

## Muscle fiber type is associated with obesity and weight loss

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**Tanner, Charles J., Hisham A. Barakat, G. Lynis Dohm, Walter J. Pories, Kenneth G. MacDonald, Paul R. G. Cunningham, Melvin S. Swanson, and Joseph A. Houmard.** Muscle fiber type is associated with obesity and weight loss. *Am J Physiol Endocrinol Metab* 282: E1191–E1196, 2002. First published December 18, 2001; 10.1152/ajpendo.00416.2001.—The purpose of this study was to test the hypothesis that muscle fiber type is related to obesity. Fiber type was compared 1) in lean and obese women, 2) in Caucasian (C) and African-American (AA) women, and 3) in obese individuals who lost weight after gastric bypass surgery. When lean (body mass index  $24.0 \pm 0.9$  kg/m<sup>2</sup>,  $n = 28$ ) and obese ( $34.8 \pm 0.9$  kg/m<sup>2</sup>,  $n = 25$ ) women were compared, there were significant ( $P < 0.05$ ) differences in muscle fiber type. The obese women possessed fewer type I ( $41.5 \pm 1.8$  vs.  $54.6 \pm 1.8\%$ ) and more type IIb ( $25.1 \pm 1.5$  vs.  $14.4 \pm 1.5\%$ ) fibers than the lean women. When ethnicity was accounted for, the percentage of type IIb fibers in obese AA was significantly higher than in obese C ( $31.0 \pm 2.4\%$  vs.  $19.2 \pm 1.9\%$ ); fewer type I fibers were also found in obese AA ( $34.5 \pm 2.8\%$  vs.  $48.6 \pm 2.2\%$ ). These data are consistent with the higher incidence of obesity and greater weight gain reported in AA women. With weight loss intervention, there was a positive relationship ( $r = 0.72$ ,  $P < 0.005$ ) between the percentage of excess weight loss and the percentage of type I fibers in morbidly obese patients. These findings indicate that there is a relationship between muscle fiber type and obesity.

adiposity; African-American; insulin resistance; morbid obesity; skeletal muscle

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SKELETAL MUSCLE IS A HETEROGENEOUS organ consisting of different muscle fiber phenotypes. In human skeletal muscle, histochemical staining for pH-sensitive myosin ATPase activity has revealed two major classifications of fiber type, the type I and type II fibers (3, 28, 31). The fast-twitch, type II fibers can be broadly categorized into type IIa and type IIb fibers, although other subclasses exist (3, 29, 31). The type I, or slow-twitch, muscle fibers tend to be oxidative and vascularized, whereas the type IIb fibers (fast twitch) are glycolytic

in nature (28, 31). The type I fibers are also insulin sensitive compared with type II muscle (8, 13, 17).

In humans, there can be substantial heterogeneity of muscle fiber types within a given mixed muscle group. Simoneau and Bouchard (32) concluded that, in the vastus lateralis,  $\geq 25\%$  of the North American Caucasian population possessed either less than 35% or more than 65% type I fibers; a range of 13–98% type I fibers has been reported (31). Several factors may be linked with such variance. We have observed that obese individuals exhibit fewer type I and more type IIb muscle fibers than lean subjects (9). Other research has reported a negative relationship between adiposity and the relative percentage of type I muscle fibers (9, 21, 36) and an increased percentage of type IIb muscle fibers in patients with type 2 diabetes (9, 23), in their insulin-resistant offspring (27), and in obese subjects (18, 19, 21, 23). Such findings make it tempting to speculate that there is a relationship between muscle fiber composition and obesity.

The purpose of the current study was to test the hypothesis that muscle fiber type is related to obesity. We tested this hypothesis in several ways. First, muscle fiber type in obese and lean women was compared. Second, current statistics indicate that, in the United States, African-American women have an increased prevalence of obesity, are more insulin resistant, exhibit a reduced ability to oxidize fat, and have twice the incidence of type 2 diabetes compared with Caucasian women (2, 4, 10, 14, 20–22, 25). If obesity is related to muscle fiber type, obese African-American women would be expected to possess fewer type I fibers than their Caucasian counterparts. Finally, obese individuals often exhibit a propensity for relatively minimal weight loss with intervention and/or are prone to weight recidivism (15, 25, 29, 37). This may be a function of a hampered ability of skeletal muscle to oxidize lipid (15), which could be linked with a reduced prevalence of type I muscle fibers. We therefore determined whether muscle fiber composition correlates with the

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ability to decrease body mass with weight loss intervention.

## METHODS

**Study design and subjects.** Subjects were women undergoing elective abdominal surgery (hysterectomy or gastric bypass). Body mass, stature, ethnicity, and age were recorded as part of preoperative procedures. Subjects were categorized into groups on the basis of ethnicity (Caucasian, African-American) and obesity status. During surgery, a biopsy of the rectus abdominus was obtained for subsequent fiber type analyses. All procedures were approved by the University Review Board, and informed consent was obtained before any procedures. Some of the morbidly obese subjects who underwent gastric bypass surgery were also examined ~12 mo after surgery, when they were weight stable (29). Mass and stature were obtained, and the decrease in body mass and body mass index (BMI) and proximity to ideal weight (29) were calculated.

**Fiber type.** Muscle fiber type was determined with methods previously utilized in this laboratory (9). Briefly, a section (20–50 mg) of the rectus abdominus was teased off and mounted in an OCT/trigacanth gum mixture. The mounted muscle was frozen in isopentane cooled over liquid nitrogen. Muscle was sectioned in 10- $\mu$ m slices and stained for ATPase activity at a pH of 4.54 and 10.9 (3). This pH range permitted the distinction of types I, IIa, and IIb fibers (3). The individuals counting the fibers had no knowledge of the nature of the subjects (i.e., race, obesity status).

**Weight loss.** Some of the subjects were morbidly obese (>100 lbs over ideal body weight) women undergoing gastric bypass surgery to induce weight loss (29). To examine the relationship between muscle fiber type and weight loss, body mass was obtained at a postoperative clinical visit ~12 mo after the surgery. The relationship between the change in body mass with intervention and muscle fiber composition at the time of surgery was determined.

**Statistics.** Factorial analysis of variance (ANOVA) was used to compare muscle fiber characteristics between the groups according to either obesity or ethnicity. A  $2 \times 2$  factorial ANOVA was used to test for an interaction between obesity and ethnicity. Contrast comparisons were used to determine the specific difference when a significant interaction was obtained. Repeated-measures ANOVA was used to test for differences with weight loss intervention. Pearson correlation coefficients were performed to examine the relationship between muscle fiber type and weight loss. Interpretation was similar when the data were compared with non-parametric methods. Statistical significance was denoted at the  $P \leq 0.05$  level.

## RESULTS

**Subjects.** BMI and age are presented in Table 1. By group, subjects were lean African-American ( $n = 8$ ), obese African-American ( $n = 11$ ), lean Caucasian ( $n = 20$ ), or obese Caucasian ( $n = 14$ ). Mean data for the population were, for age,  $41.4 \pm 0.9$  yr; for BMI,  $28.8 \pm 0.9$  kg/m<sup>2</sup>; for type I fibers,  $48.9 \pm 1.6\%$ ; for type IIa fibers,  $32.2 \pm 1.1\%$ ; and for type IIb fibers,  $18.9 \pm 1.4\%$ . The majority of the women ( $n = 51$ ) in this population were undergoing hysterectomy surgery. Subjects undergoing gastric bypass surgery were classified as morbidly obese (BMI >40 kg/m<sup>2</sup> or >45.5 kg over ideal body weight).

Table 1. Age and body mass index for subjects

Group	Age, yr	BMI, kg/m <sup>2</sup>
African-American		
Lean ( $n = 8$ )	$41.3 \pm 2.3$	$25.4 \pm 1.3^*$
Obese ( $n = 11$ )	$42.3 \pm 2.3$	$33.3 \pm 1.3$
Caucasian		
Lean ( $n = 20$ )	$42.0 \pm 1.6$	$24.1 \pm 0.9^*$
Obese ( $n = 14$ )	$39.9 \pm 1.8$	$34.6 \pm 1.1$

Values are means  $\pm$  SE;  $n$ , no. in group. BMI, body mass index. \*Significantly different ( $P < 0.05$ ) from obese subjects within that racial group.

**Muscle fiber type and obesity.** Mean BMI values for the lean and obese groups, regardless of ethnicity, are presented in Fig. 1. The obese subjects had a significantly ( $P < 0.001$ ) higher BMI than the lean group ( $24.0 \pm 0.9$  vs.  $34.8 \pm 0.9$  kg/m<sup>2</sup>; range for lean group 18.0–27.8 kg/m<sup>2</sup>; range for obese group 28.6–46.5 kg/m<sup>2</sup>). The lean subjects had a significantly ( $P < 0.001$ ) higher percentage of type I ( $54.6 \pm 1.8$  vs.  $41.5 \pm 1.8\%$ ) and a lower percentage of type IIb ( $14.4 \pm 1.5$  vs.  $25.1 \pm 1.5\%$ ) muscle fibers than the obese subjects (lean vs. obese, respectively; Fig. 1). As presented in Fig. 2, adiposity (BMI) was positively related ( $r = 0.49$ ,  $P < 0.001$ ) to the relative percentage of type IIb fibers.

**Muscle fiber type, obesity, and ethnicity.** As presented in Fig. 3, the African-American subjects possessed a significantly ( $P < 0.01$ ) lower percentage of type I muscle fibers than the Caucasians without account taken for adiposity ( $51.8 \pm 1.8$  vs.  $43.7 \pm 2.8\%$  for Caucasian vs. African-American, respectively). Conversely, the skeletal muscle of the African-American subjects contained significantly ( $P < 0.01$ ) more type IIb fibers ( $16.3 \pm 1.2$  vs.  $23.4 \pm 2.9\%$ , for Caucasian vs. African-American subjects, respectively) (Fig. 3).

There was a significant interaction between ethnicity and obesity status ( $P = 0.03$ ) when the percentages of type I muscle fibers were compared. As presented in Fig. 4, there was no difference ( $P < 0.05$ ) in the percentage of type I fibers between the lean Caucasian and African-American subjects ( $55.1 \pm 2.1$  vs.  $54.1 \pm 1.8\%$  for Caucasian vs. African-American, respectively). However, muscle from the obese African-American subjects contained significantly ( $P < 0.05$ ) fewer type I fibers than muscle of their Caucasian counterparts ( $48.6 \pm 2.2$  vs.  $34.5 \pm 2.8\%$  for Caucasian vs. African-American obese subjects, respectively) (Fig. 4). The lean African-Americans possessed significantly ( $P < 0.05$ ) more type I fibers than the obese subjects of this ethnicity. A similar result was obtained when type I fiber percentage was compared between the lean and obese Caucasians ( $P < 0.001$ ), with the lean individuals possessing more type I fibers than the obese ones.

There was a significant interaction ( $P = 0.03$ ) when the percentage of type IIb muscle fibers was compared between lean and obese Caucasians and African-Americans. As presented in Fig. 4, there was no difference ( $P < 0.05$ ) in the relative percentage of type IIb fibers between the lean Caucasian and African-American subjects ( $13.8 \pm 1.7$  vs.  $15.0 \pm 2.1\%$  for Caucasian vs.

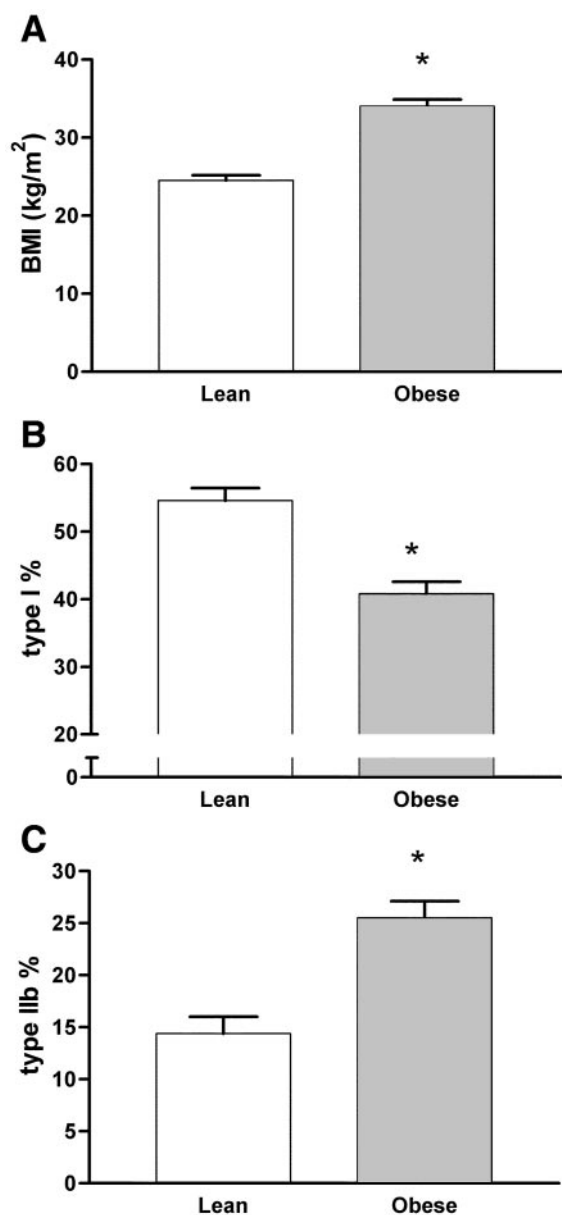


Fig. 1. Adiposity, as determined by body mass index (BMI) (A) and muscle fiber type (type I%, B; type IIb%, C) in lean ( $n = 28$ ) and obese ( $n = 25$ ) women. \*Significant difference ( $P < 0.05$ ) between lean and obese women.

African-American, respectively). Muscle from the obese African-Americans contained significantly ( $P < 0.001$ ) more type IIb fibers than muscle from their obese Caucasian counterparts ( $19.2 \pm 1.9$  vs.  $31.0 \pm 2.4\%$  for Caucasian vs. African-American, respectively) (Fig. 4). Within the African-Americans, the obese subjects possessed significantly ( $P < 0.01$ ) more type IIb fibers than the lean subjects. A similar result was obtained when type IIb fiber percentage was compared between the lean and obese Caucasians ( $P < 0.05$ ), with the obese exhibiting relatively more type IIb fibers than the lean subjects.

**Weight loss and fiber type.** Data on 14 morbidly obese subjects (10 Caucasian, 4 African-American) who un-

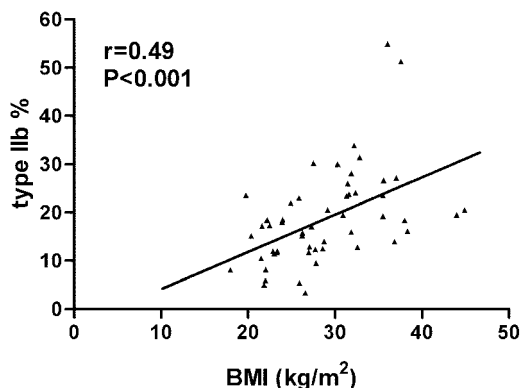


Fig. 2. Relationship between adiposity (BMI) and percentage of type IIb muscle fibers in lean and obese women.

derwent gastric bypass surgery to induce weight loss are presented. All of these women met the standards for morbid obesity, thus qualifying them for the intervention. Mean preoperative age was  $43.2 \pm 1.8$  yr. Mean preoperative mass was  $139.9 \pm 6.8$  kg, which decreased ( $P < 0.001$ ) to  $102.3 \pm 6.3$  kg ~12 mo after the intervention. Initial BMI was  $52.2 \pm 2.3$  kg/m<sup>2</sup> and decreased to  $37.8 \pm 2.2$  kg/m<sup>2</sup> after weight loss ( $P < 0.001$ ). Fiber type obtained from the rectus abdominus at the time of the surgery was for type I,  $41.1 \pm 3.1\%$ ; for type IIa,  $43.4 \pm 4.1\%$ ; and for type IIb,  $15.5 \pm 3.3\%$ . As presented in Fig. 5, there were significant and positive relationships between the relative percentage of type I muscle fibers at the time of the surgery and

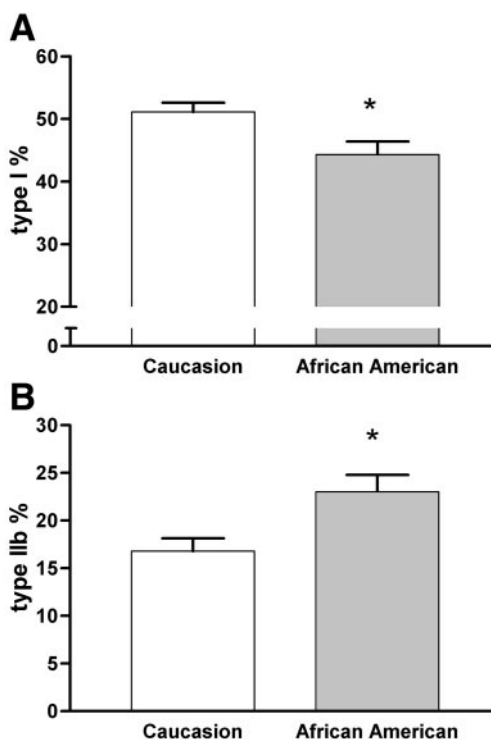


Fig. 3. Comparison of muscle fiber type (type I%, A; type IIb%, B) in Caucasian ( $n = 34$ ) and African-American ( $n = 19$ ) women. \*Significant difference ( $P < 0.05$ ) between Caucasian and African-American subjects.

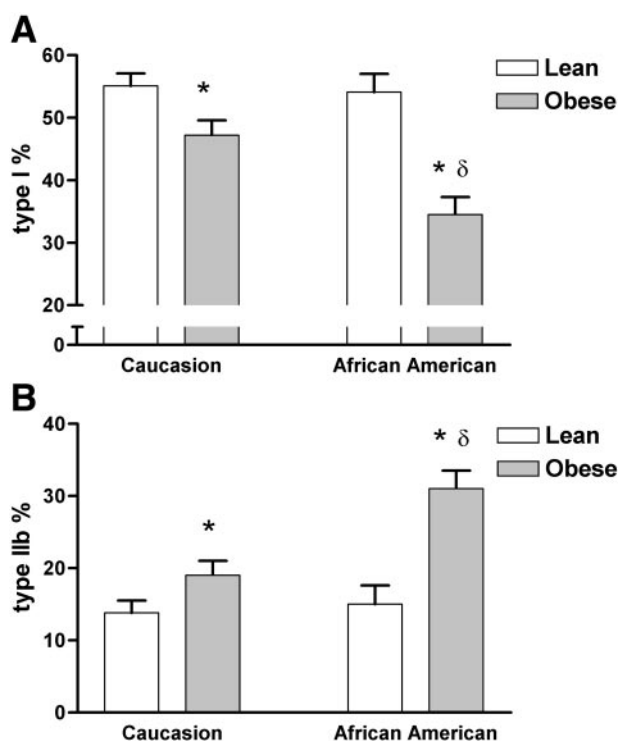


Fig. 4. Comparison of type I (A) and type IIb (B) muscle fibers in lean and obese Caucasian and African-American women. Nos. of subjects in each group: lean African American ( $n = 8$ ); obese African-American ( $n = 11$ ); lean Caucasian ( $n = 20$ ); obese Caucasian ( $n = 14$ ). \*Significant difference ( $P < 0.05$ ) between lean and obese women within that ethnic group.  $\delta$ Obese African-American group was different from all other groups ( $P < 0.05$ ).

the change in BMI ( $r = 0.55$ ,  $P < 0.05$ ) or body mass ( $r = 0.56$ ,  $P < 0.05$ ). The percentage of excess body weight lost with intervention was also related ( $r = 0.72$ ,  $P < 0.005$ ) to the initial percentage of type I muscle fibers (Fig. 5).

## DISCUSSION

The main finding of this study was a relationship between muscle fiber type and obesity. This relationship was supported by several pieces of data. First, obese women possessed a higher relative percentage of type IIb and a lower percentage of type I muscle fibers than lean controls (Figs. 1 and 2). A new finding was that muscle from obese African-American women contained a lower percentage of type I muscle fibers than comparably obese Caucasians (Fig. 4). This observation is consistent with the higher incidence of obesity and greater weight gain reported in this ethnic group and observations of insulin resistance and reduced lipid oxidation in African-Americans (2, 4, 10, 14, 20, 22, 25, 26, 37). Finally, morbidly obese women with a higher proportion of oxidative, type I muscle fibers tended to reduce body mass more substantially with weight loss intervention (Fig. 5). To our knowledge, this is the first evidence indicating a relationship between the capacity for weight loss and fiber type in morbidly obese subjects. Together, these data suggest that histochemically determined muscle fiber composi-

tion is at least partially predictive of obesity. In our laboratory, the relationship between obesity and fiber type may be a function of the inclusion of morbidly obese subjects (9); the upper ranges of obesity may need to be included to discern a fiber type/obesity relationship. Other studies have not reported a relationship between obesity and muscle fiber type (6, 33–35).

It is not clear whether the reduced percentage of type I muscle fibers developed during the course of the obese state or whether it was an intrinsic defect predisposing individuals toward obesity. Simoneau and Bouchard (32) calculated that  $\sim 45\%$  of the variance in fiber type in humans is explained by inherited factors and 40% by the environment. A factor related to heredity and lifestyle that may influence fiber type is hyperinsulinemia. Obese individuals typically exhibit elevated fasting and/or postprandial plasma insulin concentrations (25). In rodents, the inducement of hyperinsulinemia with insulin infusion resulted in an increased percentage of type IIb muscle fibers at the expense of type I fibers (11). In humans, we reported (12) an increase in myosin heavy-chain isoform IIx (IIb) mRNA after 3 h of insulin infusion. It thus cannot be discerned whether the reduced percentage of type I and increased percentages of type II and type IIb muscle fibers are a consequence of, or an inherent aspect of, the obese state.

The type II, and particularly the type IIb, phenotype is insulin resistant (8, 13, 17), which provides a poten-

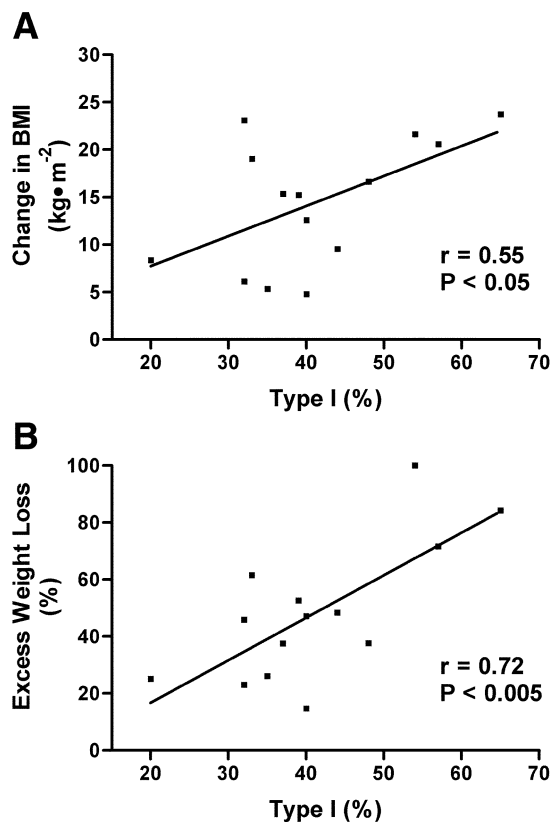


Fig. 5. Relationships between loss in BMI (A) and excess body mass (B) and the percentage of type I muscle fibers in morbidly obese gastric bypass patients  $\sim 12$  mo after surgery.

tial linkage between muscle fiber type, obesity, and insulin resistance. Type II muscle fibers are also deficient in relation to lipid disposal (6, 28). A prevalence of type II fibers may thus result in the partitioning of lipid toward storage in skeletal muscle (i.e., intramuscular triglyceride) or adipose tissue rather than oxidation within skeletal muscle, resulting in positive fat balance. In support of a relationship between fiber type and whole body lipid oxidation, Mrad et al. (24) reported that rodents that gained the most mass with high-fat feedings possessed significantly fewer type I fibers than littermates that gained little to no weight. A decrement in whole body fat oxidation has also been observed in individuals with more type II fibers (16, 36). Others have reported that skeletal muscle from obese individuals is markedly lower in terms of oxidative capacity and mitochondrial content and has an increased intracellular lipid concentration, which is linked with insulin resistance (5, 6, 15, 33, 35). However, it is not evident whether these defects associated with muscle fiber type develop during the course of the obese state or are present before the development of obesity.

Adiposity varied widely in the subjects examined in this study (Fig. 2). An interesting finding was that, despite this heterogeneity, the mean muscle fiber type for the rectus abdominus approximated 50% type I fibers ( $48.9 \pm 1.6\%$ ). Our data thus agree with other findings from the vastus lateralis (see Ref. 31) indicating that the average fiber type for most mixed muscle groups in humans is ~50% type I and 50% type II muscle fibers. The current study, however, provides the additional information that ethnicity and obesity are factors that must be considered with the examination of muscle fiber type. In relation to ethnicity, Ama et al. (1) reported an increased percentage of type II fibers in lean, African-American men compared with Caucasians. In the present study, we observed a similar racial difference (Fig. 3) in women. The predominance of type II fibers in our African-Americans compared with Caucasian-Americans, however, was primarily due to the obese individuals, as there were no differences in fiber type between lean African-American and Caucasian women (Fig. 4).

In summary, we observed a reduced percentage of type I and an increased percentage of type IIb muscle fibers in obese individuals compared with their lean counterparts. There was also a reduced percentage of type I muscle fibers in obese African-American women compared with obese Caucasian women. This correlates with the higher incidence of obesity and greater weight gain reported in African-American women. Finally, morbidly obese individuals with a greater percentage of type I muscle fibers tended to lose more body mass with weight loss intervention. These findings indicate that there is a relationship between muscle fiber type and obesity.

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