UC Irvine
UC Irvine Previously Published Works

Title

Fitness, fatness, and the effect of training assessed by magnetic resonance imaging and skinfold-thickness measurements in healthy adolescent females

Permalink

https://escholarship.org/uc/item/3xg7w0b2

Journal

American Journal of Clinical Nutrition, 66(2)

ISSN

0002-9165

Authors

Eliakim, A

Burke, GS

Cooper, DM

Publication Date

1997-08-01

DOI

10.1093/ajcn/66.2.223

Copyright Information

Peer reviewed

Fitness, fatness, and the effect of training assessed by magnetic resonance imaging and skinfold-thickness measurements in healthy adolescent females[1-3]

Alon Eliakim, Georgine S Burke, and Dan M Cooper

ABSTRACT The relation between fitness and adiposity is particularly relevant to adolescent females in whom fitness is known to decrease and fatness to increase. However, little is known about the interaction of these variables in normally active, nonobese subjects. Our major hypotheses were that adiposity would be inversely correlated with physical fitness and that even a relatively brief intervention would lead to measurable, site-specific changes in body fat. We used a cross-sectional protocol to correlate body adiposity with indexes of fitness and a prospective study design to examine body adiposity before and after a 5-wk period of endurance training in 44 nonobese females aged 15–17 y (control group, $n = 22$; training group, $n = 22$). Adiposity was assessed by magnetic resonance imaging of the abdomen and thigh as well as by standard skinfold-thickness measuring techniques. Fitness was assessed by using cycle ergometer measurements of maximal oxygen uptake ($\dot{V}O_2$max). There were significant negative correlations between $\dot{V}O_2$max normalized to body weight and subcutaneous abdominal, thigh, and skinfold estimates of fat. However, when $\dot{V}O_2$max was normalized to muscle volume these correlations were not significant. Abdominal fat increased in direct proportion to body weight (scaling factor = 1.14 ± 0.16) but thigh fat increased proportionately less (scaling factor = 0.38 ± 0.12, $P < 0.05$). Training increased thigh muscle mass significantly only in the midmuscle region and prevented the observed fat increase in the distal thigh of the control subjects. Body fat distribution in adolescent females appeared to be affected by many factors, including overall body weight and the level of physical activity. *Am J Clin Nutr* 1997;66:223–31.

INTRODUCTION

In adults, there is growing recognition that body fat and its distribution are related to levels of physical fitness and to risk factors for coronary artery disease, but far less is known about these relations in children (1, 2). Physical inactivity during childhood and adolescence may play a role in the development of obesity later in life (3, 4). Thus, understanding the relation between fitness and adiposity is particularly relevant to adolescent females, in whom fitness is known to decrease and fatness to increase, during puberty (4, 5). Finally, it is becoming increasingly understood that fat distribution differs throughout the body and that adipose tissue at different sites may respond differently to metabolic stimuli, nutritional stimuli, or both (6).

We showed recently that 5 wk of training led to substantial increases in fitness (assessed by progressive exercise testing) and total thigh muscle volume [assessed by magnetic resonance imaging (MRI)] in a group of 22 healthy adolescent females who were neither excessively sedentary nor highly trained competitive athletes. No significant changes in these indexes were observed in 22 untrained, age-matched control subjects (7). In the present study, the focus was on training-induced changes in skinfold-thickness measurements, subcutaneous abdominal adipose tissue (SAAT), intraabdominal adipose tissue (IAAT), and MRI measurements of site-specific changes in thigh fat and musculature in the same group of adolescent females.

Our observations and previous studies by other investigators (4, 8) led us to four related hypotheses: *1*) that adiposity, in contrast with muscle mass, would be inversely correlated with physical fitness in healthy adolescent females; *2*) that the relation between adiposity and body weight is not uniform throughout the body (ie, an increase in body weight is not necessarily accompanied by an equal increase in fat in the thigh and the abdomen); *3*) that even a relatively brief intervention (ie, 5 wk of endurance training) would lead to measurable changes in body fat; and *4*) that changes in adiposity, musculature, or both would not necessarily be uniform within the abdomen (ie, IAAT compared with SAAT) or the thigh.

The study was designed as both a cross-sectional and prospective interventional set of experiments. The cross-sectional component consisted of data from all 44 participants before the onset of training, and these data were used to test hypotheses 1

and 2. The group of 44 was divided randomly into a control ($n = 22$) and training group ($n = 22$). The prospective interventional data were used to test hypotheses 3 and 4.

SUBJECTS AND METHODS

Subjects

As reported previously (7), 44 healthy adolescent girls volunteered for the study. The participants were all students at Torrance High School (Torrance, CA) and were enrolled in an honors anatomy class during the summer of 1995 (July–August) with class hours from 0800 to 1230; 61.4% were Asian, 20.4% white, and 18.2% Hispanic. No attempt was made to recruit subjects who participated in competitive extramural athletic programs. The study was approved by the Institutional Human Subject Review Board and informed consent was obtained from the subjects and their parents or guardians.

Methods

The study was designed to examine subjects in late puberty aged 15–17 y. Weight was measured by using standard techniques. Assessment of pubertal status was performed by conducting a medical history and physical examination, in all of the subjects; 95% of the subjects were found to be at Tanner stage V according to the criteria of breast development and pubic hair.

Subjects were prescreened for participation in high school–level athletics by physicians unrelated to the study. Individuals using medication for a chronic condition (other than bronchodilators), with a history of chronic lung or heart disease, or with a history of smoking or drug or alcohol abuse were excluded.

Subjects were randomly assigned to control ($n = 22$) and training ($n = 22$) groups. All subjects participated in the 2-h daily teaching program. During the remaining time, the training group members underwent endurance-type training consisting of running, aerobic dance, competitive sports (eg, basketball), and occasional weightlifting. These activities were varied in duration and intensity throughout the week primarily to encourage maximal participation of the subjects. On average, aerobic or endurance-type activities accounted for ≈90% of the time spent in training. Of the 90%, ≈50% involved running, 25% team sports, and 25% aerobic dance. Training was directed by a member of the Torrance High School faculty. The duration of the study was 5 wk.

The control group participated in a computer workshop designed to improve their computer skills and used this time to analyze some of the data collected from the study. No attempt was made to influence extracurricular levels of physical activity in either the control or training group. Staff members responsible for anthropometric measurements, MRI studies, and fitness tests were blinded to the subject's group assignment.

Skinfold-thickness measurements

Triceps, biceps, subscapular, and suprailiac skinfold thicknesses were measured to the nearest 0.1 mm with Lange skinfold calipers (Cambridge Scientific Instruments, Inc, Cambridge, MD) by using standard techniques (9). Measurements were made on the right side of the body. All measurements pre- and postintervention were performed by the same individual.

Calculation of percentage body fat was based on standard equations (9). Body density was calculated from the regression equation of Durnin and Rahaman (10) for adolescent girls. There was an intraobserver variability in these measurements of ≈5%.

MRI of thigh musculature and fat

Studies were done before and immediately after the 5-wk protocol in all 44 subjects. We chose to examine the musculature of the right thigh because these muscles would be largely involved in the endurance-type training program as described above. MRI was used previously to assess muscle and fat (8, 11–13).

MRI was performed with a General Electric (Waukesha, WI) 1.5-T whole-body MRI system. A body coil was used for both signal detection and for radiofrequency transmission for imaging. The subject was positioned with the lower extremities moved into the isocenter of the magnet bore. Pilot image coronal sections were obtained to select an image including the distal femur. Twelve axial sections beginning at the knee to a level of 2–3 cm below the femoral neck were obtained. These axial sections were 2 cm thick with no gap and were obtained with a T1-weighted sequence with a time-to-echo of 12 ms and a repetition time of 400 ms. The matrix was 192 × 256 with two acquisitions at each phase encode step.

The muscle and fat were easily identified in the serial MRI sections and were measured by using computerized planimetry to determine the cross-sectional area of muscle and fat (**Figure 1**). In the thigh, intraobserver variability of fat and muscle was ≈2%. The percentage of each thigh section consisting of fat and muscle was then calculated. The total thigh muscle and fat volumes (in mL) were estimated by summing the respective volumes in each serial section [ie, fat cross-sectional area (in cm^2) × 2 cm]. Finally, we calculated the ratio of muscle to fat volumes.

Abdominal MRI

Abdominal MRI was performed at the level of the umbilicus. SAAT was clearly demarcated in the magnetic resonance images and, therefore, was easily measured by trained observers. Intraobserver variability was ≈2%. IAAT was not as well outlined in this population, which was reflected in an intraobserver variability of ≈15%. We summed SAAT and IAAT to determine an estimate of total abdominal adipose tissue (TAAT). The percentages of SAAT, IAAT, and TAAT were calculated as the fat cross-sectional area divided by the cross-sectional area of the whole abdomen at the level of the umbilicus (ie, %SAAT, %IAAT, and %TAAT). Studies were done before and after the training intervention.

Measurements of maximal oxygen uptake

Fitness was assessed first by using measurements of maximal oxygen uptake ($\dot{V}O_2$max). Each subject performed a ramp-type progressive exercise test on a cycle ergometer on which the subject exercised to the limit of her tolerance. Subjects were vigorously encouraged during the high-intensity phases of the exercise protocol. Gas exchange was measured breath-by-breath (14) and $\dot{V}O_2$max was determined as described previously for children and adolescents (15). Mean peak heart rate was 182 ± 15 beats/min and the mean peak respiratory ex-
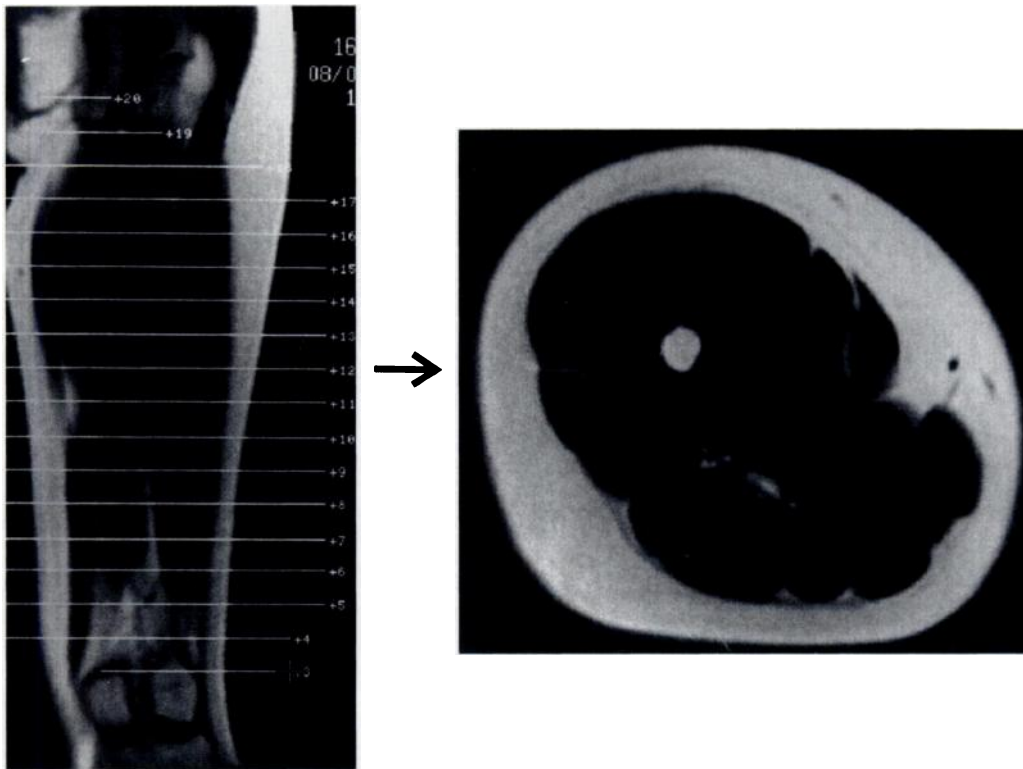
FIGURE 1. Magnetic resonance images of the right thigh. Left panel: the 12 axial sections beginning at the knee to a level 2–3 cm below the femoral neck. Right panel: cross-sectional image of fat and musculature at the midthigh.

change ratio was 1.17 ± 0.08, suggesting that close to maximal values were likely achieved. $\dot{V}O_2$max values were normalized to body weight, a commonly used method to normalize exercise responses in subjects of different body sizes and weights (16). We additionally analyzed $\dot{V}O_2$max by normalizing it to the MRI determination of right thigh muscle volume.

Statistical analysis

As noted, the study was designed as both a cross-sectional and prospective interventional set of experiments. The cross-sectional component was analyzed by using data from all 44 participants before the onset of training. To determine possible effects of ethnicity on body fat, its distribution, and its relation to fitness, we used analysis of variance (ANOVA) to examine the indexes of fitness and adiposity described above. In addition, we calculated the principal components from the skinfold-thickness and MRI measures, according to the method reported by Malina et al (17). Finally, we examined partial correlations between each of the indexes of fitness and adiposity, controlling for any effects of ethnicity.

Standard techniques of linear regression and correlation were used to determine the relations among fitness and indexes of adiposity, and between different methods (ie, MRI and skin-fold-thickness measurements) of assessing adiposity. We used standard methods to compare regression coefficients between different variables (18). Where appropriate, we used multiple linear regression to determine the relative contribution of these variables (eg, the effects of body weight, thigh muscle volume, thigh fat volume, SAAT, and IAAT on fitness).

We determined the scaling factor between indexes of fat (thigh or abdominal) and body weight and between $\dot{V}O_2$max

and muscle volume using the standard allometric equation $y = a \times M^b$, where y is a variable of adiposity or $\dot{V}O_2$max, M is an index of body mass (weight or thigh muscle volume), and b is the scaling factor. The scaling factor was determined by iterative curve fitting of the allometric equation (16, 19, 20).

For the interventional aspect of the study, unpaired t tests were used to compare data from subjects randomly assigned to either the control or training group before the training intervention. Paired t tests (appropriately modified for multiple comparisons) were used for within-group comparisons to evaluate the effect of training on thigh muscle and fat cross-sectional area, SAAT, IAAT, and skinfold-thickness measurements. Finally, we also used unpaired t tests to compare the pre- and postintervention changes in thigh fat and muscle of each MRI section between the control and training groups.

RESULTS

Cross-sectional analysis

Height, weight, body mass index, and variables of adiposity are summarized for the study sample in **Table 1**. There were no significant differences that could be attributed to ethnicity by ANOVA.

Hypothesis 1

Fitness expressed as $\dot{V}O_2$max/kg was inversely correlated with skinfold-thickness and MRI indexes of relative adiposity (**Table 2** and **Figure 2**). Qualitatively different results were obtained when we used fitness expressed as $\dot{V}O_2$max normalized to muscle mass. $\dot{V}O_2$max normalized to thigh muscle

TABLE 1
Weight, height, BMI, and indexes of relative adiposity in the study sample[1]

	Asian ($n = 25$)	White ($n = 11$)	Hispanic ($n = 8$)	All subjects ($n = 44$)
Weight (kg)	56.0 ± 1.5	64.8 ± 4.8	58.9 ± 5.4	58.3 ± 1.7
Height (cm)	160.7 ± 0.9	161.7 ± 2.0	159.5 ± 1.6	160.7 ± 0.7
BMI (kg/cm²)	21.7 ± 0.5	24.6 ± 1.5	23.1 ± 2	22.5 ± 0.6
Body fat (%)[2]	28.7 ± 0.8	32.1 ± 1.5	30.3 ± 2.2	29.8 ± 0.7
SAAT (%)	37.0 ± 1.9	45.0 ± 3	42.9 ± 4.6	40.1 ± 1.6
IAAT (%)	7.4 ± 0.6	4.8 ± 0.5	7.0 ± 0.5	6.8 ± 0.4
TAAT (%)	43.9 ± 2.2	49.2 ± 3.9	50.9 ± 5.0	46.2 ± 1.8
Thigh fat (%)	42.3 ± 1.4	46.8 ± 2.2	46.2 ± 2.2	44.2 ± 1.1

[1] $\bar{x}$ ± SEM. SAAT, subcutaneous abdominal adipose tissue; IAAT, intraabdominal adipose tissue; TAAT, total abdominal adipose tissue.

[2] Derived from skinfold-thickness measurements.

volume did not correlate with any of these variables of adiposity. Analysis of principal components derived from the skinfold-thickness and MRI measures produced similar results as did the partial correlations adjusted for ethnicity.

Multiple-linear-regression analysis of $\dot{V}O_2$max as a function of body weight and indexes of adiposity (SAAT, IAAT, TAAT, thigh fat, and skinfold thicknesses) revealed only two significant relations: a positive one for body weight ($r = 0.53$, $P < 0.05$) and a negative one for thigh fat ($r = -0.32$, $P < 0.05$). When we included muscle volume in the model, only muscle volume was positively correlated with $\dot{V}O_2$max ($r = 0.6$, $P < 0.01$), and there were no negative effects of adiposity. Finally, the scaling factor relating $\dot{V}O_2$max to muscle mass was 0.91 ± 0.13, which was not significantly different from 1.0.

Hypothesis 2

The regression equations for the relations between body weight and percentage thigh fat, %SAAT, and %TAAT were as follows:

Thigh fat (%) = 0.29 × weight + 27.0 ($r = 0.47, P < 0.005$)   (1)

SAAT (%) = 0.72 × weight − 2.1 ($r = 0.75, P < 0.0005$)   (2)

TAAT (%) = 0.74 × weight + 2.6 ($r = 0.69, P < 0.0005$)   (3)

Note that the relations between weight and either %SAAT or %TAAT were virtually interchangeable. As noted in Table 1, %IAAT was quite small, thus, it is not surprising that %SAAT appears to be the dominant variable when considering abdominal adiposity. The slope of the regression equation for percentage thigh fat and body weight differed significantly from the slopes for %SAAT and body weight and %TAAT and body weight ($P < 0.05$).

Scaling factors relating body weight to variables of adiposity are shown in **Table 3**. The scaling factors for TAAT and thigh fat as absolute values were similar. However, the scaling factor for percentage thigh fat was significantly less than the scaling factor for %TAAT. This finding prompted us to examine the relation between muscle volume and fat volume within the thigh. Linear regression of the ratio of thigh muscle to thigh fat volume as a function of body weight is shown in **Figure 3**. The ratio decreased significantly as weight increased in the sample population.

Comparison of skinfold thicknesses and MRI assessment of body fat

Percentage body fat derived from skinfold thicknesses was significantly correlated with %SAAT ($r = 0.81, P < 0.0005$) and percentage thigh fat ($r = 0.47, P < 0.005$). To avoid the possible confounding effect of the equations used to derive percentage body fat from skinfold-thickness measurements, we also correlated the sum of the skinfold thicknesses with the MRI-derived estimates of fat. The correlation coefficient for sum of skinfold thicknesses and SAAT was $r = 0.72$ ($P < 0.0001$) and for sum of skinfold thicknesses and thigh fat was $r = 0.74$ ($P < 0.0001$). Percentage thigh fat was correlated with %SAAT ($r = 0.65$, $P < 0.0005$), and the correlation between thigh fat volume and SAAT was $r = 0.81$ ($P < 0.0001$). Finally, note that IAAT was only correlated with SAAT ($r = 0.41$, $P < 0.003$).

TABLE 2
Individual correlation coefficients for fitness expressed either as maximal oxygen consumption per kilogram body weight or as maximal oxygen consumption per muscle volume as a function of indexes of relative adiposity[1]

	$\dot{V}O_2$max normalized to body weight (mL · min⁻¹ · kg⁻¹)		$\dot{V}O_2$max normalized to muscle volume (mL · min⁻¹ · cm⁻³)	
	r	P	r	P
Body fat (%)[2]	−0.43	<0.02	0.02	NS
SAAT	−0.47	<0.005	0.05	NS
IAAT	−0.14	NS	−0.17	NS
TAAT	−0.46	<0.005	0.01	NS
Thigh fat (%)	−0.57	<0.002	0.06	NS

[1] SAAT, subcutaneous abdominal adipose tissue; IAAT, intraabdominal adipose tissue; TAAT, total abdominal adipose tissue.

[2] Derived from skinfold-thickness measurements.
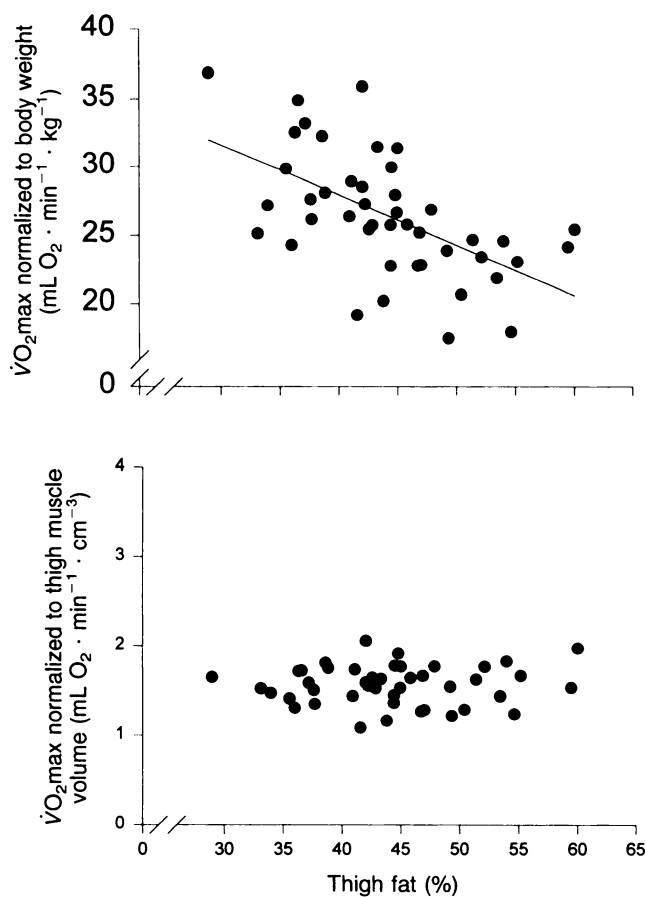
FIGURE 2. Cross-sectional relation between mean percentage thigh fat assessed by magnetic resonance imaging and fitness determined by maximal oxygen consumption ($\dot{V}O_2$max) normalized to body weight ($r = -0.57$, $P < 0.002$) and $\dot{V}O_2$max normalized to thigh muscle volume ($r = 0.06$, NS). Size-independent components of $\dot{V}O_2$max were not related to adiposity.

FIGURE 3. Ratio of thigh muscle volume to thigh fat volume as a function of body weight in 44 healthy adolescent females. The regression equation was $y = -0.029x + 4.19$ ($r = -0.45$, $P < 0.005$).

Anthropometric measurements

Changes in the sum of skinfold thicknesses and in percentage body fat derived from skinfold thicknesses were observed in both the control and training groups over the course of the intervention. The sum of skinfold thicknesses decreased in the control group (from 60.6 ± 4.2 to 54.3 ± 3.2 mm, $P < 0.005$) and in the training group (from 74.6 ± 5.4 to 64.3 ± 4.4 mm, $P < 0.05$). Percentage body fat derived from skinfold thicknesses decreased only in the control group (from 28.7 ± 0.9% to 27.0 ± 0.8%, $P < 0.005$).

MRI of abdominal fat

There were no significant differences in %SAAT between the control (37.9 ± 2.3%) and training (42.3 ± 2.2%) groups before the training intervention. No significant differences in %SAAT were observed in either group after the intervention: 37.8 ± 2.3% and 42.3 ± 2.3% in the control and training groups, respectively. There were no significant differences in %IAAT between the control (6.6 ± 0.4%) and training (7.1 ± 0.5%) groups before the training intervention. No significant differences in %IAAT were observed in either group after the intervention (6.8 ± 0.5% and 7.4 ± 0.5% in the control and training groups, respectively).

MRI of thigh musculature

There were no significant differences in thigh muscle cross-sectional area between the control and training groups at the beginning of the study. Training led to significant increases in thigh muscle cross-sectional area only in the midregion of the thigh muscle [MRI serial sections 7–15 (Figure 1 and **Figure 4**), $P < 0.003$ per measurement]. No significant changes were found in the muscle margins (Figure 4). The within-group comparisons were corroborated by between-group comparisons for each magnetic resonance section.

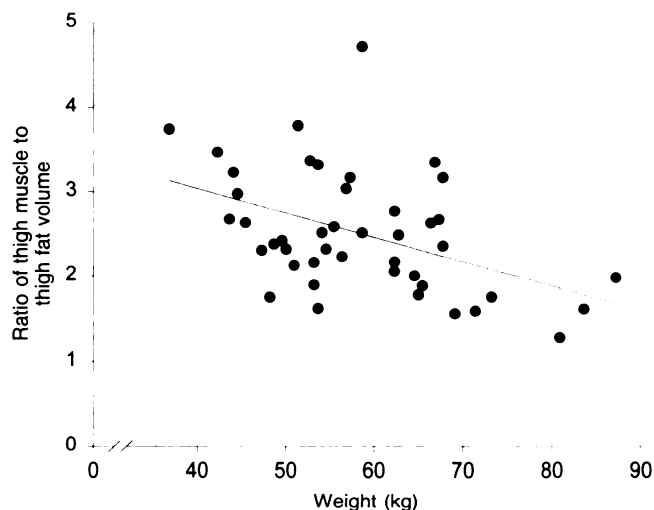## Prospective interventional study

Sample population

Before the training intervention, there were no significant differences in weight between the subjects randomly assigned to the control and training groups. There were no significant changes in weight in either group after the study period.

TABLE 3

Scaling factors (b) for the equation $y = a \times M^b$, where y is a variable of adiposity and M is body weight[1]

	Scaling factor	
	Absolute value	Relative value
	cm^2	%
SAAT	1.63 ± 0.25	1.14 ± 0.16
IAAT	0.37 ± 0.35	−0.11 ± 0.3
TAAT	1.48 ± 0.24	0.99 ± 0.16
Thigh fat	1.41 ± 0.13	0.38 ± 0.12

[1] $\bar{x}$ ± SEM. SAAT, subcutaneous abdominal adipose tissue; IAAT, intraabdominal adipose tissue; TAAT, total abdominal adipose tissue.

MRI of thigh fat

There was no significant difference in thigh fat volume between the control and training groups before the training
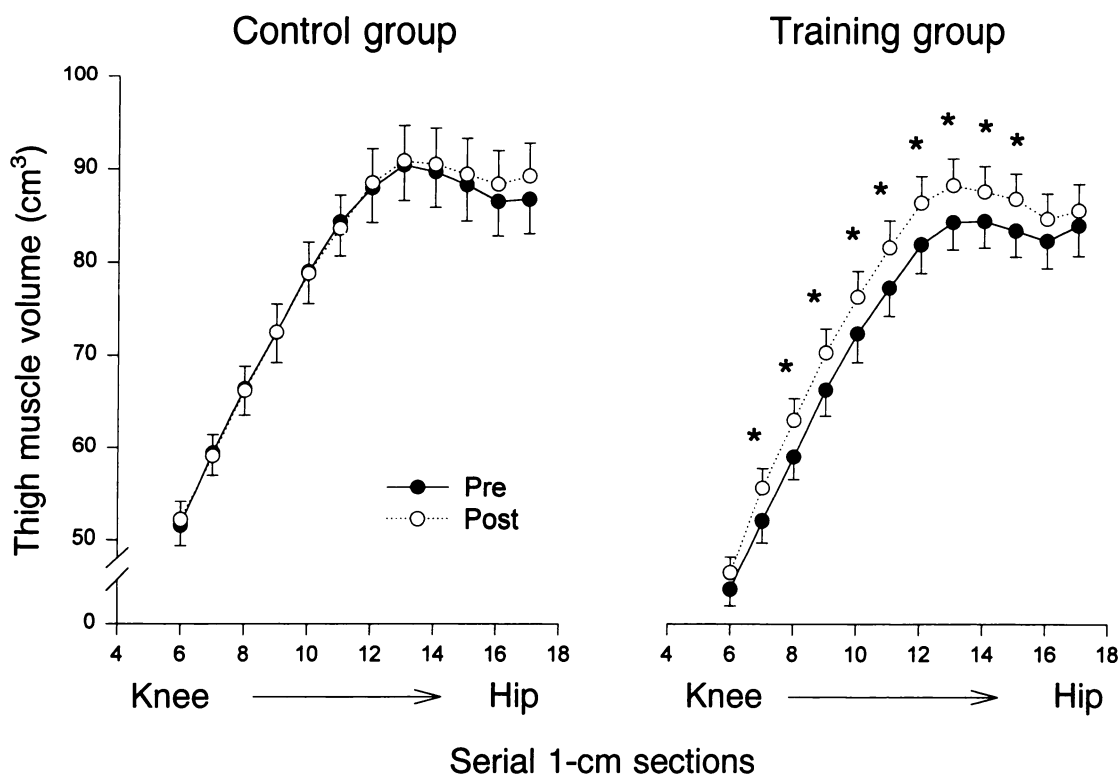
FIGURE 4. Thigh muscle volume before and after the 5-wk study period in control subjects and in the training group. Training-induced increases in thigh muscle volume occurred in the central parts of the thigh muscle (magnetic resonance imaging serial sections 7–15).

program (795 ± 65 and 883 ± 48 cm³, respectively). There were no significant changes in thigh fat volume between the control and training groups after the course (807 ± 67 and 902 ± 53 cm³, respectively), and no significant differences between the groups.

Although there was no significant change in percentage thigh fat after the training program in the training group, there was a significant increase in percentage fat in the distal thigh (MRI serial sctions 6–10, $P < 0.003$) in the control subjects at the end of the study period (**Figure 5**). The within-group comparisons were corroborated by between-group comparisons for each magnetic resonance section.

DISCUSSION

Cross-sectional studies

Differences among ethnic groups

Previous investigators noted differences in body composition among ethnic groups (17). It was not a goal of this study to examine these differences, and, indeed, our sample population was not selected a priori with any consideration of ethnicity. Although differences in the mean values among the three ethnic groups represented were found (Table 1), they were not significant. Moreover, partial correlations adjusted for ethnicity did not show significant differences in the relation between fitness and indexes of adiposity. Perhaps future studies designed specifically to examine issues of fitness and adiposity in the context of ethnicity might show significant relations.

Relation between body fat and fitness

We found that $\dot{V}O_2$max normalized to body weight was inversely correlated with percentage body fat estimated either by skinfold-thickness measurements or MRI. However, variability in the relative proportion of fat and muscle can confound the determination of fitness when $\dot{V}O_2$max is normalized to body weight. This is because $\dot{V}O_2$max is determined primarily by the metabolically active exercising muscle whereas body weight includes both muscle and fat [eg, the indirect evidence of Davies et al (21) from the early 1970s]. Indeed, we showed previously in children and adolescents that many obese children were as fit as nonobese children even when $\dot{V}O_2$max/kg in some of the obese subjects was low (22).

It is useful to consider at least two separate components of fitness: muscle size–dependent and muscle size–independent factors. In the former, training-induced increases in measurements like $\dot{V}O_2$max are mediated by increases in muscle mass; in the latter, increases result from other factors such as greater muscle tissue capillary or mitochondrial density, alterations in muscle fiber type, or both. Muscle size–dependent and muscle size–independent factors were shown in this sample population in whom training led to an increase in thigh muscle mass of ≈4% but to a significantly greater (12%) increase in $\dot{V}O_2$max (7).

One interpretation of the present finding [and the findings of other investigators (23)] of a decrease in $\dot{V}O_2$max/kg with increasing adiposity (Table 2, Figure 2) is that the proportion of muscle was smaller in heavier individuals. But measurements of muscle size (specifically of muscle groups activated by cycle
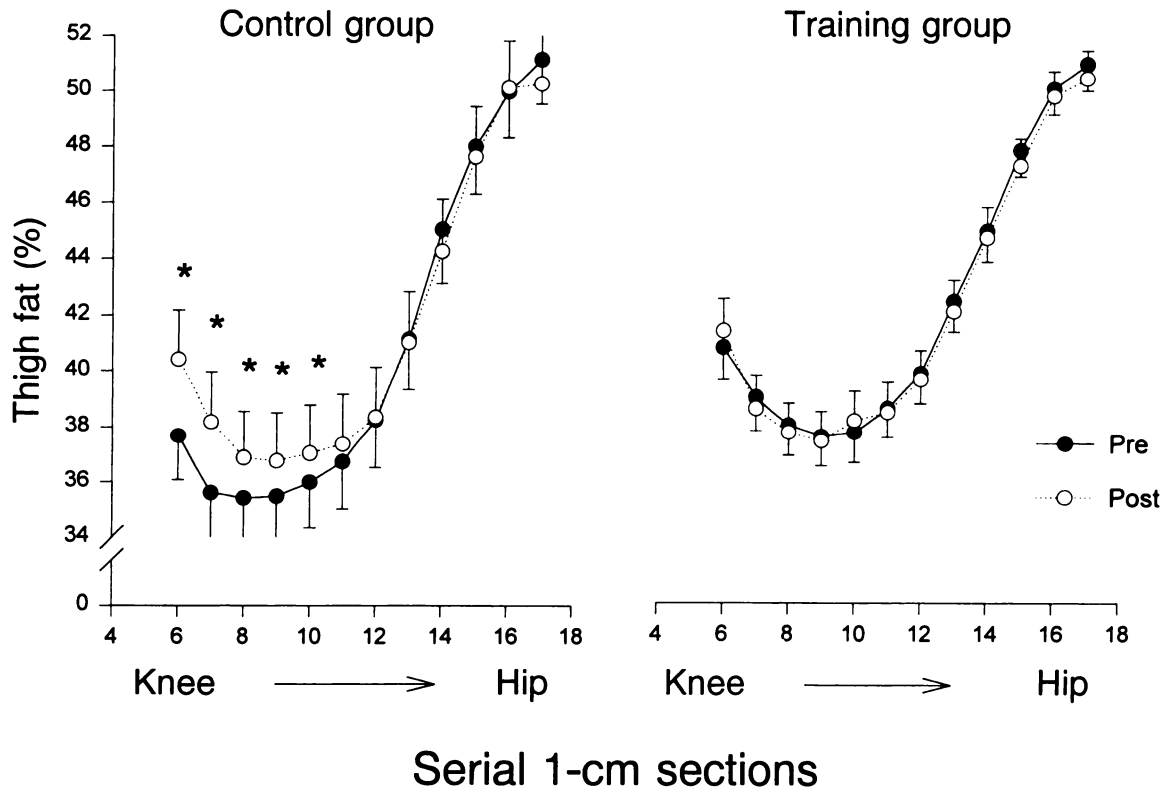
FIGURE 5. Percentage thigh fat before and after the 5-wk study period in control subjects and in the training group. Training prevented the significant increase in distal thigh fat (magnetic resonance imaging serial sections 6–10) that was observed in the control group.

ergometer exercise) have not been readily available. An advantage of using MRI data in the present study was that muscle volume could be estimated, and we found that there was no correlation between $\dot{V}O_2max$ normalized to muscle mass and relative fatness (both abdominal and thigh) (Table 2, Figure 2). Moreover, $\dot{V}O_2max$ scaled directly (ie, a scaling factor not different from 1.0) with muscle volume in this population. This suggested to us that the muscle size–independent components of $\dot{V}O_2max$ were not related to fatness in the study population.

The decrease in $\dot{V}O_2max/kg$ with increasing fatness that we observed occurred because the proportion of muscle volume to fat volume in the thigh decreased as weight increased (Figure 3). This finding was corroborated by the multiple-linear-regression analysis identifying only thigh fat as a negative determinant of $\dot{V}O_2max$. But care must be exercised in extrapolating our data to truly obese populations. In obese populations, psychosocial or mechanical factors might lead to profound physical inactivity and a consequent reduction in muscle size–independent components of fitness; therefore, we speculate that the relation between muscle volume and $\dot{V}O_2max$ would be different from what we found in basically healthy, nonobese adolescent females.

Adiposity and body weight

Both thigh fat and abdominal fat (TAAT and SAAT) were significantly correlated with body weight. This in and of itself was not surprising (bigger people are likely to have more muscle, fat, bone, etc, in absolute terms); however, what is important is to determine the changes in relative adiposity as a function of body size. Linear-regression and allometric analy-

sis showed that the relative adiposity of the thigh and abdomen increased with body weight.

However, we found that as body weight increased in a population of healthy adolescent girls, the proportional increase in central fat was substantially greater than the proportional increase in thigh fat. The concepts of gynecoid versus android obesity are used to distinguish between sex-related peripheral and central patterns of weight gain characteristic of adult populations (24). Our data suggest that within this sample of adolescent females, overall weight gain was associated with greater relative increases in central than in thigh fat.

The mechanisms that determine patterns of fat distribution are not known; however, centrally located fat seems to be a fairly strong indicator of metabolic abnormalities such as hyperlipidemias and insulin resistance (24, 25). Recent studies (26), however, identified IAAT as the strongest predictor of coronary artery risk factors (eg, hypercholesterolemia, hypertension, and insulin resistance) in obese adolescent females. In our study of mostly nonobese subjects, the increase in %TAAT with body weight was due primarily to the increase in SAAT. This lack of a relation between body weight and IAAT may have been due to the difficulty in making this measurement, due to the relatively small proportion of IAAT in our population of relatively nonobese subjects. From a methodologic perspective, IAAT (both absolute and as a percentage) was correlated with SAAT; perhaps SAAT may also prove to be an indicator of greater risk for obesity, metabolic abnormalities, hypertension, and consequently heart disease later in life.

Prospective interventional study

Our analysis of individual serial sections of the thigh showed that the previously reported increase in total muscle volume occurred primarily in the central parts of the thigh muscle (7) (Figure 4). This finding corroborates the findings of studies by Roman et al (8), who focused on biceps training in elderly men, in which the response to training was most marked in the midmuscle. Thus, although the midmuscle seems to be the most sensitive, measurements from this site alone may overestimate training-induced changes in total muscle volume.

The mechanisms responsible for this particular anatomic distribution of muscle in response to training are not fully known, but probably result from both biomechanical and developmental factors. The midmuscle is the least constrained part of the muscle (ie, farthest from attachment to bones and joints); hence, hypertrophy would be expected to be greatest in this location. Whether or not the response of growth factors to training is spatially regulated within a muscle is not currently known.

In contrast with the prediction of our third hypothesis, total thigh fat volume (measured by MRI) was not affected significantly by 5 wk of training. However, qualitatively different results were obtained when we examined individual thigh sections by MRI. We found that the proportion of fat in the distal thigh increased significantly in the control group but not in the training group (Figure 5). We speculate that the training intervention prevented the gain in distal thigh fat that was observed in control subjects during the summer vacation. Perhaps the increase in distal thigh fat in the control subjects resulted from generally reduced daily physical activity in the summer months compared with that during the regular school term.

Comparison between skinfold thicknesses and MRI determinations

Our data shed additional light on the comparison between MRI and skinfold-thickness assessments of body composition. First, we noted a strong correlation between percentage body fat derived from the sum of skinfold-thickness measures and from MRI measurements of abdominal fat. To our knowledge, this particular comparison has not been made by other investigators; however, MRI and skinfold-derived variables have been generally well correlated in other studies. For example, Ross et al (27) found significant relations between subcutaneous abdominal fat cross-sectional area (determined by serial magnetic resonance images at the level of L4-L5) and single-site skinfold-thickness measurements ($r = 0.80$ and 0.85 for the subscapular and triceps, respectively).

In contrast with the strong correlation between percentage body fat (derived from skinfold thickness) and %SAAT, percentage body fat (derived from skinfold thickness) was not as strongly correlated with percentage thigh fat. The lower r value for this comparison may reflect discrepancies in fat distribution between upper-body (skinfolds) and lower-body measurements (thigh). Moreover, as our data showed, the proportion of fat in different parts of the thigh did not change uniformly (eg, increases were found only in the distal thigh fat over the 5-wk period of observation in the control subjects). Among the different methods used for assessment of body fat, MRI is one

that provides sufficient discrimination to detect localized anatomic changes in muscle or fat.

There were many discrepancies between MRI and skinfold-thickness measurements of adiposity. For example, we were surprised to find that the sum of skinfold thicknesses decreased in both the control and training groups, suggesting a loss in body fat, whereas the MRI assessment of abdominal fat showed no significant changes. We have no explanation for this discrepancy. Bias on the part of the individual performing the skinfold-thickness measurements pre- and posttraining is a possibility, although the technician was not aware of the subject's group at the time of measurement. One problem is that there are no universally accepted sites in children in which to take skinfold-thickness measurements. Indeed, Malina et al (17) strongly suggest that measurements be made in at least one lower extremity site to differentiate between upper- and lower-body fat and to distinguish between central and peripheral fat. Had we used this approach, perhaps the observed discrepancies between MRI and skinfold-thickness assessments would not have been as great. Finally, note that many investigators have questioned the accuracy of the skinfold-thickness techniques for following changes in body composition that occur over relatively short periods of time (28, 29).

In summary, this analysis of abdominal fat, thigh fat, and fitness in adolescent females showed that the distribution of body fat appeared to be affected by many factors, including overall body weight and level of physical activity. Indeed, the decrease in relative fitness with increased adiposity was related to muscle size–dependent rather than to muscle size–independent components of fitness. A brief training intervention increased midmuscle cross-sectional area and prevented the increase in percentage distal thigh fat that was observed in the control subjects. Previous investigators suggested that the increase in obesity observed in adolescent females appears to be related more to decreased physical activity than to an increase in fat intake (30, 31). This observation, along with the results of the present study, tend to substantiate the beneficial role that exercise may play in the long-term health status of adolescent females.   ▓

REFERENCES

1. Malina RM, Beunnen GP, Classens AL, et al. Fatness and physical fitness of girls 7–17 years. Obes Res 1995;3:221–31.
2. Pivarnik JM, Fulton JE, Taylor WC, Snider SA. Aerobic capacity in black adolescent girls. Res Q Exerc Sport 1993;64:202–7.
3. Mullins AJ. The prognosis in juvenile obesity. Arch Dis Child 1958;33:307–14.
4. Poskitt EME. The fat child. In: Brook CGD, ed. Clinical paediatric endocrinology. 3rd ed. Cambridge, United Kingdom: Blackwell Science, Ltd, 1995:210–33.
5. Centers For Disease Control and Prevention. Vigorous physical activity among high school students—United States, 1990. MMWR Morb Mortal Wkly Rep 1992;41:33–5.
6. Alexander HG, Dugdale AE. Fascial planes within subcutaneous fat in humans. Eur J Clin Nutr 1992;46:903–6.
7. Eliakim A, Barstow TJ, Brasel JA, et al. The effect of exercise training on energy expenditure, muscle volume, and maximal oxygen uptake in adolescent females. J Pediatr 1996;129:537–43.
8. Roman WJ, Fleckenstein J, Stray-Gundersen J, Alway SE, Peshock R,

Gonyea WJ. Adaptations in the elbow flexors of elderly males after heavy-resistance training. J Appl Physiol 1993;74:750–4.

9. Brook CGD. Determination of body composition of children from skinfold measurements. Arch Dis Child 1971;46:182–4.

10. Durnin JVGA, Rahaman MM. The assessment of the amount of fat in the human body from measurements of skinfold thicknesses. Br J Nutr 1967;21:681–3.

11. Parkkola R, Kujala U, Rytokoski U. Response of the trunk muscles to training assessed by magnetic resonance imaging and muscle strength. Eur J Appl Physiol 1992;65:383–7.

12. Abate N, Burns D, Peshock RM, Garg A, Grundy SM. Estimation of adipose tissue mass by magnetic resonance imaging: validation against dissection in human cadavers. J Lipid Res 1994;35:1490–6.

13. Engstrom CM, Loeb GE, Reid JR, Forrest WJ, Avruch L. Morphometry of the human thigh muscles: a comparison between anatomical sections and computer tomographic and magnetic resonance images. J Anat 1991;176:139–56.

14. Beaver WL, Lamarra N, Wasserman K. Breath-by-breath measurement of true alveolar gas exchange. J Appl Physiol 1981;51:1662–75.

15. Cooper DM, Weiler-Ravell D, Whipp BJ, Wasserman K. Aerobic parameters of exercise as a function of body size during growth in children. J Appl Physiol 1984;56:628–34.

16. Cooper DM. Development of the oxygen transport system in normal children. In: Bar-Or O, ed. Advances in pediatric sport sciences: biological issues. Vol 3. Champaign, IL: Human Kinetics Books, 1989:67–100.

17. Malina RM, Huang YC, Brown KH. Subcutaneous adipose tissue distribution in adolescent girls of 4 ethnic groups. Int J Obes 1995;19:793–7.

18. Edwards AL. An introduction to linear regression and correlation. San Francisco: WH Freeman and Co, 1976.

19. Gould SJ. Allometry and size in ontogeny and physiology. Biological reviews of the Cambridge Philosophical Society 1966;41:587–640.

20. Sjodin B, Svedenhag J. Oxygen uptake during running as related to body mass in circumpubertal boys: a longitudinal study. Eur J Appl Physiol 1992;65:150–7.

21. Davies CTM, Barnes C, Godfrey S. Body composition and maximal exercise performance in children. Hum Biol 1972;44:195–214.

22. Cooper DM, Poage J, Barstow TJ, Springer C. Are obese children truly unfit? Minimizing the confounding effect of body size on the exercise response. J Pediatr 1990;116:223–30.

23. Rowland TW. Effects of obesity on aerobic fitness in adolescent females. Am J Dis Child 1991;145:764–8.

24. Walton C, Lees B, Crook D, Worthington M, Godsland IF, Stevenson JC. Body fat distribution, rather than overall adiposity, influences serum lipids and lipoproteins in healthy men independently of age. Am J Med 1995;99:459–64.

25. Gutin B, Islam S, Manos T, Smith C, Cucuzzo C, Stachua M. Relations of percentage of body fat and maximal aerobic capacity to risk factors of atherosclerosis and diabetes in black and white 7–11 year-old children. J Pediatr 1994;125:847–52.

26. Caprio S, Hyman LD, McCarthy S, Lange R, Bronson M, Tamborlane WV. Fat distribution and cardiovascular risk factors in obese adolescent girls: importance of the intraabdominal fat depot. Am J Clin Nutr 1996;64:12–7.

27. Ross R, Leger L, Morris D, De Guise J, Guardo R. Quantification of adipose tissue by MRI: relationship with anthropometric variables. J Appl Physiol 1992;72:787–95.

28. Katch FI, Hortobagyi T. Validity of surface anthropometry to estimate upper-arm muscularity, including changes with body mass loss. Am J Clin Nutr 1990;52:591–6.

29. Young A, Stokes M, Round JM, Edwards RHT. The effect of high-resistance training on the strength and cross-sectional area of the human quadriceps. Eur J Clin Invest 1983;13:411–7.

30. Schlicker SA, Borra ST, Regan C. The weight and fitness status of United States children. Nutr Rev 1994;52:11–7.

31. Sallis JF. Epidemiology of physical activity and fitness in children and adolescents. Crit Rev Food Sci Nutr 1993;33:403–8.