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Muscle fiber type is associated with obesity and weight loss

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Running head: Fiber type and obesity

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ABSTRACT

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 comparing lean (BMI, 24.0$\pm$0.9 kg/m^2; n=28) and obese (34.8$\pm$0.9 kg/m^2, n=25) women there were significant (P<0.05) differences in muscle fiber type. The obese women possessed less type I (41.5$\pm$1.8 vs 54.6$\pm$1.8%) and more type IIb (25.1$\pm$1.5 vs 14.4$\pm$1.5%) fibers than the lean. When accounting for ethnicity, the percentage of type IIb fibers in obese AA was significantly higher than in obese C (31.0$\pm$2.4% vs 19.2$\pm$1.9%); less type I fibers were also found in obese AA (34.5$\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 there is a relationship between muscle fiber type and obesity.

Keywords: adiposity, African American, insulin resistance, morbid obesity, skeletal muscle

INTRODUCTION

Skeletal muscle is a heterogenous 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 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, while the type IIb fibers (fast-twitch) are glycolytic in nature (28,31). The type I fibers are also insulin sensitive compared to 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 at least 25% of the North American Caucasian population possessed either less than 35% or more than 65% type I fibers; a range of 13 to 98% type I fibers has been reported (31). Several factors may be linked with such variance. We have observed that obese individuals exhibit less 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), 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 to Caucasian women (2,4,10,14,20,22,25,21).

If obesity is related to muscle fiber type, obese African American women would be expected to possess less 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 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 pre-operative procedures. Subjects were categorized into groups based upon 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 obtained prior to any procedures. Some of the morbidly obese subjects who underwent gastric bypass surgery were also examined approximately 12 mo. after surgery, when they were weight stable (29). Mass and stature were obtained and the decrease in body mass and BMI and proximity to ideal weight (29) 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 μM slices and stained for ATPase activity at a pH of 4.54 and 10.9 (3). This pH range permitted the distinction of type 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 morbidy 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 post-operative clinical visit approximately 12 months 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 Factoral analysis of variance (ANOVA) was used to compare muscle fiber characteristics between the groups according to either obesity or ethnicity. A 2 X 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 Body mass index and age are presented in Table 1. The number of subjects in each group were: lean African American (n=8); obese African American (n=11); lean Caucasian (n=20); obese Caucasian (n=14). Mean data for the population were age, 41.4 ± 0.9 y; BMI, 28.8 ± 0.9 kg/m^2; type I fibers, 48.9 ± 1.6%; type IIa fibers, 32.2 ± 1.1%; and type IIb fibers, 18.9 ± 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^2 or > 45.5 kg over ideal body weight).

Muscle fiber type and obesity Mean body mass index for the lean and obese groups, regardless of ethnicity, are presented in Figure 1. The obese subjects had a significantly ($P<0.001$) higher BMI than the lean group (24.0 ± 0.9 vs 34.8 ± 0.9 kg/m^2; range for lean group 18.0 to 27.8 kg/m^2; range for obese group 28.6 to 46.5 kg/m^2). The lean subjects had a significantly (P<0.001) higher percentage of Type I (54.6 ± 1.8 vs 41.5 ± 1.8%) and a lower percentage of Type IIb (14.4 ±1.5 vs 25.1 ± 1.5%) muscle fibers than the obese subjects (lean vs obese, respectively; Figure 1). As presented in Figure 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 Figure 3, the African American subjects possessed a significantly (*P*<0.01) lower percentage of type I muscle fibers than the Caucasians without accounting for adiposity (51.8 ± 1.8 vs 43.7 ± 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 ± 1.2 vs 23.4 ± 2.9%, for Caucasian vs African American, respectively) (Figure 3).

There was a significant interaction between ethnicity and obesity status (*P*=0.03) when comparing the percentage of type I muscle fibers. As presented in Figure 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 ± 2.1 vs 54.1 ± 1.8% for Caucasian vs African American, respectively). However, muscle from the obese African American subjects contained significantly (*P*<0.05) less type I fibers than their Caucasian counterparts (48.6 ± 2.2 vs 34.5 ± 2.8% for Caucasian vs African American obese subjects, respectively) (Figure 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 comparing type I fiber percentage between the lean and obese Caucasians (*P*<0.001), with the lean individuals possessing more type I fibers than obese.

There was a significant interaction (*P*=0.03) when comparing the percentage of type IIb muscle fibers between lean and obese Caucasians and African Americans. As presented in Figure 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 ± 1.7 vs 15.0 ± 2.1% for Caucasian vs African American, respectively).

Muscle from the obese African Americans contained significantly ($P<0.001$) more type IIb fibers than their obese Caucasian counterparts (19.2 ± 1.9 vs 31.0 ± 2.4% for Caucasian vs African American, respectively) (Figure 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 comparing type IIb fiber percentage 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 underwent gastric bypass surgery to induce weight loss are presented. All these women met the standards for morbid obesity, thus qualifying them for the intervention. Mean preoperative age was 43.2 ± 1.8 y. Mean preoperative mass was 139.9 ± 6.8 kg which decreased ($P<0.001$) to 102.3 ± 6.3 kg approximately 12 mo. after the intervention. Initial BMI was 52.2 ± 2.3 kg/m^2 and decreased to 37.8 ± 2.2 kg/m^2 after weight loss ($P<0.001$). Fiber type obtained from the rectus abdominus at the time of the surgery was type I, 41.1 ± 3.1%; type IIa, 43.4 ± 4.1%; type IIb, 15.5 ± 3.3%. As presented in Figure 5, there were significant and positive relationships between the relative percentage of type I muscle fibers at the time of the surgery and the change in BMI (r=0.55, $P<0.05$) or body mass (r=0.56, $P<0.05$). The percent of excess body weight lost with intervention was also related (r=0.72, $P<0.005$) to the initial percentage of type 1 muscle fibers (Figure 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 less type I muscle fibers than lean controls (Figures 1,2). A new finding was that muscle from obese African American women contained a lower percentage of type I muscle fibers than comparably obese Caucasians (Figure 4). This observation is consistent with the higher incidence of obesity and greater weight gain reported in this ethnic group and observations of reduced lipid oxidation and insulin resistance in African Americans (4,2,10,14,20,22,25,26,37). 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 (Figure 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 composition 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 if the reduced percentage of type I muscle fibers developed during the course of the obese state or was an intrinsic defect predisposing individuals toward obesity. Simoneau and Bouchard (32) calculated that about 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 (MHC) isoform IIx (IIb) mRNA after 3 hrs 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 potential 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 which gained the most mass with high-fat feedings possessed significantly less 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 if these defects associated with muscle fiber type develop during the course of the obese state or are present prior to the development of obesity.

Adiposity varied widely in the subjects examined in this study (Figure 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 (cf. 31) indicating that the average fiber type for most mixed muscle groups in humans is approximately 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 examining muscle fiber type. In relation to ethnicity, Ama et al (1) reported an increased percentage of type II fibers in lean, black African men compared to Caucasians. In the present study we observed a similar racial difference (Figure 3) in women. The predominance of type II fibers in our African-Americans compared to 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 (Figure 4).

In summary, we observed a reduced percentage of type I and an increased percentage of type IIb muscle fibers, in obese individuals compared to their lean counterparts. There was also a reduced percentage of type I muscle fibers in obese African American women compared to 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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REFERENCES

1) Ama, P.F.M., J.A. Simoneau, M.R. Boulay, O. Serresse, G. Theriault, and C. Bouchard. Skeletal muscle characteristics in sedentary black and Caucasian males. *J. Appl. Physiol.* 61:1758-1761, 1986.

2) Brancati, F.L., W.H. Kao, A.R. Folson, R.L. Watson, and M. Szlo. Incident type 2 diabetes mellitus in African American and white adults: the Atherosclerosis Risk in Communities Study. *J. Am. Med. Assoc.* 283:2253-2259, 2000.

3) Brooke, M.H., and K.K. Kaiser. The three myosin adenosinetriphosphatase systems: the nature of their pH lability and sulfhydryl dependence. *J. Histochem. Cytochem.* 18:670-672, 1970.

4) Chitwood, L.F., S.P. Brown, M.J. Lundy, and M.A. Dupper. Metabolic propensity toward obesity in black vs white females: responses during rest, exercise, and recovery. *Int. J. Obesity* 20:455-462, 1996.

5) Goodpaster, B.H., R. Theriault, S.C. Watkins, and D.E. Kelley. Intramuscular lipid content is increased in obesity and decreased by weight loss. *Metabolism* 49:467-472, 2000.

6) He, J., S. Watkins, D.E. Kelley. Skeletal muscle lipid content and oxidative enzyme activity in relation to muscle fiber type in type 2 diabetes and obesity. *Diabetes* 50:817-823, 2001.

7) Hedman, A., L. Berglund, B. Essen-Gustavsson, R. Reneland, and H. Lithell. Relationships between muscle morphology and insulin sensitivity are improved after adjustment for intra-individual variability in 70-year old men. *Acta Physiol. Scand.* 169:125-132, 2000.

8) Henriksen, E.J., R.E. Bourey, K.J. Rodnick, L. Koranyi, M.A. Permutt, and J.O. Holloszy. Glucose transporter protein content and glucose transport capacity in rat skeletal muscles. *Am. J. Physiol.* 259:E593-E598, 1990.

9) Hickey, M.S., J.O. Carey, J.L. Azevedo, J.A. Houmard, W.J. Pories, R.G. Israel, and G.L. Dohm. Skeletal muscle fiber composition is related to adiposity and in vitro glucose transport rate in humans. Am. J. Physiol. (Endocrinol. Metab.) 268:E453-E457, 1995.

10) Hickner, R.C., J. Privette, K. McIver, and H. Barakat. Fatty acid oxidation in African-American and Caucasian women during physical activity. *J. Appl. Physiol*. 90:2319-2324, 2001.

11) Holmgang, A. Z. Brzezinska, and P. Bjorntorp. Effects of hyperinsulinemia on muscle fiber composition and capillarization in rats. *Diabetes* 42:1073-1081, 1993.

12) Houmard, J.A., D.S. O'Neill, D. Zheng, M.S. Hickey, and G.L. Dohm. Impact of hyperinsulinemia on myosin heavy chain gene regulation. *J. Appl. Physiol*., 86:1828-1832, 1999.

13) James, D.E., A.B. Jenkins, E.W. Kraegen. Heterogeneity of insulin action in individual muscles in vivo: euglycemic studies in rats. *Am. J. Physiol.* 248:E567-E574, 1985.

14) Karter, A.J., E.J. Mayer-Davis, J.V. Selby, R.B. D'Agostino, S.M. Haffner, P. Sholinsky, R. Bergman, M.F. Saad, and R.F. Hamman. Insulin sensitivity and abdominal obesity in African-American, Hispanic, and Non-Hispanic White men and women. *Diabetes* 45:1547-1555, 1996.

15) Kelley, D.E., B. Goodpaster, R.R. Wing, and J.A. Simoneau. Skeletal muscle fatty acid metabolism in association with insulin resistance, obesity, and weight loss. *Am. J. Physiol.* 277:E1130-E1141, 1999.

16) Kempen, K.P.G., W.H.M. Saris, H. Kuipers, J.F.C. Glatz, and G.J. van der Vusse. Skeletal muscle metabolic characteristics before and after energy restriction in human obesity: fibre type, enzymatic B-oxidative capacity and fatty acid-binding protein content. *Eur. J. Clin. Invest.* 28:1030-1037, 1998.

17) Kern, M., A.J. Wells, M.J. Stephens, W.C. Elton, E.J. Friedman, B. Tapscott, H.P. Pekela, and G.L. Dohm. Insulin responsiveness in skeletal muscle is determined by glucose transporter (Glut4) protein level. *Biochem. J.* 270:397-400, 1990.

18) Kriketos, A.D., D.A. Pan, S. Lillioja, G.J. Cooney, L.A. Baur, M.R. Milner, J.R. Sutton, A.B. Jenkins, C. Bogardus, and L.H. Storlien. Relationships between muscle morphology, insulin action, and adiposity. *Am. J. Physiol.* 270:R1332-R1339, 1996.

19) Krotkiewski, M. and P. Bjorntorp. Muscle tissue in obesity with different distribution of adipose tissue. Effects of physical training. *Int. J. Obes.* 10:331-341, 1986.

20) Kuczmarksi, R.J. K.M. Flegal, S.M. Campbell, and C.L. Johnson. The national health and nutrition examination survey. *JAMA* 272:205-211, 1994.

21) Lillioja, S., A.A. Young, C.L. Culter, J.L. Ivy, W.G.H. Abbott, J.K. Zawadzki, H. Yki-Jarvinen, L. Christin, T.W. Secomb, and C. Bogardus. Skeletal muscle capillary density and fiber type are possible determinants of in vivo insulin resistance in man. *J. Clin. Invest.* 80:415-424, 1987.

22) Lovejoy, J.C., J.A. de la Bretonne, M. Klemperer, and R. Tulley. Abdominal fat distribution and metabolic risk factors: Effects of race. *Metabolism* 45:1119-1124, 1996.

23) Marin, P., B. Anderson, M. Krotkiewski, and P. Bjorntorp. Muscle fibre composition and capillary density in women and men with NIDDM. *Diabetes Care* 17:382-386, 1994.

24) Mrad, J.A., F. Yakubu, D. Lin, J.C. Peters, J.B. Atkinson,and J.O. Hill. Skeletal muscle composition in dietary obesity-susceptible and dietary obesity-resistant rats. *Am. J. Physiol.* 262:R684-R688, 1992.

25) Must, A. J. Spadaro, E.H. Coakley, A.E. Field, G. Colditz, and W.H. Dietz. The disease burden associated with overweight and obesity. *J. Am. Med. Assoc.* 282:1523-1529, 1999.

26) Nicklas, B.J., D.M. Berman, D.C. Davis, C. L. Dobrovolny, and K.E. Dennis. Racial differences in metabolic predictors of obesity among premopausal women. *Obes. Res.* 7:463-468, 1999.

27) Nyholm, B., Z. Qu, A. Kaal, S.B. Pedersen, C. Gravholt, J. Andersen, B. Saltin, and O. Schmitz. Evidence of an increased number of type IIb muscle fibers in insulin-resistant first-degree relative of patients with NIDDM. *Diabetes* 46:1822-1828, 1997.

28) Pette, D. H. Peuker, R.S. Staron. The impact of biochemical methods for single fiber analysis. *Acta Physiol. Scand.* 166;261-277, 1999.

29) Pories, W.J., M.S. Swanson, K.G. MacDonald, S.B. Long, P.G. Morris, B.M. Brown, H.A. Barakat, R.A. deRamon, R.G. Israel, J.M. Dolezal, and G.L. Dohm. Who would have thought it? An operation proves to be the most effective therapy for adult-onset diabetes mellitus. *Annals of Surgery* 222:339-352, 1995.

30) Raben, A., E. Mygind, and A. Astrup. Lower activity of oxidative key enzymes and smaller fiber areas in skeletal muscle of postobese women. *Am. J. Physiol.* 275:E47-E494, 1998.

31) Saltin, B. and P.D. Gollnick. Skeletal muscle adaptability: significance for metabolism and performance. In: *Handbook of Physiology. Skeletal Muscle.* Bethesda, MD: Am. Physiol. Soc., 1983, vol. 10, chapt. 19, p 555-631, 1983.

32) Simoneau, J-A, and C. Bouchard. Genetic determination of fiber type proportion in human skeletal muscle. *FASEB J.* 9:1091-1095, 1995.

33) Simoneau, J-A, and C. Bouchard. Skeletal muscle metabolism and body fat content in men and women. *Obesity Res.* 3:23-29, 1995.

34) Simoneau, J-A, and D.E. Kelley. Altered glycolytic and oxidative capacities of skeletal muscle contribute to insulin resistance in NIDDM. *J. Appl. Physiol*. 83:166-171, 1997.

35) Simoneau, J-A, J.H. Veerkamp, L.P. Turcotte, and D.E. Kelley. Markers of capacity to utilize fatty acids in human skeletal muscle: relation to insulin resistance and obesity and effects of weight loss. *FASEB J.* 13:2051-2060, 1999.

36) Wade, A.J., M.M. Marbut, and J.M. Round. Muscle fibre type and aetiology of obesity. *Lancet* 335:805-808, 1990.

37) Williamson, D.F., H.S. Kahn, P.L. Remington, and R.F. Anda. The 10-year incidence of overweight and major weight gain in US adults. *Arch. Intern. Med.* 150:665-672, 1990.

38) Zierath, J.R, L. He, A. Guma, E. Odegaard Wahlstrom, A. Klip, and H. Wallberg-Henriksson. Insulin action and glucose transport and plasma membrane GLUT4 in skeletal muscle from patients with NIDDM. *Diabetologia* 39:1180-1189, 1196.

FIGURE LEGENDS

Figure 1 Adiposity, as determined by body mass index (BMI) (A), and muscle fiber type (type I%, B; type IIb%, C) in the lean (n=28) and obese (n=25) women.

*****Significantly different ($P<0.05$) between lean and obese.

Figure 2 Relationship between adiposity (body mass index, BMI) and the percentage of type IIb muscle fibers in lean and obese women.

Figure 3 Comparison of muscle fiber type (type I%, A; type IIb%, B) in Caucasian (n=34) and African American (n=19) women.

*****Significantly different ($P<0.05$) between Caucasian and African American.

Figure 4 Comparison of type I (A) and type IIb (B) muscle fibers in lean and obese Caucasian and African American women. The number of subjects in each group were: lean African American (n=8); obese African American (n=11); lean Caucasian (n=20); obese Caucasian (n=14).

*****Significantly different ($P<0.05$) between lean and obese within that ethnic group.

[d]Obese African American group was different from all other groups ($P<0.05$).

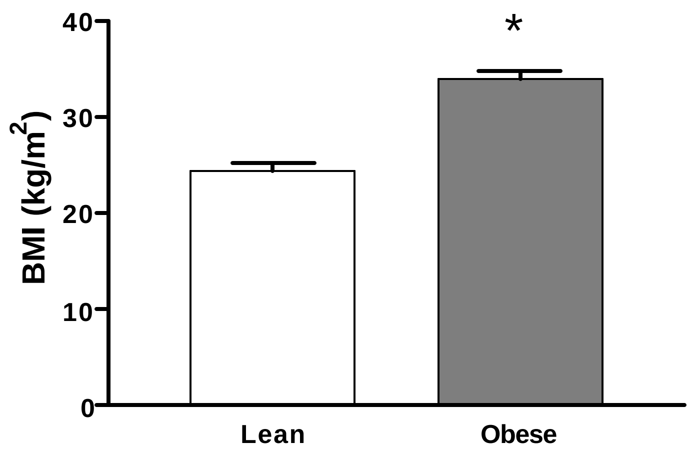
Figure 5 Relationships between the loss in body mass index (BMI) (A) and excess body mass (B) and the percentage of type I muscle fibers in morbidly obese gastric bypass patients approximately 12 months after the surgery.

Table 1. Mean (± SE) age (y) and body mass index (BMI, kg/m^2) for the subjects.

Group	Age	BMI
African American		
Lean (n=8)	41.3 ± 2.3	25.4 ± 1.3*
Obese (n=11)	42.3 ± 2.3	33.3 ± 1.3
Caucasian		
Lean (n=20)	42.0 ± 1.6	24.1 ± 0.9*
Obese (n=14)	39.9 ± 1.8	34.6 ± 1.1

*Significantly different ($P<0.05$) from obese subjects within that racial group.

A


BMI (kg/m2)
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40
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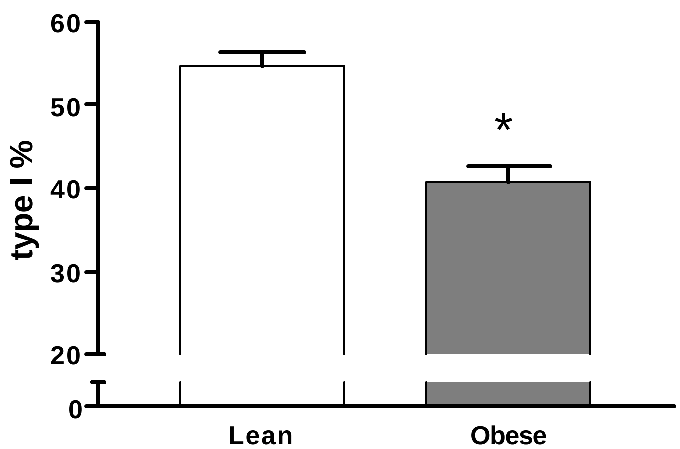
Lean
Obese

B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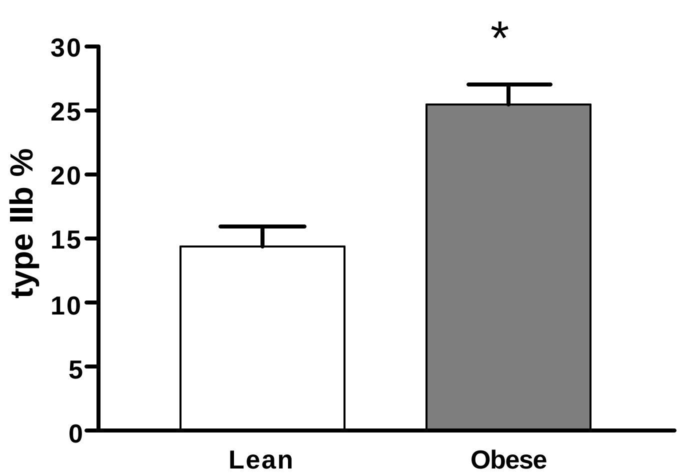
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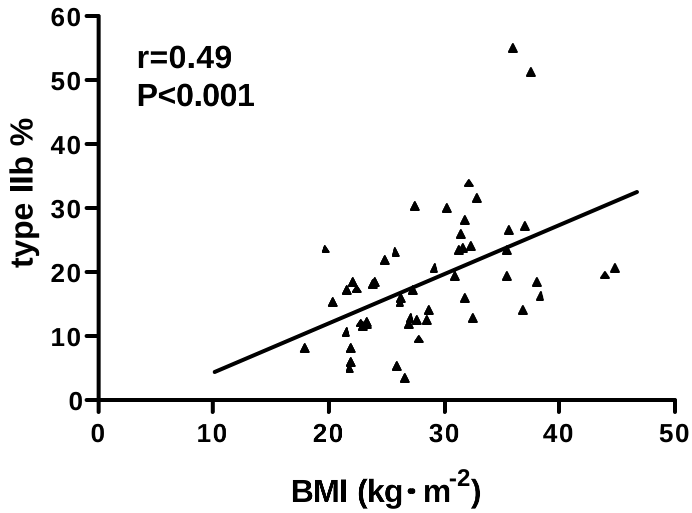
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P<0.001
type IIb %
BMI (kg·m^{-2})
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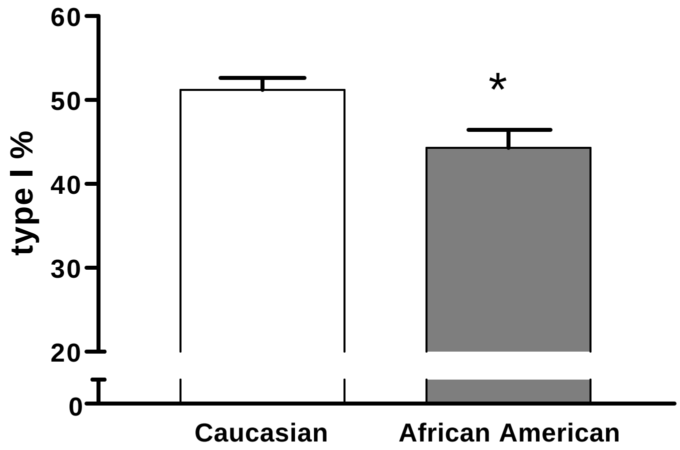
A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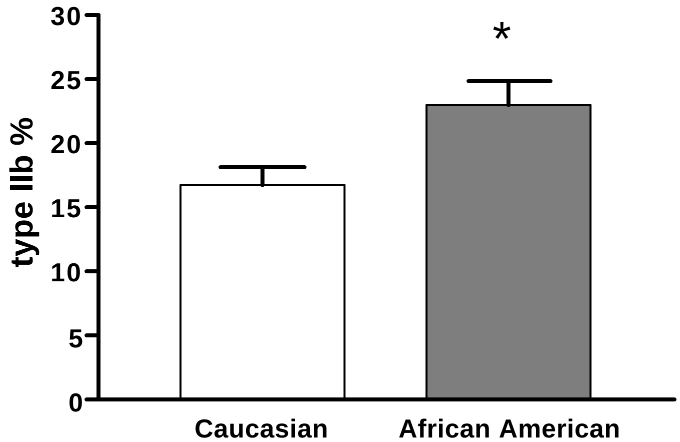
type I %
*
Caucasian
African American

B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type IIb %
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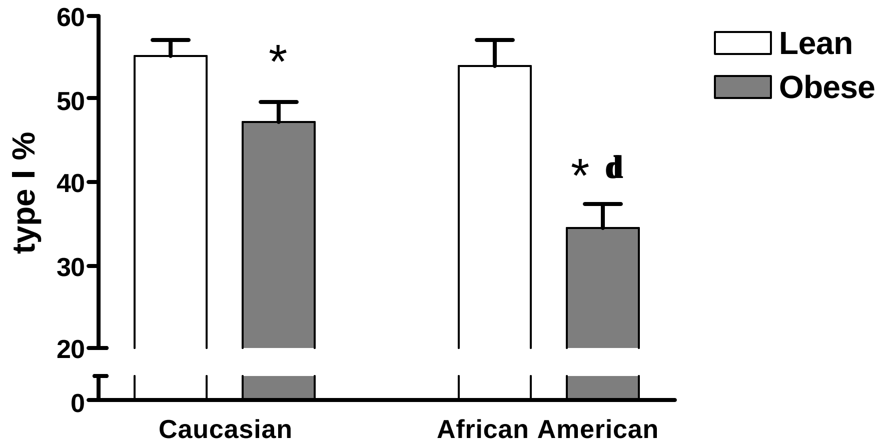
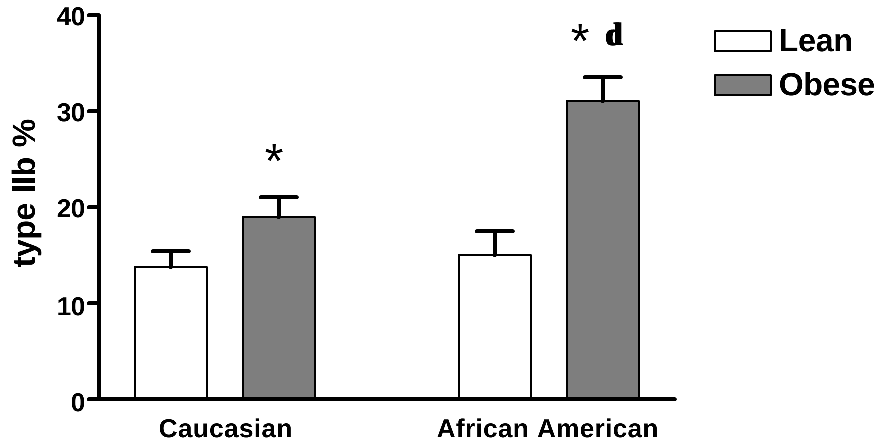
Caucasian
African American

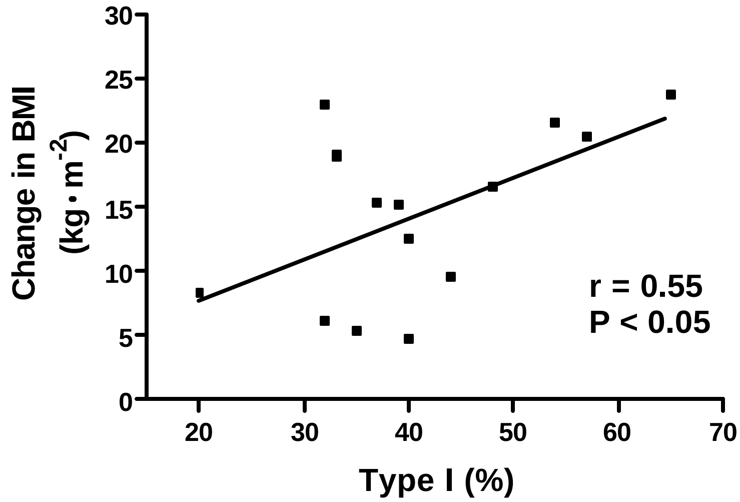
A


60
50
40
30
20
0
type I %
*
* d
Lean
Obese
Caucasian
African American

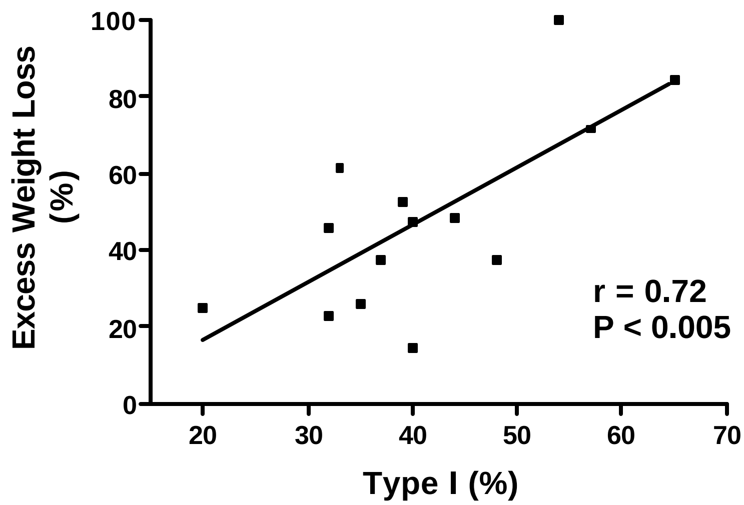
B


40
30
20
10
0
type IIb %
*
* d
Lean
Obese
Caucasian
African American

A


Change in BMI
(kg·m-2)
30
25
20
15
10
5
0
20
30
40
50
60
70
Type I (%)
r = 0.55
P < 0.05

B


Excess Weight Loss
(%)
100
80
60
40
20
0
20
30
40
50
60
70
Type I (%)
r = 0.72
P < 0.005