropometric</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Wt, kg</td>
<td>-11.4 ± 3.5*</td>
<td>11.5</td>
<td>-11.6 ± 3.7*</td>
</tr>
<tr>
<td>WC, cm</td>
<td>-8.5 ± 4.0*</td>
<td>7.8</td>
<td>-12.9 ± 4.0†</td>
</tr>
<tr>
<td>HC, cm</td>
<td>-6.7 ± 3.3*</td>
<td>5.9</td>
<td>-8.0 ± 4.5*</td>
</tr>
<tr>
<td>WHR, cm</td>
<td>-0.03 ± 0.03*</td>
<td>1.9</td>
<td>-0.05 ± 0.05*</td>
</tr>
<tr>
<td>MRI</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>SAT, liters</td>
<td>-6.5 ± 2.1*</td>
<td>23.7</td>
<td>-5.9 ± 2.8*</td>
</tr>
<tr>
<td>VAT, liters</td>
<td>-1.5 ± 0.8*</td>
<td>31.7</td>
<td>-1.8 ± 1.0*</td>
</tr>
<tr>
<td>LT, liters</td>
<td>-1.6 ± 1.9*</td>
<td>2.6</td>
<td>-1.1 ± 2.5</td>
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Values are means ± SD; n = no. of subjects. Abs, absolute change; %, %change; WC, waist circumference (last rib); HC, hip circumference; WHR, waist-to-hip ratio derived by using last rib WC. * Significant within-group difference (P < 0.05); † significantly different from DO (P < 0.005).
Peak oxygen uptake (VO₂peak) was determined by using a treadmill test that employed a constant speed of either 4.8 or 5.6 km/h depending on the subject’s capabilities. The initial grade was set at 0% for the first 2 min, after which time it increased by 2% for the third minute and by 1% every minute thereafter. Standard spirometry techniques with a Beckman metabolic measurement cart (Sensormedics, Fullerton, CA) were used to determine oxygen uptake (VO₂). It was assumed that VO₂peak was attained when no increase in VO₂ was observed despite further increases in treadmill grade.

Energy Cost of Exercise

Aerobic exercise. The oxygen cost of both treadmill walking and stationary cycling as determined by using the equations given by the American College of Sports Medicine (2). Howley et al. (20) have previously reported that direct measurement of metabolic equivalent (MET) values with the use of the Stairmaster 4000 were ~20% lower than those presented by using the equation provided by the manufacturer. Therefore the MET values obtained when using the stair stepper were reduced by 20% before estimation of the oxygen cost. Energy expenditure of all three modes of exercise was subsequently determined by multiplying the oxygen cost by 21.1 kJ/l (5.04 kcal/l).

Resistance exercise. On the basis of data reported by Ballor et al. (4), the energy expenditure of the resistance exercise program was estimated to be 28 kJ (120 kcal) per session.

Statistical Analysis

Data are presented as means ± SD. A mixed two-way analysis of variance (MANOVA; group x time) was employed to assess the treatment effects on all dependent variables. A MANOVA was used to assess the potential relationship between changes in SAT and VAT. Scheffe’s post hoc comparisons were used to locate specific treatment effects. A paired t-test was used to determine the effects of resistance exercise on muscular strength within the DR group and the effects of aerobic exercise on VO₂peak within the DA group. Linear regression analysis was used to assess the simple relationships among variables. Statistical procedures were performed by using SYSTAT (50).

Determination of Sample Size and Statistical Power

The sample size required to observe a significant difference in MRI measurements was determined by using a t-test (single tailed) (34). The algorithm used to determine the associated power for small- sample-size designs was adapted from Kvanli (23). For MRI-VAT volume, the precision (SD) in our laboratory is 10% (0.4 liter) and the expected difference is 35% or 1.7 liters (40). The corresponding values for MRI-SAT are 3% (1.2 liters) and the expected difference is 25% or 9.0 liters (40). On the basis of these data and an α of 0.05, the sample size required to obtain a meaningful difference in VAT or SAT is <3. A sample size of 11 subjects provides a power of 90% to detect a difference of 0.2 liter in VAT volume and of 0.6 liter in SAT volume.

RESULTS

Adherence to Diet and Exercise

With few exceptions, complete dietary intake records were submitted by all subjects as required. Analysis of the dietary records indicated that the mean energy intake was 7.5 ± 1.2, 7.8 ± 0.9, and 7.6 ± 1.2 MJ/day for the DO, DA, and DR groups, respectively (P > 0.05). The corresponding diet-induced energy deficits were 4.0 ± 0.7, 4.1 ± 0.8, and 4.8 ± 1.0 MJ for the DO, DA, and DR groups, respectively (P > 0.05). The mean dietary fat intake for the DO, DA, and DR groups was 19.0 ± 5.3, 22.2 ± 6.3, and 35.3 ± 1.6%, respectively (P > 0.05).

For the DA group, attendance for the exercise sessions averaged 92% (range 85–98%). The duration of the exercise sessions averaged 37.0 ± 7.0 min. The average exercise intensity for the 16-wk exercise period was 77.0 ± 4.0% of the maximum predicted heart rate (220 – age). With respect to exercise modality, ~45% of the exercise was performed on the treadmill, 32% stair stepping, and 23% on the stationary bicycle. The mean energy expenditure for the DA group was 111.0 ± 48.3 MJ.

VO₂peak

The pretreatment VO₂peak for the DO group (2.83 ± 0.4 liters) was not different (P > 0.05) from that of the DA (3.10 ± 0.6 liters) or the DR (3.40 ± 0.5) groups. In response to the aerobic exercise program, VO₂peak increased by 14% (P < 0.01) within the DA group (0.38 ± 0.4 liters). Within the DO and DR groups, VO₂peak did not change (P > 0.05).

Strength-Training Performance

Improvements in strength training were determined by using four (two upper and two lower body) of the eight exercises. The mean increase for the two upper body exercises was 12% (P < 0.05) because, between weeks 4 and 16, the mean weight lifted increased from 107 to 116 lb, for the “chest press” and from 125 to 142 lb for the “lateral pulldown” exercise. The mean increase for the two lower body exercises was 20% (P < 0.05) because the mean weight lifted for the “leg extension” exercise increased (P < 0.05) from 132 to 164 lb. and from 79 to 90 lb. for the “leg curl” exercise.

Effects of Diet and Exercise on Selected Anthropometric Variables

The changes observed for selected anthropometric variables are given in Table 2. Significant reductions were observed for all anthropometric variables within all groups (P < 0.01). With the exception of waist circumference, a between-group analysis revealed that the reductions observed for all variables were not significantly different (P > 0.05).

Effects of Diet and Exercise on Total and Regional AT Distribution

The influence of diet and exercise on total (whole body) SAT and VAT volume is given in Table 2. Within all groups, significant (P < 0.01) reductions were observed for both VAT (~35%) and SAT (~25%). There were no between-group differences when the reductions in SAT and VAT were compared (MANOVA, P > 0.10). The MANOVA revealed that there were no significant effects for groups when differences in SAT and VAT were considered simultaneously (P > 0.10). As illustrated in Fig. 3 for all groups, the relative reduction in SAT was greater than the reduction in VAT.
VAT volume was significantly greater than the corresponding reduction in whole body SAT volume (P < 0.01). In addition, the reduction in VAT volume was greater (P < 0.05) than the corresponding reduction in abdominal SAT volume derived by using the same five images (one below to three above L4-L5) used to calculate VAT (data not shown).

The effects of weight loss on the regional mobilization of SAT were determined by comparing the relative reductions in SAT volume for the leg (gluteal-femoral) and abdominal regions. Figure 4 shows that for the DO group, the reduction for SAT in the leg was not different from that in the abdominal region (P > 0.05). However, for both exercise groups, the relative reduction in abdominal SAT (~27%) was greater (P < 0.05) than that observed for the leg region (~20%).

The effects of weight loss on the regional distribution of VAT were determined by analyzing the change in VAT for four images extending from one below to two above L4-L5. Analysis revealed that the reduction in VAT for the four images was not different across groups (P > 0.05). Thus the reduction in VAT was uniform throughout the abdomen and was ~35% for all groups (Fig. 5). Figure 6 illustrates a typical example of the reductions observed for SAT and VAT for a series of MR images throughout the abdomen.

**Effects of Diet and Exercise on Total and Regional LT Distribution**

The changes observed for whole body MRI-LT are given in Table 2. A significant (P < 0.05) reduction in MRI-LT was observed for the DO group (~1.6 ± 1.9 liters) but not the DA or DR groups (P > 0.05). Although statistically significant, the reduction in LT within the DO group was relatively small, ~2.6% (Table 2). The influence of weight loss on intra-abdominal LT is illustrated in Fig. 7. For all groups there were no significant (P > 0.05) changes in intra-abdominal LT, indicating that these tissues were preserved during weight loss and that the loss in LT observed in the DO group resulted from losses in the appendicular region.

The effects of diet- and exercise-induced weight loss on skeletal muscle are illustrated in Figs. 8 and 9. Whole body SM (Fig. 8) was maintained (P > 0.05) in both exercise groups, but not within the DO group (P < 0.05). Inspection of Fig. 9 reveals that the reduction in SM within the DO group resulted from decreases in both upper and lower body SM. Conversely, within the DA and DR groups, the preservation of SM was observed for both upper and lower body regions (P > 0.05). The contribution of SAT, VAT, and LT to the reduction in whole body volume is presented in Fig. 10. A between-group analysis demonstrated that for SAT and VAT the relative reduction was not different (P > 0.05). The relative reduction in SM volume observed for the DO group (~7%) was different from the small increase in SM observed in both the DA and DR groups (P < 0.05).

**DISCUSSION**

The influence of weight loss on AT and LT distribution in obese men was determined by using a whole body multislice MRI model. In response to a 12-kg...
weight loss induced by DO, DA, or DR, our findings support the following observations. 1) VAT is substantially (~35%) and uniformly mobilized throughout the abdomen. 2) SAT is significantly (~25%) reduced in response to all treatments and is preferentially mobilized from the abdominal region, as opposed to the gluteal-femoral region (leg), in response to diet and exercise, but not DO. 3) VAT is preferentially reduced, by comparison with SAT, in response to all treatments. 4) In contrast to DO, the combination of diet and exercise resulted in a greater reduction of VAT compared to SAT.

**Fig. 6.** Four pre- (Pre) and posttreatment (Post) MR images obtained every 5 cm beginning at L₄-L₅ level on a male subject who participated in DA program. Adipose tissue appears white, and non-adipose tissue appears dark.

**Fig. 7.** Pre and Post intra-abdominal LT volume values for DO, DA, and DR groups. Intra-abdominal LT was derived by using 5 MR images obtained every 5 cm, beginning at L₄-L₅. Values are means ± SD.

**Fig. 8.** Pre and Post whole body SM tissue volume values for DO, DA, and DR groups. Values are means ± SD.
Influence of Diet- and Exercise-Induced Weight Loss on AT Distribution in Men

In this study, a greater reduction in VAT volume (~35%) was observed compared with whole body or abdominal SAT volume (~25%) in response to DO or the combination of diet and exercise. This is consistent with a previous report indicating that, in men, on the basis of data obtained from a single CT image in the abdomen, diet-induced weight loss is associated with a preferential reduction in VAT area compared with SAT area (8). These findings also agree with reports showing that, in women, VAT is preferentially mobilized in response to diet (46) or the combination of diet and exercise (40). This preferential reduction in VAT may be partially explained by the observation that omental and mesenteric adipocytes are more sensitive to lipolytic stimulation compared with abdominal or femoral SAT adipocytes (14).

At this point, present knowledge indicates that weight loss on the order of 12 kg induced by DO or the combination of diet and exercise is associated with a 30–35% loss in VAT in both genders. This is a positive observation with important clinical implications for at least two reasons. First, VAT accumulation is a strong positive correlate of metabolic markers for cardiovascular disease and NIDDM (11, 15, 45). Second, compared with women, men accumulate greater quantities of VAT (27, 41). Whether reductions in VAT are related to concurrent reductions in metabolic risk factors for cardiovascular disease and NIDDM in men has not been reported. However, it has been shown that reductions in visceral adiposity are independently related to improvements in metabolic risk factors in women (12).

The data presented also demonstrate that regardless of treatment, the mobilization of VAT was uniform throughout the abdominal region. In other words, the relative reduction in VAT volume (cm³), derived by using multiple images, was not different from the reductions in VAT area (cm²) observed for any single MR image in the abdominal region. This observation implies that a single axial MRI or CT image located in the abdominal region is appropriate for assessing the influence of weight loss on VAT distribution in men.

In response to all three treatments, a substantial reduction in whole body SAT volume was observed. For the DO group, the reduction in SAT was uniform over the entire body. However, for the two exercise groups we observed a greater mobilization of SAT from the abdominal compared with gluteal-femoral (leg) region. This observation agrees with a previous report showing that, in obese women, the combination of diet and exercise results in a greater reduction in SAT from the abdomen compared with the appendicular region (40). Schwartz et al. (44) have shown that weight loss induced by exercise alone is associated with a preferential reduction in abdominal obesity in older men. These observations may be partially explained by regional differences in the adrenergic regulation of lipolysis in VAT during rest and exercise conditions (3). Whereas α-adrenergic inhibitory effects regulate abdominal SAT lipolysis during resting conditions, β-adrenergic stimulatory effects modulate abdominal SAT lipolysis during exercise (3). Arner et al. (3) have shown that during aerobic exercise in both genders, there is a marked increase in the mobilization of lipid from abdominal SAT, whereas only a minor increase in lipolytic activity was observed in femoral SAT. Thus it would appear that the inclusion of exercise has an influence on the reduction of abdominal SAT that is greater than DO. Because both VAT (11, 15, 45) and abdominal SAT (1) are related to metabolic disturbances, these findings provide strong support for the added benefit of exercise as a means of reducing abdominal adiposity and thus health risk.

The findings reported here confirm a previous observation from this laboratory (38) and others (9, 19) that despite the greater negative energy balance induced by exercise within the DA and DR groups, the loss of body weight was not different from the DO group. For the DR group, this observation is not surprising, given the modest increase in energy expenditure attributable to the performance of resistance exercise per se in this study. However, the mean energy expenditure attributable to aerobic exercise for the DA group (~26,500 kcal) was substantial; thus additional weight loss should have been observed. Two lines of evidence support this view. First, because there was no change in MRI-LT, and, assuming that the energy equivalent of 1 kg of AT
is 6,000 kcal, it is estimated that the reduction in AT due to the addition of exercise in the DA group should have been ~4.5 kg. Second, given the sample size in this study, an additional AT loss of this magnitude was well within the detectable limits of the MRI method employed to measure change in AT. Thus the fact that additional weight loss in the form of AT was not observed in the DA group is perplexing. Heymsfield et al. (19) suggest that the additional energy deficit induced by exercise is masked both by a reduced rate of water loss as well as a reduction in the effectiveness of exercise-induced energy loss. The authors speculate that the retention of water may be partially explained by the glycoen-sparing effect associated with moderate endurance exercise (43). Another factor that may have contributed to the equivalent weight loss was a disproportionate underreporting of energy intake by both DA and DR groups. This is unlikely, however, because underreporting of energy intake in free living subjects is related to the degree of adiposity (28), which suggests that the underreporting should have been similar among groups. It is also unlikely that the DA and DR groups consumed more food in response to exercise because obese untrained subjects do not commonly change energy intake when exposed to exercise training (47). On the other hand, it is possible that fatigue within both exercise groups induced a reduction in daily activity levels that compensated for the energy expended during supervised exercise. Using doubly labeled water, Goran and Poehlman (17) reported that those who exercised intensely during structured physical activity perform less unstructured physical activity for the remainder of the day compared with controls, and thus, 24-h energy expenditure was not different.

In summary, although our results do not support the hypothesis that the addition of exercise to a dietary regimen provides added benefit with respect to weight loss or AT reduction, it is unlikely that this observation reflects a biological truth but, rather, a weakness inherent to the methodology employed. Future studies of similar design would benefit from the inclusion of doubly labeled water data.

Influence of Diet- and Exercise-Induced Weight Loss on LT Distribution in Men

That the addition of aerobic or resistance exercise to a program of energy restriction results in a uniform preservation of LT and SM that is greater than energy restriction alone confirms a previous study in which similar observations were reported for obese women (38). Ballor et al. (4) report that the addition of resistance exercise to a regimen of energy restriction results in a preservation of lean body mass compared with energy restriction alone in women. Taken together, these findings indicate that in both genders the addition of exercise preserves LT and its principal constituent, SM. Moreover, our observation that there was a uniform preservation of SM indicates that there is no increase in SM in one anatomical region that is masked by a corresponding decrease in another. Thus the addition of either aerobic or resistance exercise did not result in a redistribution of SM tissue.

The preservation of LT and SM in response to diet and exercise is important for two reasons. First, LT contributes to the maintenance of resting energy expenditure and daily energy requirements (49). Second, the maintenance of SM would facilitate potential improvements in functional capacity despite weight loss. Indeed, impressive increases in VO2peak and muscular strength were observed within the DA and DR groups, respectively. For VO2peak, the improvements noted in this study are similar to those reported for a similar study, in which VO2peak increased by 14% (33).

Consistent with previously reported data from this laboratory (39), substantial increases in muscular strength in response to diet and resistance exercise occurred in the absence of a concurrent increase in SM volume. These observations identify a limitation when MRI is used to assess the influence of weight loss on SM. That is, for a given change in MRI-SM cross-sectional area (cm²), it is not possible to quantify the potential contribution for any one of the SM tissue constituents (i.e., extracellular water, interstitial and intramuscular triglyceride, and contractile or noncontractile protein).

However, given the increase in upper and lower body strength observed for the men in this study, it is likely that increases in contractile protein and/or muscle fiber area did occur but were masked by decreases in any one of the other SM constituents. Several lines of evidence support this view. First, the increases reported here for muscular strength were calculated beginning with week 4. This approach was employed in an attempt to represent changes in muscle strength that were due to adaptations in SM per se, thereby omitting initial increases attributable to neuromuscular factors (42). Second, it has been reported that SM fiber area can increase in response to diet- and resistance exercise-induced weight loss despite a 3.4-kg decrease in hydrostatically weighed lean body mass (10). Finally, it has been demonstrated that MRI is sensitive enough to detect increase in SM area induced by resistance training in the absence of weight loss (48).

To determine the influence of weight loss on intra-abdominal LT, LT other than muscle and bone was measured for a 25-cm region in the abdomen (five images). With the use of this approach it was noted that intra-abdominal LT were maintained regardless of treatment. As previously stated, use of T1-weighted MRI does not permit identification of the constituents that are responsible for changes in LT. Moreover, the ability of MRI to accurately follow changes in intra-abdominal LT during weight loss has not been properly validated. Thus, for example, whether the extreme loss of VAT in all groups has influenced the identification of intra-abdominal LT posttreatment is unclear. Regardless, the possibility that LT, which include the vital organs, are preserved in response to moderate weight loss induced by diet and exercise is noteworthy and warrants further investigation.
It is apparent that the findings of this study do not argue against the merits of DO as a means of treating obesity. To the contrary, substantial reductions in SAT and VAT were observed in the DO group. Moreover, the contribution of MRI-LT to the reduction in total volume observed for the DO group reported here (~7%), while statistically significant, is substantially less than the ~26% loss in lean mass commonly associated with a diet-induced weight loss similar to that reported here (5). Similar observations have previously been reported for obese women and have suggested that the discrepancy may be explained by methodological differences used to measure changes in body composition variables (38). Taken together, our findings indicate that for either gender, although the addition of either aerobic or resistance exercise to a regimen of energy restriction provides useful benefits compared with energy restriction alone, it is clear that both modalities (DO or diet and exercise) provide clinical benefits that have hitherto been inaccurately presented. In particular, it is possible that the losses in LT normally associated with DO have been overestimated.

Summary

With the acceptance that a principal outcome of obesity reduction is to reduce adiposity concurrently with a preservation of LT and an improvement in functional capacity, our findings provide strong evidence in support of the recommendation that obesity be reduced by a daily energy deficit on the order of 1,100–1,200 kcal (5.0 MJ) induced by the combination of energy restriction and either aerobic or resistance exercise in men. These observations confirm previous findings in women and provide additional support for a moderate approach to obesity reduction in both genders.

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