EFFECTS OF MODERATE AEROBIC EXERCISE ON THE ATTENUATION OF LEAN MASS LOSS DURING RAPID WEIGHT LOSS

by

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Abstract

Background: Obesity has become a severe issue in the United States, and gastric bypass surgery has been one of the most successful tools to combat the adverse consequences of this disease. The rapid weight loss associated with gastric bypass surgery is also associated with a loss of lean mass. Lean mass maintenance is necessary for both maintenance of basal metabolic rate and ambulation; therefore, the focus of many studies has been directed toward attenuating the loss of lean mass resulting from gastric bypass surgery. Previous studies on the subject have included aerobic exercise, resistance exercise, and a combination of the two with varying results; however, all past studies have been short term (less than 4 months).

Purpose: The purpose of this study was to explore the effects of a long term (6 month) aerobic exercise program on lean mass and to determine if there were differences between the loss of lean mass in the arms and legs. It was hypothesized that the loss of lean mass would be attenuated by 6 months of exercise, and that the lean mass loss would be attenuated more in the lower body then upper body.

Methods: Forty-seven obese, adult men and women having undergone gastric bypass surgery were randomized into 2 groups: control and exercise. Control group participants received typical care following surgery whereas exercise group participants were progressed to 4-5 days per week, 30-45 min per session (120-180 min per week) of moderate intensity aerobic exercise, 60-70% maximal heart rate.

The 6 month intervention began 1-3 months post-gastric bypass surgery. Pre and post assessments were made using dual energy X-ray absorptiometry (DXA). 2-way repeated measures ANOVA was used to analyze tissue percent fat, tissue mass, fat mass, lean mass, total mass, and bone mineral content in the right side body and in segments of the right side of the body.

Results: Mean weight loss over the 6-month intervention was 19.9% of body weight. The tissue % fat decreased 10.6% (SE of diff 1.5%) in the control group and 13.2% (SE of diff 1.4%) in the exercise group. Fat mass decreased 36.5% (SEM 3.1%) in the control group and 42.6% (SEM 3.7%) in the exercise group. Lean mass decreased 2.1 % (SEM 1.5%) in the control group and 3.0% (SEM 2.6%) in the exercise group. There were no significant between groups differences.

Both groups decreased lean mass in the right upper arm (control group 0.3 kg SEM 0.1 kg; exercise group 0.4 kg SEM 0.1 kg). Lean mass in the right lower leg significantly decreased over time in the exercise group (0.1 kg SEM 0.05 kg); conversely, the control group maintained lean mass in the right lower leg.

Conclusion: The results of this study suggest a 6 month moderate intensity aerobic exercise intervention that begins 1-3 months post-gastric bypass surgery does not attenuate the loss of lean mass resulting from gastric bypass surgery. Segmentally, exercise does not lessen the loss

of lean mass in the upper arm, and actually results in a greater loss of lean mass in the lower leg as compared to the control. The loss of lean mass in the lower leg may be a result of biomechanical changes in walking patterns associated with weight loss.

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Chapter I: Introduction

Obesity is a growing concern in the United States. With over one-third of the current population classified as obese[1] and that percentage growing[2], obesity-related expense has become nearly 10% of all medical spending[3] primarily due to the associated increased incidence of cardiovascular disease.[4] Gastric bypass surgery has become a well-trusted, commonly used tool to aid in weight loss and to combat obesity-related comorbidities.[5–10] Gastric bypass surgery can produce rapid and substantial weight loss with patient's averaging a 36% weight loss[6] one year after surgery. It must be noted that 25% of that weight loss was a result of a loss of lean mass.[6,11] Gastric bypass surgery results in a greater loss of lean mass than any other weight loss surgery.[12]

Lean mass is a vital component in metabolism and ambulation. Basal metabolic rate slows significantly with rapid weight loss due mainly to the loss of lean mass.[6,13] With gastric bypass surgery a significant amount of lean mass is lost within the first 6 months post-surgery,[5,6,14] suggesting a need to prevent the loss of lean mass.

Exercise may help attenuate the loss of lean mass during a diet-induced weight loss intervention.[15] Evidence has not been found that exercise interventions with gastric bypass surgery-induced weight loss attenuates the loss in lean mass but these studies have all been short term (<4 months).[15,16] An area of concern is whether there is a difference in loss between upper and lower body because of the role the lower body plays in ambulation. To date, limited research has been done on these regional differences[17–19], specifically between the arm and leg.

The purpose of this study was two-fold: to determine whether a long-term (6 month) moderate intensity aerobic exercise intervention would attenuate the loss of lean mass associated with gastric bypass induced rapid weight loss; and, to determine whether there is a larger loss in lean mass in the arms than the legs. We hypothesized that aerobic exercise would attenuate the loss of lean mass. Segmentally, aerobic exercise would attenuate the loss of lean mass in the legs and have no effect on the loss of lean mass in the arms.

Limitations

This study is not without limitations. Participants were strongly encouraged to comply with the physical activity guidelines for their respective group, yet the actual level of compliance was the responsibility of the participant. Detailed records of physical activity were kept by participants, which may have resulted in false reporting. It should be noted that a large percentage of participants were women; therefore, no gender comparisons for this study were made.

Dual-energy X-ray absorptiometry (DXA) was used to measure body composition because of its clinically accepted accuracy and convenience; however, DXA has a weight restriction of 350 lbs. The initial assessment was made 1-3 months after gastric bypass surgery so that participants were able to meet the weight requirements of DXA. Total weight loss and lean mass loss after gastric bypass surgery would not be measured in the current study.

Delimitations

While all subjects were from Pitt County, North Carolina, results should be comparative to adults having undergone gastric bypass surgery throughout the United States because individuals undergoing gastric bypass surgery are required to meet certain health/risk and BMI criteria that are consistent across the country in order to have the surgery. The results of this study cannot be generalized to other forms of bariatric surgery or other weight loss interventions due to differences in the amount and rate of weight loss between surgical methods. In addition, the scope of this study is specific only to a moderate intensity aerobic exercise intervention

Chapter II: Review of Literature: Obesity

Since obesity has become such a significant issue in the United States, much research has been conducted on the topic. The prevalence of obesity is 35.7% [1] and continues to climb[2] along with related expenses. In 2008, obesity related medical costs were $147 billion which was nearly 10% of all medical spending.[3] The high medical spending for obesity is a result of the treatment of co-morbidities associated with obesity such as insulin resistance[20], hypertension[4,20,21], and hyperlipidemia.[22] Each co-morbidity, as well as obesity itself, are independent risk factors for cardiovascular disease.[4]

The risks associated with obesity can often be reduced by weight loss. There is an overabundance of diet and exercise plans available that "guarantee" weight loss; however, diet and exercise induced weight loss has only shown moderate, short lasting results.[21] The most successful weight loss aid is surgical—namely, gastric bypass.[23]

Gastric Bypass Surgery

Gastric bypass surgery is a procedure designed to promote weight loss and minimize risks. The majority of the stomach is sealed off, leaving only a pouch the size of an egg. The new stomach pouch is then attached to the jejunem of the small intestine, completely bypassing the duodenum—the initial portion of the small intestine. The small size of the stomach ensures severe caloric restriction which results in rapid weight loss. The small intestine is the site of greatest energy and nutrient absorption. In bypassing part of it, some of the calories consumed are also bypassed, aiding in further weight loss.

Gastric bypass results in dramatic and long term decreases in body weight, fat mass, and body fat percentage.[5,6] The incidence and severity of co-morbidities associated with obesity are also decreased. Typically, within one week post-surgery, insulin sensitivity is markedly improved.[7] Hypercholesterolemia is also improved within 3 months post-surgery and maintained at 2 years.[8] Compared to diet and exercise alone, gastric bypass patients have shown higher rates of remission of hypertension and type 2 diabetes up to 10 years post-surgery.[9,10] Though gastric bypass surgery can reduce the risk of developing these diseases, of particular interest to this study is the change in body composition associated with gastric bypass surgery.

Weight Loss

Several studies have looked at the amount of total body weight loss at one year post-gastric bypass surgery. The studies that looked at both men and women which had similar initial BMIs found similar results; Hofso et al,[9] *N*(76), initial BMI 48.7±2.5 kg/m^2, 30% body weight loss; Carey et al[6] *N*(17), BMI 48.7 ±2.5 kg/m^2, 36% body weight loss; Zalesin et al[24], *N*(32), BMI 50.1±8.9 kg/m^2, 36.5±5.5% body weight loss. However, in a sample of only women *N*(31) undergoing gastric banding (as opposed to gastric bypass), with a lower initial BMI of 43.6 kg/m^2, Giusti et al[14] found the lowest amount of weight loss, 23.3%. This difference may be due to a lower initial BMI; however, gastric bypass is associated with greater weight loss than gastric banding.[25]

Weight loss is considered to be a contributing factor in the remission of obesity-related comorbidities. There are two components of weight loss: reduction in fat mass and reduction in lean mass. It is thought that the fat loss is responsible for the reduction of obesity-related comorbidities;[8,26] however, the area of particular concern to this study is the loss of lean mass.

Importance of Lean Mass

Lean mass has two major functions: metabolism and ambulation. The amount of lean mass is significantly correlated to basal metabolic rate (BMR);[6,13] therefore, as the amount of lean mass decreases with weight loss, BMR also decreases.[6,11,27] Carey et al[5] found an average BMR decrease of 333 kcal/day with a 4.6% decrease of lean mass from pre-surgery to one month post gastric bypass surgery. In the months following, the change in BMR was not significant. By the end of the 12-month study, BMR decreased a total of 417 kcal/day with a lean mass decrease of 17.2%.[6] Carey et al's findings are lower than those reported by others. In a study of 30 men and women undergoing gastric bypass, resting metabolic rate (RMR) decreased by 573±238.8 kcal/day and lean mass decreased by 16.8% by one year post-surgery.[11] At first glance this difference could be due in part to the subtle differences in measuring BMR and RMR. BMR is usually measured in a dark room after 8 hours sleep and a 12 hour fast, whereas with RMR environmental considerations are usually less stringent. However, in this study, RMR was measured after a 12 hour fast and overnight stay at the study facility. It is the opinion of the author that the difference between BMR and RMR in this case were merely semantics. The actual cause of the difference in findings is unclear. Nevertheless, this study further indicates that BMR is reduced due to the weight loss associated with gastric bypass surgery.

Research has been done to discern whether this change in BMR is solely attributable to lean mass loss. Findings suggest a significant portion of the decrease in BMR is due to loss of lean mass; however, some of the decrease in BMR is due to metabolic adaptation to the intervention.[27] Yet, lean mass is an important element of BMR and a reduction of lean mass leads to a significant reduction in BMR. Both the addition of regular physical activity[21] and the continuation of a decreased caloric intake are necessary to maintain weight loss.

Lean mass is also vital to ambulation. Ambulation, as it relates to physical function, is often studied in older populations. The elderly are studied because of their frailty and low-muscle mass associated with increased age. Sarcopenia, defined as appendicular muscle mass >2 SD below the average, is associated with a reduced physical ability to perform activities of daily living such as walk one-quarter mile, crouch or bend down, stand from an armless chair, etc.[28] Maintaining a normal amount of lean mass is essential to being able to perform these basic activities of daily living.

With the understanding that rapid weight loss results in lean mass loss, there are concerns with weight loss interventions in the elderly. However, not enough lean mass is lost (2.7±2.4 kg) with a typical diet-induced weight loss intervention (total weight loss 7.84±6.1 kg) to impair physical function in the elderly[29] despite their initial low amounts of lean mass. The amount of fat mass loss is the major predictor in improved functionality whereas lean mass loss is not.[11] This is likely transferrable to young and middle-aged adults undergoing an intense weight loss intervention. Regardless of age, lean mass is an integral component in the ability to perform even the most basic physical tasks. There may not be enough lean mass loss with the typical diet-induced weight loss intervention to infringe upon the performance of those basic tasks. Gastric bypass-induced weight loss results in above average loss of lean mass which may have the potential to hinder functionality.[12] More research needs to be done in this field to determine the effects of lean mass loss in obese individuals on functionality.

An accurate method of measuring lean mass is by dual-energy X-ray absorptiometry (DXA).[30–32] DXA uses high and low-energy photons and an X-ray tube with a filter to differentiate between bone, lean, and fat tissue. DXA gives measurements for the whole body as well as limbs and torso compartments. It is convenient and non-invasive with minimal exposure to radiation (<1mrem).[32] DXA measurements are also replicable[32,33] and as a result, multiple measurements can be used to compare changes in body composition within an individual.

The overall body composition changes associated with bariatric surgery are well documented. Currently, laparoscopic adjustable gastric banding is best documented. Two studies with similar populations and measurement procedures reported that lean mass loss can be as little as 12.6% (total weight loss, 19%)[34] to as much as 17.4% (total weight loss, 23.3%)[14] of total weight loss in patients that underwent gastric banding surgery. Fewer studies have been conducted on gastric bypass patients; however the available data tend to report a higher lean mass loss of 21[11] -24.8[6]% (total weight loss, 38±19%[11]; 36%[6]). Gastric bypass surgery results in significantly more lean mass and total weight loss than typical diet-induced weight loss interventions[17,29] and other forms of bariatric surgeries.[25] The higher loss of lean mass may be due to a greater overall weight loss in the same time frame suggesting that weight loss occurs at a faster rate after gastric bypass surgery than gastric banding.

Studies show that the loss of lean mass has a strong positive correlation to the rate of weight loss; as weight decreases, so does lean mass. With gastric bypass, weight loss is rapid in the first 6 months post-surgery, but then tapers off.[5] Carey et al followed a group of participants from pre-gastric bypass surgery to 6 months post[5], and 6 months to one year post-surgery.[6] The results of the studies are summarized in Tables 1 and 2. Body weight, fat mass and lean mass had the quickest rate of loss in the first month but slowed through the next 5 months. In months 6-12, body weight and fat mass continued to decrease whereas lean mass did not change. Lean mass actually increased by 0.7 kg which is interesting but not statistically significant. In the first 6 months post-surgery, the percent of weight loss comprised of fat mass and lean mass loss was 66.9% and 33.1% respectively. From 6-12 months, 100% of the weight loss was attributed to fat loss. Combined (0-12 months) 75% of weight loss was due to a loss in fat mass, and 24.8% due to lean mass loss. The percentages do not sum to 100% assumedly as a result of the 0.7 kg gain in lean mass and/or rounding errors. All of the loss of lean mass occurs in the first 6 months post-surgery; therefore, any efforts to combat a loss in lean mass after a surgical weight loss intervention must begin as soon as the patient heals, recovers, and adopts adequate stable nutrient intake patterns.

Table 1: Rate of weight loss

Measure (Rate of loss)	0-1 months (kg/mo)*	1-3 months (kg/mo)*	3-6 months (kg/mo)*	6-12 months (kg/mo)**
Body weight	12.3	6.8	4.6	1.9
Fat Mass	8.7	3.9	3.3	1.9
Lean Mass	3.3	2.9	1.3	0
% Fat	2.3%/mo	0.8%/mo	1.4%/mo	1.4%/mo

Table 2: Source of weight loss

	0-6 months*	6-12 months**	0-12 months**
Fat mass	66.9%	100%	75%
Lean mass	33.1%	0%	24.8%
% Fat	7.9%	8.5%	16.4%

*Carey et al[5]
**Carey et al[6]

Differentiation of Lean Mass

Lean mass can be considered in two parts: fat free mass (FFM) and low density lean tissue (LDLT). LDLT is muscle tissue that is marbled with lipid and is considered “lean” but of a decreased density due to lipid depots. It is created in the body because of a decreased capacity in the muscle for fat oxidation.[35] It has been speculated that LDLT is part connective tissue and part low-density skeletal muscle.[36] The research methods involved in differentiating lean tissue are fairly new and highly expensive. More research in this field is necessary to understand the importance of LDLT in obesity and in weight loss.

The ratio of lean mass to fat mass varies within the body. For example, it is natural to have greater amounts of FFM in the legs than in the arms.[16,37] This is likely attributable to the load bearing function of the legs. Obese individuals have greater body mass therefore, greater leg mass. However, it has been suggested that the greater leg mass is not due to FFM; rather it is due solely to greater amounts of LDLT and adipose, one-third and two-thirds respecively.[36] Thus, obese individuals have the same amount of FFM as normal-weight individuals but greater amounts of LDLT.[36]

It is understood that lean mass is lost during periods of rapid weight loss although limited research has been done to isolate the location of the lean mass that is lost. Chomentowski et al[17] found lower limb and trunk lean mass decreased with diet-induced weight loss whereas upper limb and erector spinae muscles did not change. Contrastingly, Pereira et al[18] studied body composition pre- and 6 months post- gastric bypass surgery and found both upper and lower limb LM decreased significantly. The study's aim was at the validity of the use of ultrasound as a tool to discern body composition by using DXA as the criterion. This further suggests the need for research on limb differences in weight loss. The difference in results may be due to the difference between diet[17] and surgical[18] weight loss interventions, but the mechanism for this difference is unknown.

Exercise

Research shows that exercise can attenuate the loss of FFM associated with diet interventions. Janssen and Ross studied the effects of a diet intervention with and without an exercise program (both aerobic and resistance exercise were studied independently) on obese adults.[15] In the 16 week intervention there was a 12% decrease in body weight. Some FFM was lost in all groups but the only significant decrease occurred in the diet only group (5%-women, 8%-men). There was no significant difference between exercise groups which suggests that aerobic training is no less effective than resistance training in maintaining FFM during weight loss.[15] A study by Ross et al used the same methods but with only male subjects and found similar results.[38] This provides evidence that aerobic exercise may be sufficient to lessen the loss in FFM inherent to diet-induced weight loss.

The first 6 months after gastric bypass surgery are known to have the greatest effect on FFM.[5,6] Although FFM loss during diet-induced weight loss can be attenuated by a short term exercise intervention[15,38], gastric bypass-induced FFM loss cannot. Stegen et al[39] studied the effects of moderate aerobic exercise (60-75% HRR) combined with resistance training on gastric bypass patients. Exercise training began one month after surgery and lasted 12 weeks—3 training sessions per week. The control group lost 10.5% FFM; the trained group lost 8.5% FFM. Both groups lost significant FFM but there was no evidence of a significant difference between groups. In a similar study by Castello et al[19], the exercise group was only aerobically trained. Participants walked on a treadmill 3 days per week for 12 weeks at 50-70% HRmax for 40 minutes plus a 10 minute warm up and a 10 minute cool down. Following the 12 weeks of training, 10.4% FFM was lost in the control group, 7.9% lost in the trained group. Again, significant FFM was lost in both groups, but there was no significant difference between groups. Both studies described here only list total body composition changes as a result of short term exercise interventions. To the author's knowledge, long-term exercise interventions (>4 months) after gastric bypass surgery have not been studied, nor have individual limb differences in LM loss.

Summary

Gastric bypass surgery is considered to be a safe and effective weight loss intervention for obese individuals. The loss of lean mass associated with rapid weight loss is a concern for ambulation and metabolism. There is limited information on the regional lean mass loss whether it is from the arm, leg, or both. The purpose of this study was to determine whether a long-term moderate intensity aerobic exercise intervention would attenuate the loss of lean mass during gastric bypass-induced weight loss and whether there is a difference in lean mass loss between the arms and legs. We hypothesized that exercise would attenuate the loss of lean mass. We also hypothesized that exercise would attenuate the loss of lean mass in the legs and have no effect on the loss of lean mass in the arms because of the load-bearing function of the legs.

Chapter III: Methods

Participants

The participants of the current study are participants of a larger study, *Physical Activity Following Surgery-Induced Weight Loss,* conducted by Dr. Joseph Houmard at East Carolina University. Forty-seven adult, male and female gastric bypass patients were locally recruited for the study.

Inclusion Criteria

Volunteers were included if they fulfilled the following criteria: undergone bariatric surgery one to three months previously, reside locally, BMI <60 kg/m^2 prior to surgery, 21-60 years old, able to walk 3-4 blocks without assistance, and were granted exercise clearance by a cardiologist based on results of a graded exercise test.

Exclusion Criteria

Volunteers were excluded if they presented any of the following: type 2 diabetes, uncontrolled hypertension or hypothyroidism, anemia, cancer within the past 5 years, current or past heart disease, current anti-coagulation therapy, use of steroids or other drugs that would alter metabolism, pregnancy during the previous 6 months or lactating or currently planning pregnancy, smoker, or alcohol/drug abuse in the previous 12 months.

Experimental design

Participants were randomly placed in one of two groups—exercise or control—using a permuted blocks approach stratified by gender. The blocks were of random sizes of 4 and/or 8 to reach equal sample sizes in each group.

Exercise group (EXG): Participants were progressed to 4-5 days per week, 30-45 min per session (120-180 min per week) of moderate intensity aerobic exercise, 60-70% maximal heart rate.

Control group (CG): Participants received their usual care following surgery, including information on physical activity. They were also asked to participate in monthly health education sessions. Participants were encouraged not to exercise during the duration of the study; however, they were able to use our facility for 3 months after completion of the study with exercise instruction at no charge.

Physical activity intervention

A 6-month program of exercise training was conducted after completion of body composition assessment. Participants engaged in a minimum of 3 and a maximum of 5 exercise sessions weekly; the exercise prescription was formulated based on exercise stress test data and the progression of the participant through the exercise program in terms of exercise tolerance. The ECU facility (FITT Building, Main Campus) has treadmills, stationary bikes, and walking tracks that were used for supervised exercise. At least one exercise session per week was supervised within the FITT Building for each participant. This assured that the target exercise intensity and duration was achieved. Subjects were instructed on the proper use of a wireless heart rate monitor (Polar, Finland) to record exercise duration and mean heart rate. Participants kept detailed logs of exercise sessions (supervised and unsupervised) including type of exercise, duration, and average heart rate for that activity.

For the first 4 weeks, participants were instructed to exercise for as long as feasible (~10-15 min) per session at an intensity level within the range of 60-70% of their maximal heart rate. During the next three months, participants were progressed based their individual ability to tolerate the activity level. After the first 3 months participants achieved a minimum of 120 minutes per week of combined supervised and unsupervised exercise. For the unsupervised exercise sessions, participants were instructed to use a stationary cycle or treadmill at home, or walk or bicycle outdoors for a similar duration. Participants were contacted one to three times weekly to discuss their programs and progress. The level of activity performed by the participants was consistent with American College of Sports Medicine (ACSM), American Diabetes Association (ADA) and American Heart Association (AHA) exercise guidelines.

Initially for some participants, exercising for 30 minutes at an intensity of 60-70% of maximal heart rate was too challenging. Therefore, in an effort to facilitate compliance, some participants were allowed multiple short-bouts of exercise rather than one continuous bout. Participants were still encouraged to accumulate the minimal level of exercise per day (i.e., 30 min/d) as recommended by the ACSM, ADA, and AHA guidelines. Intermittent exercise was performed in exercise bouts of at least 10 minutes and repeated until the goal for the day was achieved.

Initial and post-intervention assessment

For the purpose of the current study, height and weight were measured as well as body composition. Dual energy x-ray absorptiometry (DXA) (Lunar Prodigy Advance. EnCore 2007. Version 11.40.004) was used to determine the following body composition measurements: whole body, right arm and leg, right upper and lower arm, and right upper and lower leg tissue percent fat (excludes bone), region percent fat (includes bone), tissue percent lean, tissue mass (excludes bone), fat mass (FM), lean mass (LM) (excludes bone), and total mass (includes bone). Due to size restrictions, a hemi-scan was used. DXA assumes both sides of the body are equal; therefore total body measurements are estimated by scanning only the right half of the body. Thus, for the purpose of specificity, measurements were reported in terms of right side only. This procedure is consistent with evidence from Thompson and Tanner[40] and Rothney et al.[41]

DXA's automatic total body cuts were manipulated to ensure accurate placement based on guidelines written by the program. The arm measurement cut through the gleno-humoral fossa and included the hand and fingers. Some breast tissue or overlapping trunk tissue was included due to arm placement on several participants though great care was taken to minimize inclusion. The leg was identified by the region below the top of the pelvis (marked by pelvis top cut), and the bottom of the pubic bone (marked by placing center leg cut at the bottom of the pubic bone). The leg often includes a thumb or finger due to hand placement during the scan but care was taken to minimize inclusion. See Diagram 1 for a visual representation of the body regions.

Separating the limbs into upper and lower parts took more dramatic manipulation of the total body analysis. To find the upper arm, the right and left spine cuts were moved to the apex of the humerous, trying to omit any breast tissue. The right arm cut was placed to border the lateral side of the right arm and the forearm cut was used to separate the upper and lower arm by placing it across the acromion process. Because the right trunk measurement includes the right half of the pelvis, the center leg cut was placed flush onto the pelvis top, therefore omitting the pelvis. With this manipulation, the right trunk measurements were read as the right upper arm and the right arm measurement was read as the right lower arm on the body composition ancillary analysis. No other results from this analysis could be used. See Diagram 2 for a visual representation of the manual manipulation of the total body analysis to create the right arm segments.

The upper leg measurement was created by moving the head cut down to the head of the femur. The left and right spine cuts were aligned between the legs, creating the medial border of the thigh. The right forearm cut was moved to outline the lateral side of the leg. The right arm cut was moved either flush to the head cut or to help shape the forearm cut around the hip and exclude the hand from analysis. The top pelvis and center leg cuts were placed in the center of the knee joint, just below the femoral condyles. With this manipulation, the right trunk measurements were read as the upper right leg and the right leg measurements were read as the lower leg. No other results from this analysis could be used. See Diagram 3 for a visual representation of the manual manipulation of the total body analysis to create the right leg segments.

Manual manipulation of the automated body cuts were tested and found to be replicable and reliable.

Statistical analysis

Repeated measures analysis of variance (ANOVA) was used to assess the participants' change in body weight, tissue percent fat, right arm and leg FM and LM, and total body fat and lean mass from the initial assessment to the 6 month assessment. There were 2 groups (control and exercise) and 2 time points (pre and post intervention), therefore a two-by-two ANOVA was performed. Where statistical significance was achieved ($p < 0.05$), post-hoc T-tests were used to discern significant differences. Independent t-tests were performed between groups to discern significant differences in percent, or relative change. Statistical procedures were performed using GraphPad Prism version 6 for Windows.[42]

Diagram 1: DXA Scan Body Regions

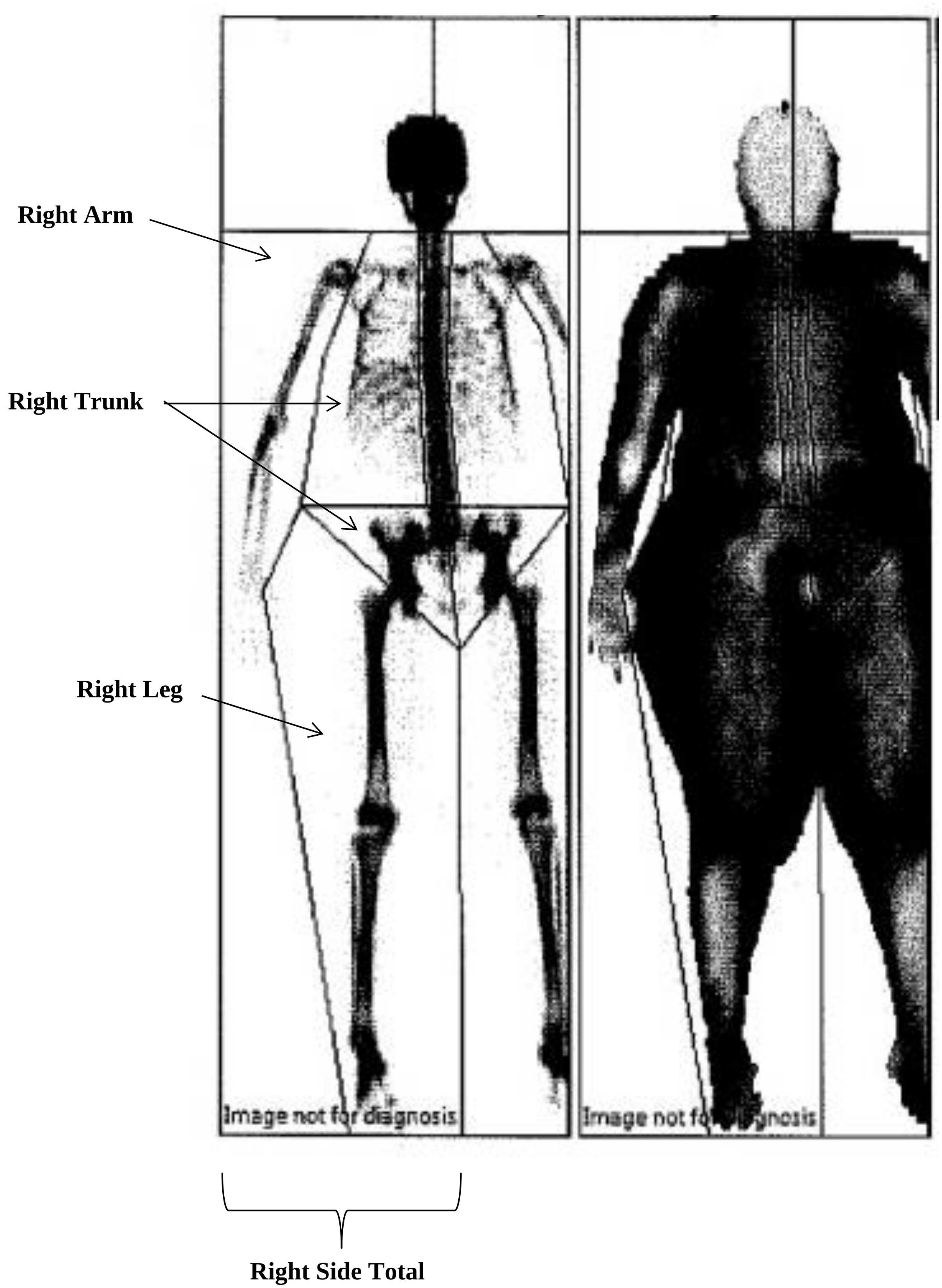


Diagram 2: DXA Scan Manipulation for Right Arm Segments

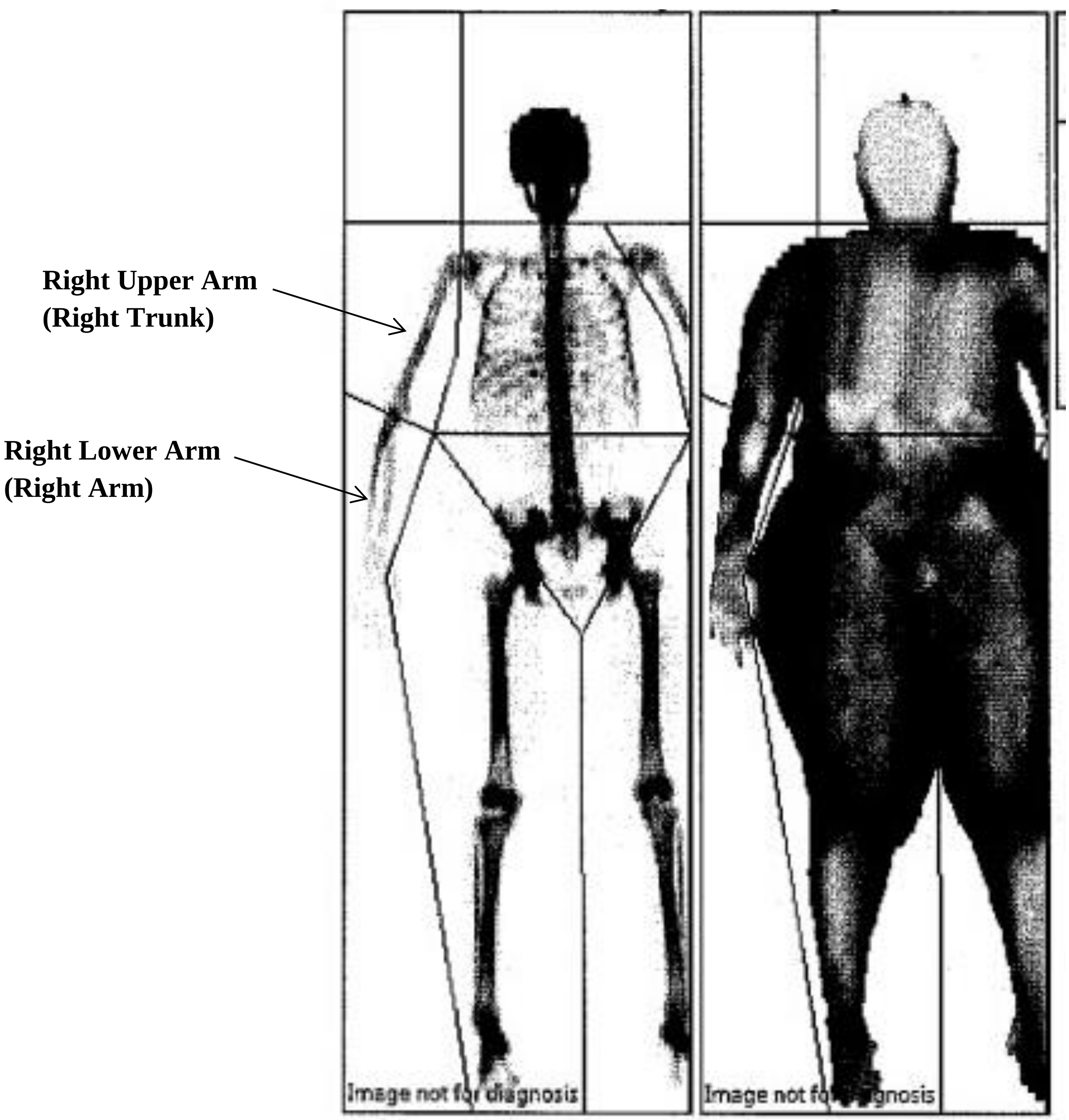
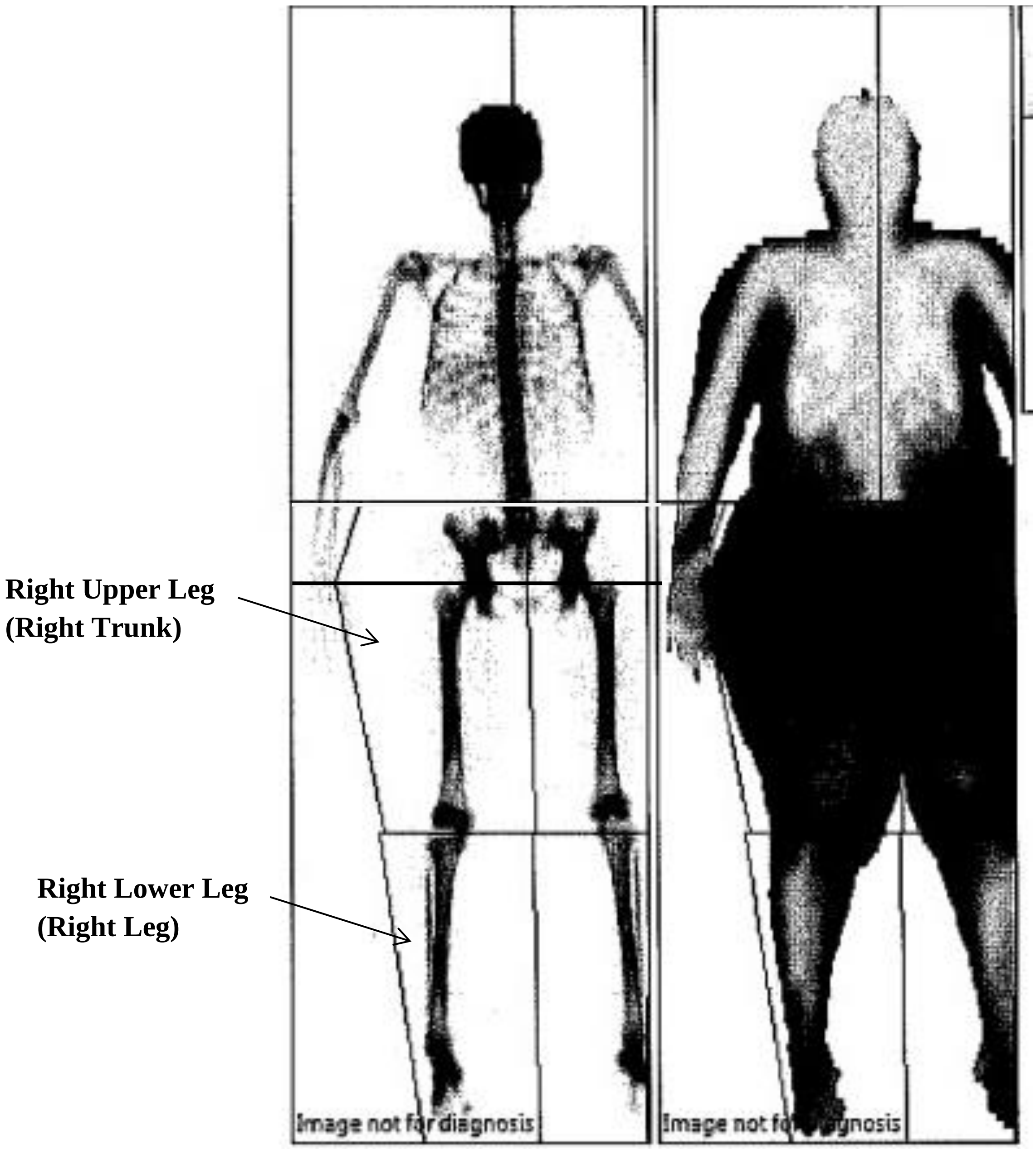


Diagram 3: DXA Scan Manipulation for Right Leg Segments



Chapter IV: Results

Forty-seven participants completed this study; 6 males, 41 females. Thirty-five participants were Caucasian and 12 were African American. The control group (CG) was comprised of 23 participants; 3 men, 19 women. The exercise group (EXG) included 24 participants; 3 men, 21 women. Only one participant's measurements were excluded from the exercise group's right upper arm analyses due to DXA operator error. The participant's measurements were deemed not different than the rest of the group. The time from surgery to baseline measurements was 72 days (standard error of mean (SEM) 5 days), ranging from 34-116 days in the control group, and 73 days (SEM 6 days), ranging from 31-133 days in the exercise group. There was no difference between groups for the baseline measurement timepoint.

Results showed no significant difference in measurements between groups at baseline. Baseline characteristics for each group are summarized in Table 3. Ages ranged from 22.4 to 61.0 years with the mean age of 42.7 years. The control group's mean initial weight was 98.6 kg (standard error of mean (SEM) 4.0 kg); mean weight loss over the 6 month intervention was 18.1 kg (standard error (SE) of diff 1.7 kg) or 18.0% (SEM 1.5%). Of the 18.1 kg weight loss, 16.6 kg was fat mass (mean decrease of 36.5%, SEM 3.1%), 1.2 kg was lean mass (mean decrease of 2.1%, SEM 1.5%). The exercise group's the mean initial weight was 106.2 kg (SEM 4.0 kg); mean weight loss over the 6 month intervention was 22.4 kg (SE of diff 1.7 kg) or 21.4% (SEM 1.3%). Of the exercise group's 22.4 kg weight loss, 10.6 kg was fat mass (mean decrease of 42.6%, SEM 3.7%), 2.2 kg was lean mass (mean decrease 4.0%, SEM 2.6%). There was no difference between groups' absolute or percent change for weight, fat mass, or lean mass loss.

Table 3: Baseline characteristics

	Control Group		Exercise Group	
	Mean	**SEM**	**Mean**	**SEM**
Age (years)	44.8	2.4	40.6	1.9
Weight (kg)	97.7	4	106.2	4
Height (m)	1.67	0.01	1.66	0.01
BMI (kg/m^2)	35.2	1.3	38.6	1.4
Tissue % Fat	49.3	1.4	50.4	1.04
Tissue % Lean	49.3	1.3	48	1.1
Fat (kg)	47.3	2.9	51.5	2.5
Lean (kg)	47.5	1.5	50.2	1.9

Right Side Total

Right side total includes the entire right half of the body. Results are summarized in Table 4. Results showed significant decreases in the exercise and control groups over time ($P<0.001$) for right side total tissue % fat (excludes bone) (Figure 1), region % fat (includes bone), tissue mass (excludes bone), fat mass (Figure 2), and total mass (includes bone), and increased in tissue % lean ($P<0.0001$). There was also a significant decrease over time in bone mineral content (BMC) ($P=0.016$). Right side total tissue % fat decreased 10.6% (SE of diff. 1.5%) in the control group and 13.2% (SE of diff. 1.4%) in the exercise group. Fat mass decreased 8.4 kg (SE of diff. 0.8 kg) in the control group and 10.6 kg (SE of diff. 0.8 kg) in the exercise group. There was some evidence that lean mass decreased over time ($P=0.027$) although post hoc tests revealed no significance (Figure 3). Lean mass decreased 1.1 kg (SE of diff. 0.5 kg) in the control group and 0.6 kg (SEM of 0.5 kg) in the exercise group. The only difference between groups was a trend toward a difference in the relative decrease of tissue mass ($P=0.095$) and total mass ($P=0.090$), with the exercise group decreasing more than the control group. These results are supported by a trend toward an interaction effect for total tissue (P=0.066), total mass (P=0.059), as well as fat tissue (P=0.061); however, post-hoc tests revealed no significant differences.

Table 4: Right Side Total Result Comparisons

Right Side Total	Control				Exercise			
	Baseline	6 mo post	Absolute change	Percent change -%	Baseline	6 mo post	Absolute change	Percent change -%
Tissue % fat (%)	49	38.5*	-10.6 ± 1.5	-22.6 ± 3.0	50.2	37*	-13.2 ± 1.4	-26.6 ± 3.4
Tissue % lean (%)	49.3	59.2*	9.9 ± 1.4	20.0 ± 2.2	48	60.6*	12.6 ±1.4	26.7 ± 3.7
Tissue (kg)	47.6	38.7*	-9.0 ± 1.1	-28.5 ± 1.6	51.2	39.4*	-11.8 ± 1.0	-23.4 ± 2.4
Fat mass (kg)	23.6	15.3*	-8.4 ± 0.8	-36.5 ± 3.1	25.8	15.2*	-10.6 ± 0.8	-42.6 ± 3.7
Lean mass (kg)	24	23.4	-0.6 ± 0.6	-2.1 ± 1.5	25.3	24.2	-1.1 ± 0.5	-4.0 ± 2.6
BMC (g)	1612	1523	-89.6 ± 66.3	-5.7 ± 2.4	1721	1579	-142 ± 64.9	-7.3 ± 4.0

Baseline is the initial measurement; 6 mo post is the measurement taken 6 months after the baseline measurements.
* (p<0.05) significantly different from baseline within the group.

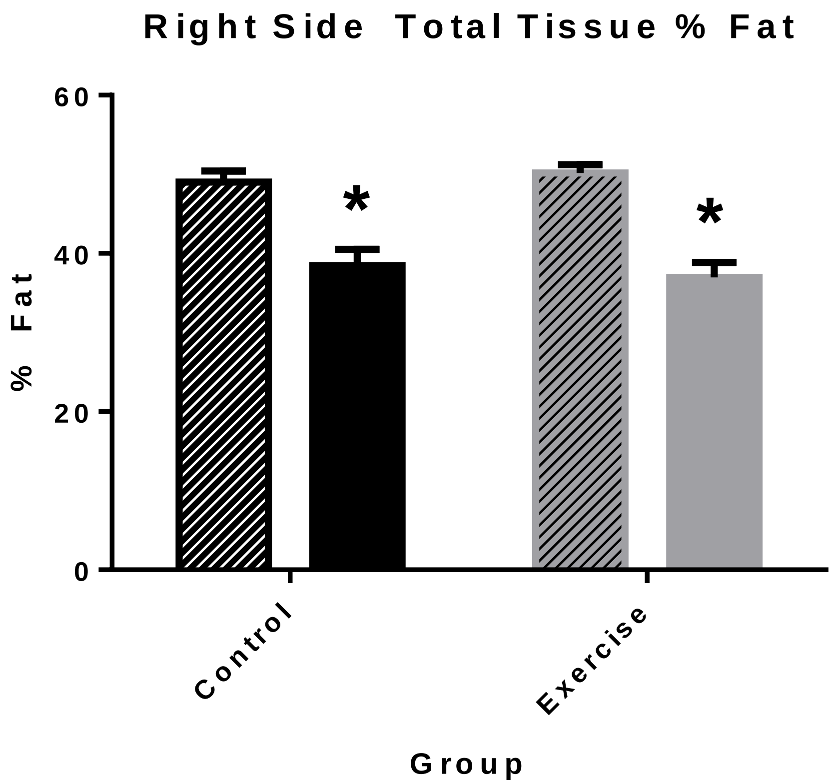


Figure 1: Right side tissue % fat comparison over 6-month intervention of the control group (CG) and exercise group (EXG). CG group with only gastric bypass, EXG group with gastric bypass and exercise. Patterned bars are pre-intervention, solid bars are post-intervention. *p<0.05 versus pre-intervention.

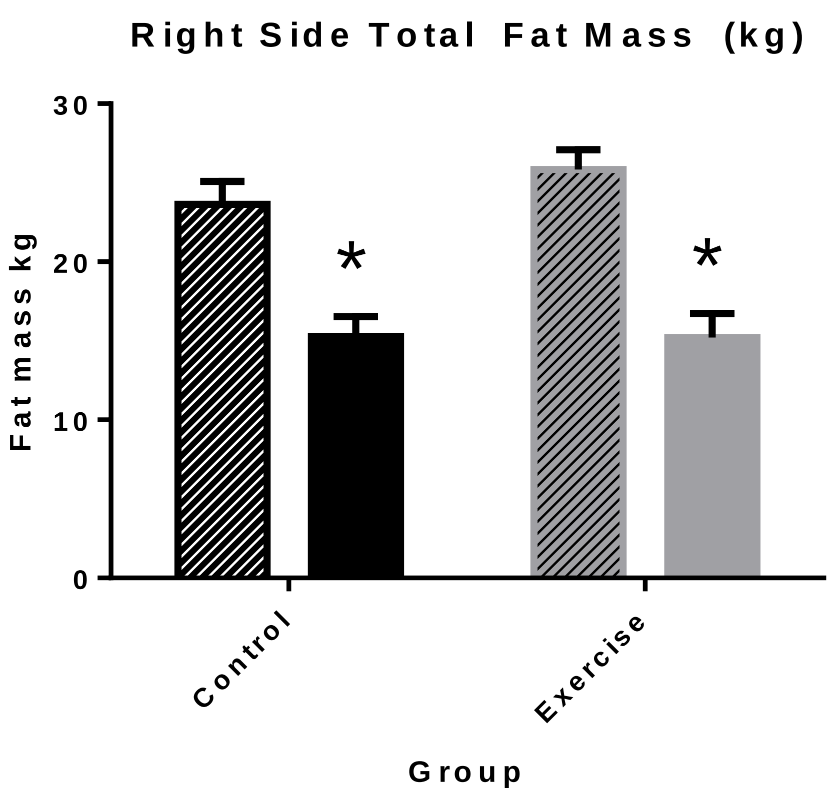


Figure 2: Right side fat mass comparison over 6-month intervention of control group (CG) and exercie group (EXG). CG group with only gastric bypass, EXG group with gastric bypass and exercise. Patterned bars are pre-intervention, solid bars are post-intervention. *p<0.05 versus pre-intervention.

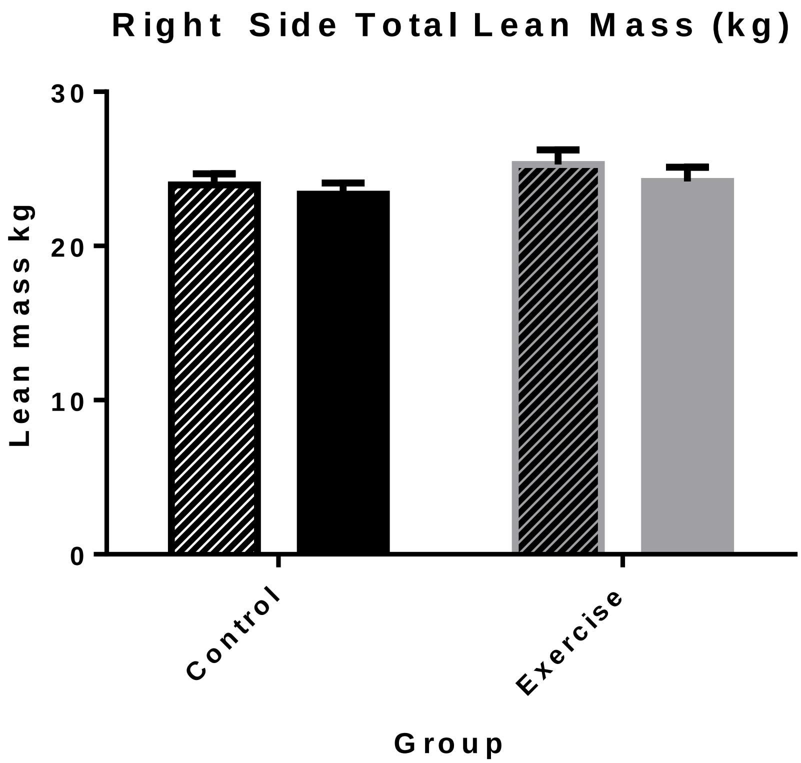


Figure 3: Right side lean mass comparison over 6-month intervention of control group (CG) and exercise group (EXG). CG group with only gastric bypass, EXG group with gastric bypass and exercise. Patterned bars are pre-intervention, solid bars are post-intervention. No significant changes were found between or within groups.

Right Trunk

Right trunk measurement is comprised of the right half of the torso, excluding the head, arms, and legs. Results are summarized in Table 5. Right trunk showed significant decreases over time for tissue % fat (excludes bone) (Figure 4), region % fat (includes bone), tissue mass (excludes bone), fat mass (Figure 5), and total mass (includes bone) (P<0.001), and an increase in tissue % lean (P<0.001). BMC also decreased over time (P=0.017) although post-hoc tests showed it was not significant. Tissue % fat decreased 12.9% (SE of diff. 1.9%) in the control group, and 15.7% (SE of diff. 1.9%) in the exercise group. Fat tissue decreased 4.7 kg (SE of diff. 0.4 kg) in the control group, and 5.8 kg (SE of diff. 0.4 kg) in the exercise group. There was a trend toward a significant difference over time in lean mass (P=0.071) (Figure 6); lean mass decreased 0.3 kg (SE of diff. 0.3 kg) in the control group and 0.5 kg (SE of diff. 0.3 kg) in the exercise group. There was no difference in relative decrease between groups for tissue % fat, fat mass, or lean mass. In contrast, the exercise group's tissue mass (P=0.032) and total mass (0.030) showed significantly greater relative decrease than the control group. Tissue mass decreased 21.5% (SEM 1.7%) in the control group and 28.5% (SEM 2.7%) in the exercise group (Figure 7). Despite the difference in relative change between groups, post hoc tests revealed no significant interaction (Figure 8).

Table 5: Right Trunk Result Comparisons

Right Trunk	**Control**				**Exercise**			
	Baseline	**6 mo post**	**Absolute change**	**Percent change -%**	**Baseline**	**6 mo post**	**Absolute change**	**Percent change -%**
Tissue % fat (%)	51	38.1*	-12.9 ± 1.9	-26.1 ± 3.4	52.4	37.6*	-14.9 ± 1.9	-29.7 ± 4.2
Tissue % lean (%)	47.9	60.3*	9.9 ± 1.4	12.4 ± 1.9	46.5	61.22*	14.7 ± 1.8	32.8 ± 5.0
Tissue (kg)	46.1	36.4*	-9.7 ± 0.9	-21.5 ± 1.7	48.8	36.2*	-12.6 ± 0.9	-26.4 ± 1.5 **
Fat mass (kg)	23.7	14.3*	-9.4 ± 0.8	-41.6 ± 3.3	25.5	14.1*	-11.5 ± 0.8	-47.3 ± 3.8
Lean mass (kg)	22.4	22.1	-0.3 ± 0.6	-1.2 ± 2.4	23.2	22.1	-1.2 ± 0.6	-2.5 ± 2.6
BMC (g)	1010	920.3	-89.7 ± 56.9	-7.3 ± 5.4	1112	1017	-95.3 ± 55.7	-8.3 ± 5.9

Baseline is the initial measurement; 6 mo post is the measurement taken 6 months after the baseline measurements.
* (p<0.05) significantly different from baseline within the group.
** (P<0.05) significantly different between groups.

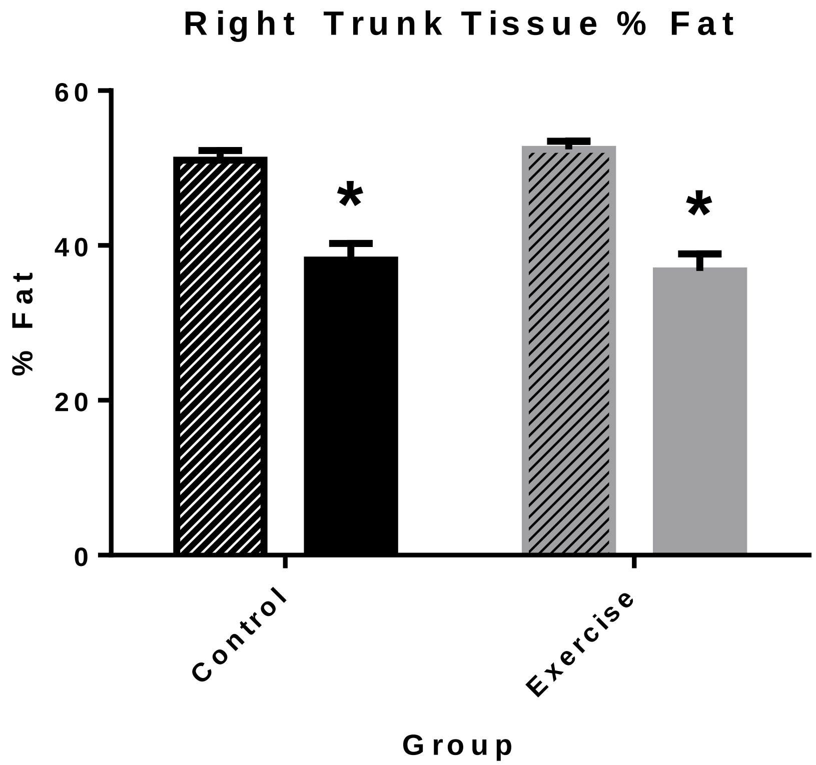


Figure 4: Right trunk tissue % fat comparison over 6-month intervention of control group (CG) and exercise group (EXG). CG group with only gastric bypass, EXG group with gastric bypass and exercise. Patterned bars are pre-intervention, solid bars are post-intervention. *p<0.05 versus pre-intervention.

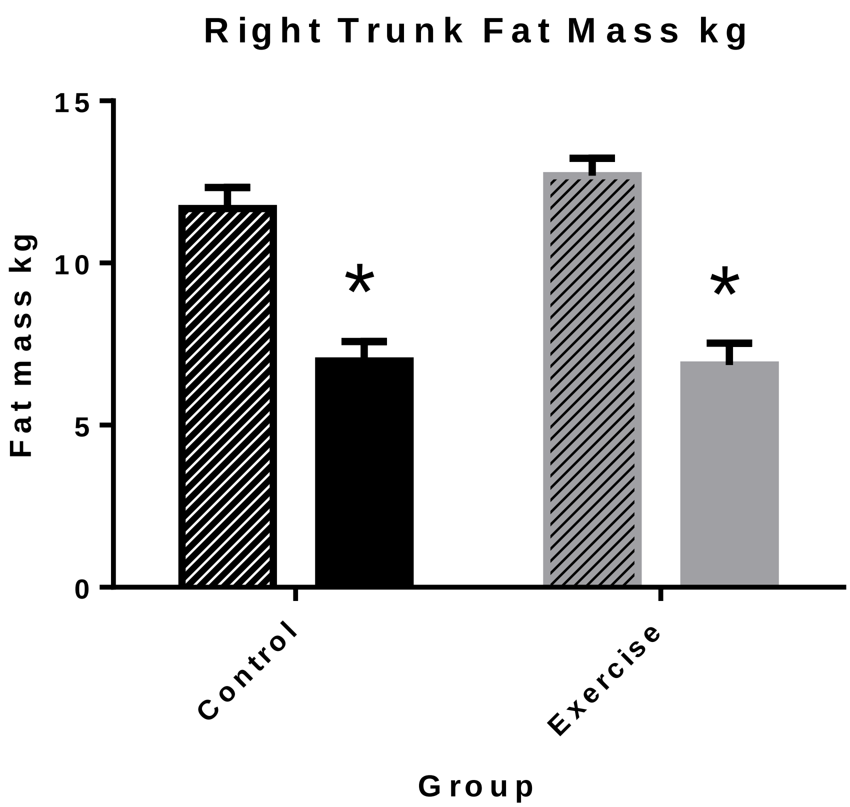


Figure 5: Right trunk fat mass comparison over 6-month intervention of control group (CG) and exercise group (EXG). CG group with only gastric bypass, EXG group with gastric bypass and exercise. Patterned bars are pre-intervention, solid bars are post-intervention. *p<0.05 versus pre-intervention.

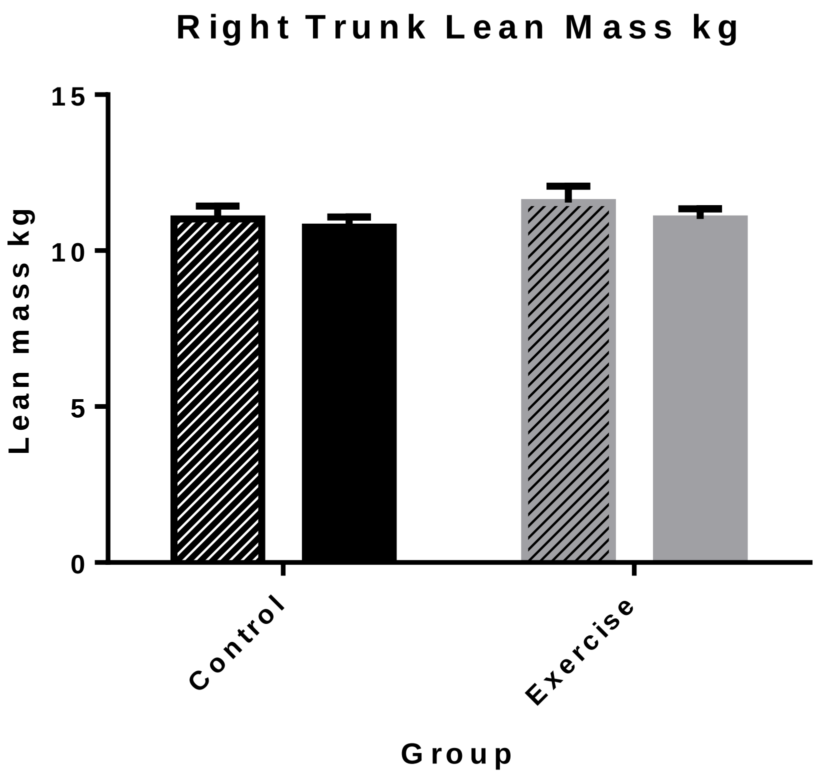


Figure 6: Right trunk lean mass comparison over 6-month intervention of control group (CG) and exercise group (EXG). CG group with only gastric bypass, EXG group with gastric bypass and exercise. Patterned bars are pre-intervention, solid bars are post-intervention. No significant differences between and within groups were found.

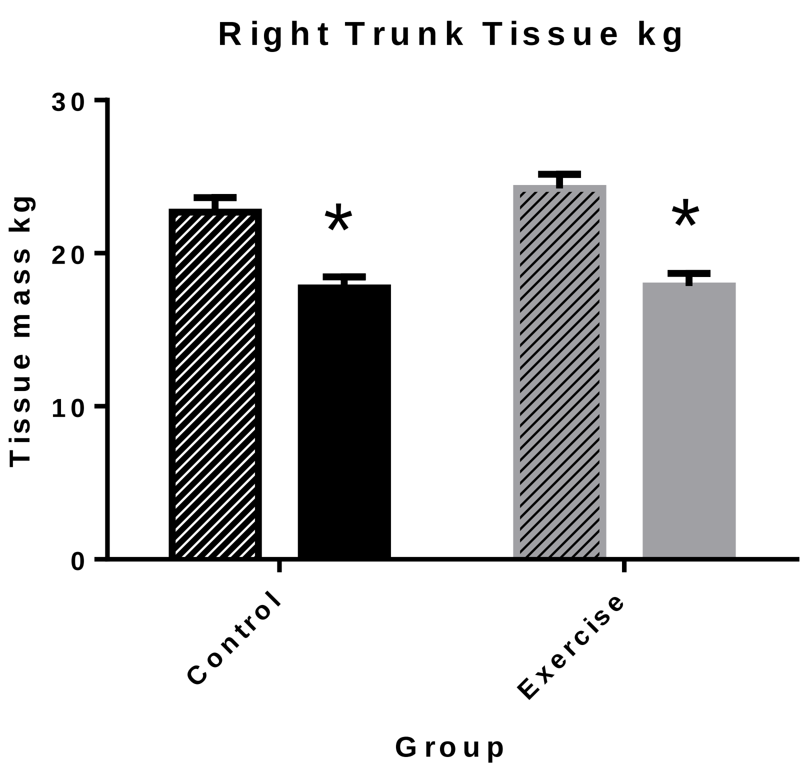


Figure 7: Right trunk tissue mass comparison over 6-month intervention of control group (CG) and exercise group (EXG). CG group with only gastric bypass, EXG group with gastric bypass and exercise. Patterned bars are pre-intervention, solid bars are post-intervention. *$p<0.05$ versus pre-intervention.

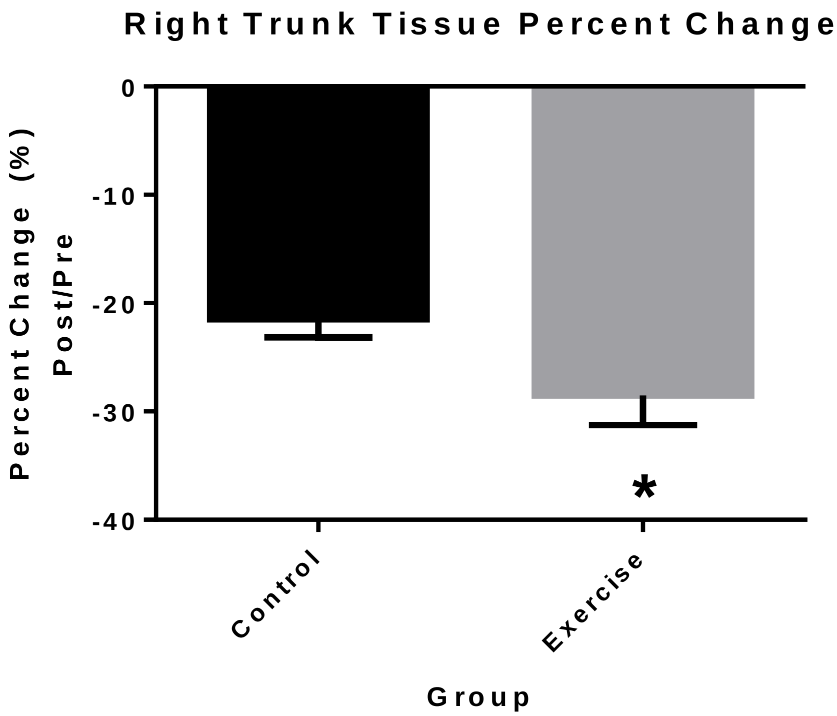


Figure 8: Percent change of right trunk tissue mass over the 6 month intervention of control group (CG) and exercise group (EXG). CG with only gastric bypass surgery, EXG with gastric bypass and exercise. *p<0.05 between groups.

Right Arm

Both groups showed significant decreases over time in right arm tissue % fat (Figure 9), region % fat, tissue mass, total mass, and fat mass (Figure 10) (P<0.001). Tissue % lean decreased only in the exercise group but was maintained in the control group thus resulting in an interaction. Table 6 summarizes the results. Tissue % fat decreased 8.8% (SE of diff. 1.3%) in the control group and 13.6% (SE of diff. 1.3%) in the exercise group. Fat mass decreased 0.8 kg (SE of diff. 0.1 kg) in the control group and 1.1 kg (SE of diff. 0.1 kg) in the exercise group. There was a trend toward a decrease over time for lean mass (Figure 12) (P=0.067). Control group lean mass decreased 0.1 kg (SE of diff. 0.05 kg) whereas exercise group lean mass decreased minimally by 0.03 kg (SE of diff. 0.05 kg). Interestingly, right arm BMC also showed a decrease over time in the control group (P=0.032), but not the exercise group (P=0.983), resulting in an interaction effect (P=0.057) (Figure 11). The control group BMC decreased 6.4 g (SE of diff. 2.4 g) whereas the exercise group did not change over time (decreased 0.04 g (SE of diff. 2.4 g)). Despite the interaction effect in BMC, there was no difference in percent change between groups (Figure 13). The right arm also showed possible interaction effects in tissue % fat (P=0.009), region % fat (P=0.019) and fat mass (P=0.05) although post-hoc tests revealed no differences between the groups.

Table 6: Right Arm Result Comparisons

Right Arm	**Control**				**Exercise**			
	Baseline	**6 mo post**	**Absolute change**	**Percent change -%**	**Baseline**	**6 mo post**	**Absolute change**	**Percent change -%**
Tissue % fat (%)	45.7	36.9*	-8.8 ± 1.3	-20.7 ± 3.1	49.9	36.3*	-28.0 ± 3.2	-26.6 ± 3.4
Tissue % lean (%)	37.6	39.3	-1.7 ± 1.9	-5.8 ± 5.3	49.5	43.7*	5.8 ± 1.8ᴪ	11.2 ± 3.4**
Tissue (kg)	47.6	38.7*	-9.0 ± 1.1	-28.5 ± 1.6	51.2	39.4*	-11.8 ± 1.0	-23.4 ± 2.4
Fat mass (kg)	23.6	15.3*	-8.4 ± 0.8	-36.5 ± 3.1	25.8	15.2*	-10.6 ± 0.8	-42.6 ± 3.7
Lean mass (kg)	24	23.4	-0.6 ± 0.6	-2.1 ± 1.5	25.3	24.2	-1.1 ± 0.5	-4.0 ± 2.6
BMC (g)	1612	1523*	-89.6 ± 66.3	-5.7 ± 2.4	1721	1579	-142 ± 64.9ᴪ	-7.3 ± 4.0

Baseline is the initial measurement; 6 mo post is the measurement taken 6 months after the baseline measurements.

***** (p<0.05) significantly different from baseline within the group.

****** (P<0.05) significantly different between groups.

ᴪ (p<0.05) significant interaction between groups.

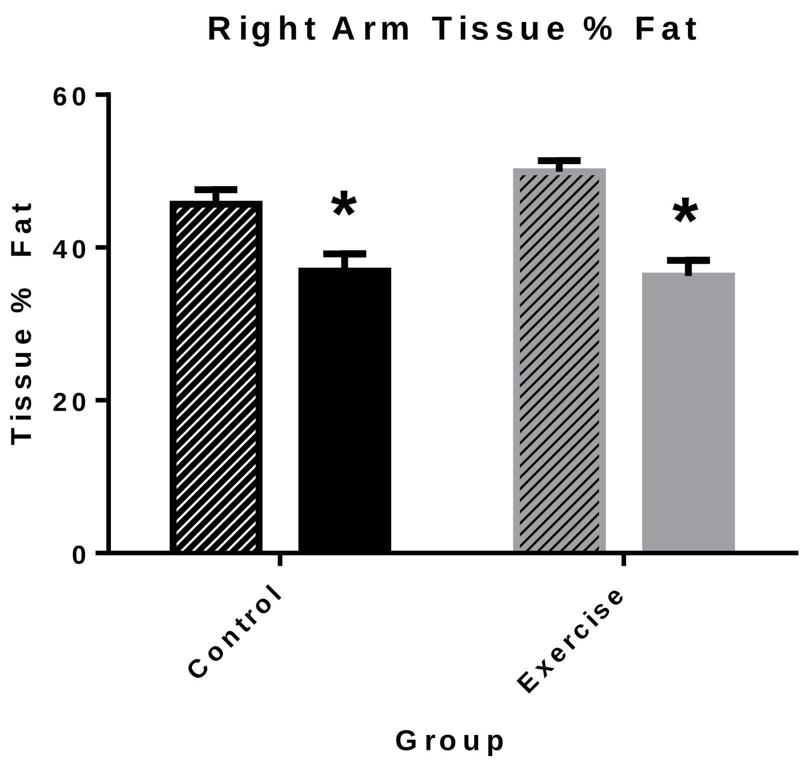


Figure 9: Right arm tissue % fat comparison over 6-month intervention of control group (CG) and exercise group (EXG). CG group with only gastric bypass, EXG group with gastric bypass and exercise. Patterned bars are pre-intervention, solid bars are post-intervention. *$p<0.05$ versus pre-intervention.

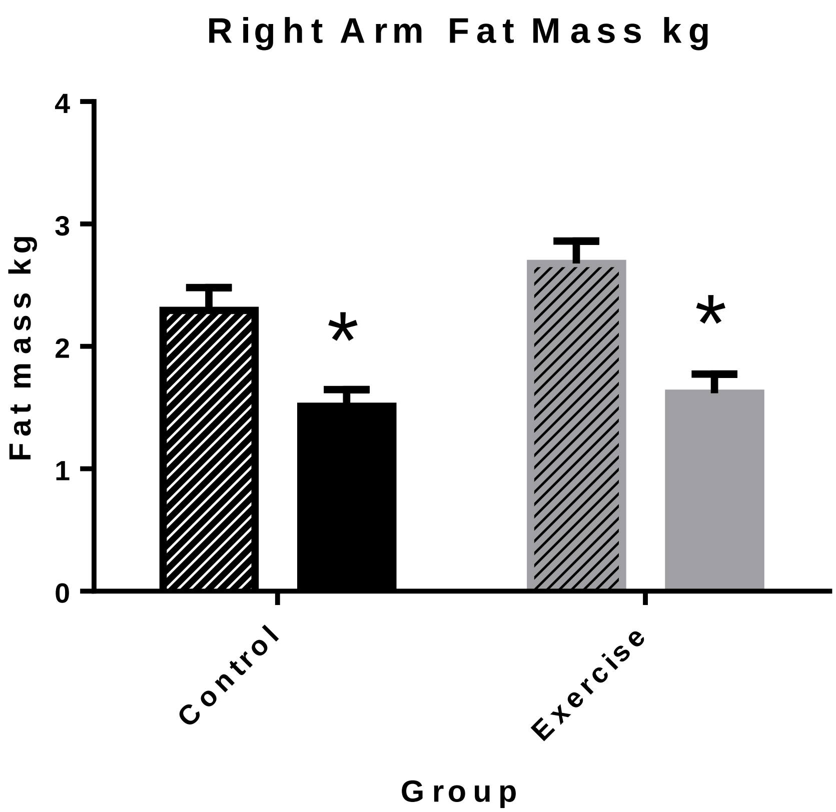


Figure 10: Right arm fat mass comparison over 6-month intervention of control group (CG) and exercise group (EXG). CG group with only gastric bypass, EXG group with gastric bypass and exercise. Patterned bars are pre-intervention, solid bars are post-intervention. *$p<0.05$ versus pre-intervention.

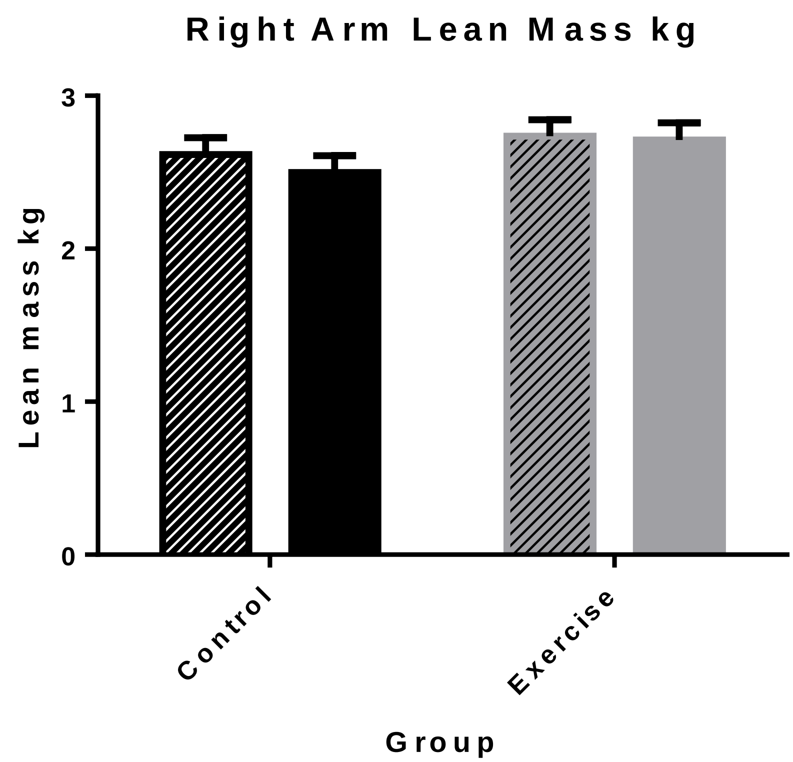


Figure 11: Right arm lean mass comparison over 6-month intervention of control group (CG) and exercise group (EXG). CG group with only gastric bypass, EXG group with gastric bypass and exercise. Patterned bars are pre-intervention, solid bars are post-intervention. No significant differences within or between groups were found.

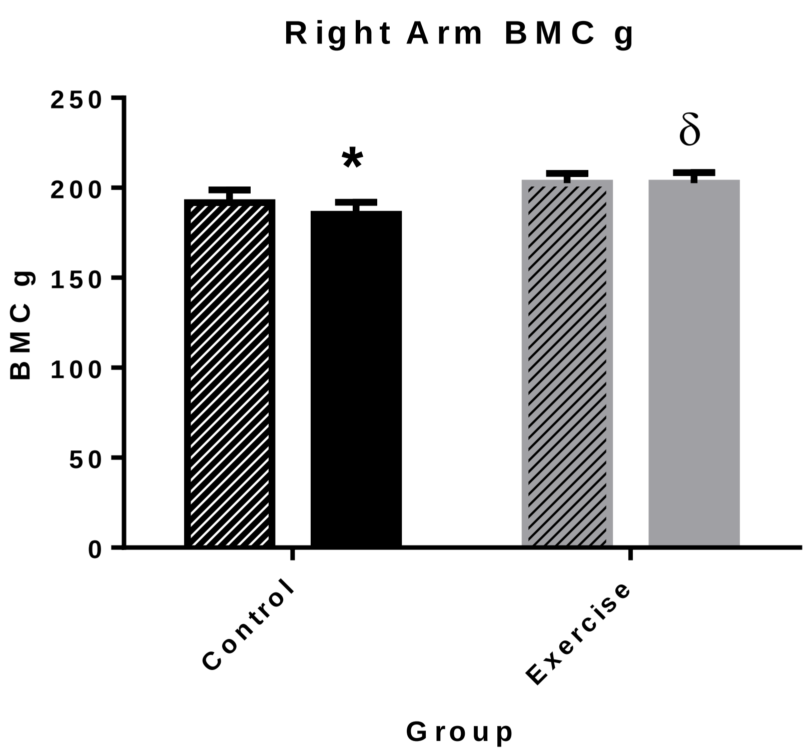


Figure 12: Right arm BMC comparison over 6-month intervention of control group (CG) and exercise group (EXG). CG group with only gastric bypass, EXG group with gastric bypass and exercise. Patterned bars are pre-intervention, solid bars are post-intervention. $*p<0.05$ versus pre-intervention. δ $p<0.05$ interaction effect versus control group post-intervention.

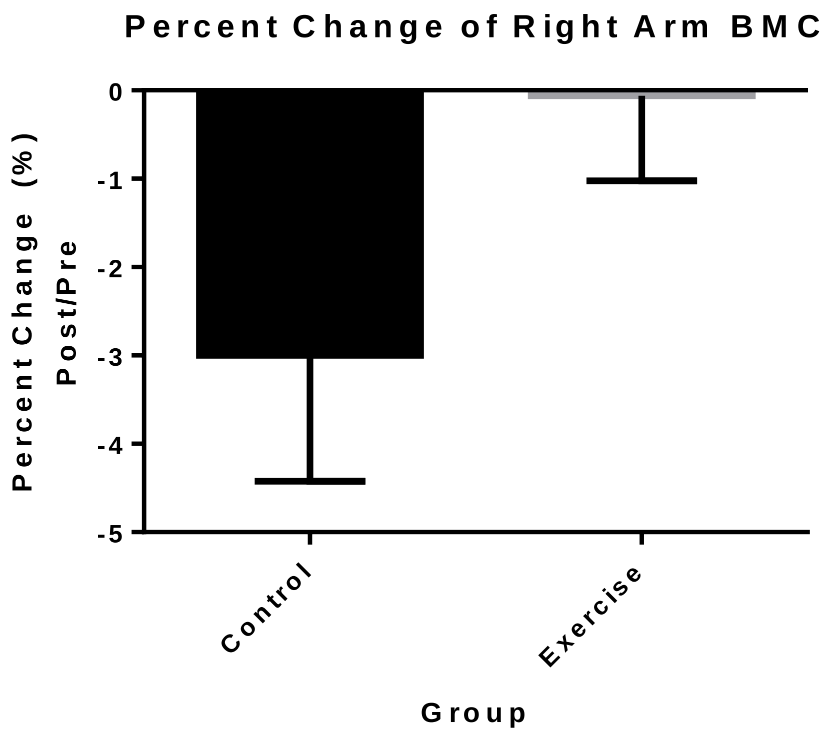


Figure 13: Percent change of right arm BMC over the 6 month intervention of control group (CG) and exercise group (EXG). CG with only gastric bypass surgery, EXG with gastric bypass and exercise. No significant differences between groups were found..

Right leg

The right leg showed significant decreases over time in both groups in tissue % fat (Figure 14) region % fat, total mass, tissue mass, and fat mass (Figure 15) (P<0.001), and a significant increase in tissue % lean (P<0.001). Results are summarized in Table 7. Right leg tissue % fat decreased 8.8% (SE of diff. 1.3%) in the control group and 11.3% (SE of Diff. 1.3%) in the exercise group. Fat mass decreased 2.8 kg (SE of diff. 0.4 kg) in the control group and 3.4 kg (SE of diff. 0.4 kg) in the exercise group. Lean mass and BMC did not change significantly over time (P=0.18; P=0.43 respectively). Lean mass (Figure 16) decreased 0.1 kg (SE of diff 0.3 kg) in the control group and 0.4 kg (SE of diff. 0.3 kg) in the exercise group. There was no evidence of interaction effects or differences in percent change between groups.

Table 7: Right Leg Result Comparisons

Right Leg	Control				Exercise			
	Baseline	6 mo post	Absolute change	Percent change -%	Baseline	6 mo post	Absolute change	Percent change -%
Tissue % fat (%)	50.1	41.3*	-8.8 ± 1.3	-18.7 ± 2.9	50.4	39.1*	-11.3 ± 1.3	-22.6 ± 3.0
Tissue % lean (%)	48.2	56.3*	8.1 ± 1.6	16.9 ± 2.0	47.0	58.3*	11.3 ±1.5	21.6 ± 3.1
Tissue (kg)	17.7	14.8*	-2.9 ± 0.6	-15.6± 1.7	19.1	15.3*	-3.8 ± 0.5	-20.2 ± 3.6
Fat mass (kg)	9.1	6.3*	-2.8 ± 0.4	-31.1 ± 3.1	9.8	6.4*	-3.4 ± 0.4	-36.7 ± 3.9
Lean mass (kg)	8.6	8.5	-0.1 ± 0.3	-1.2 ± 1.7	9.4	9.0	-0.4 ± 0.3	-4.7 ± 4.2
BMC (g)	599.6	596.9	-2.7 ± 21.5	-0.7 ± 1.3	634.9	613.8	-21.0 ± 21.1	-2.9 ± 3.9

Baseline is the initial measurement; 6 mo post is the measurement taken 6 months after the baseline measurements.

***** ($p<0.05$) significantly different from baseline within the group.

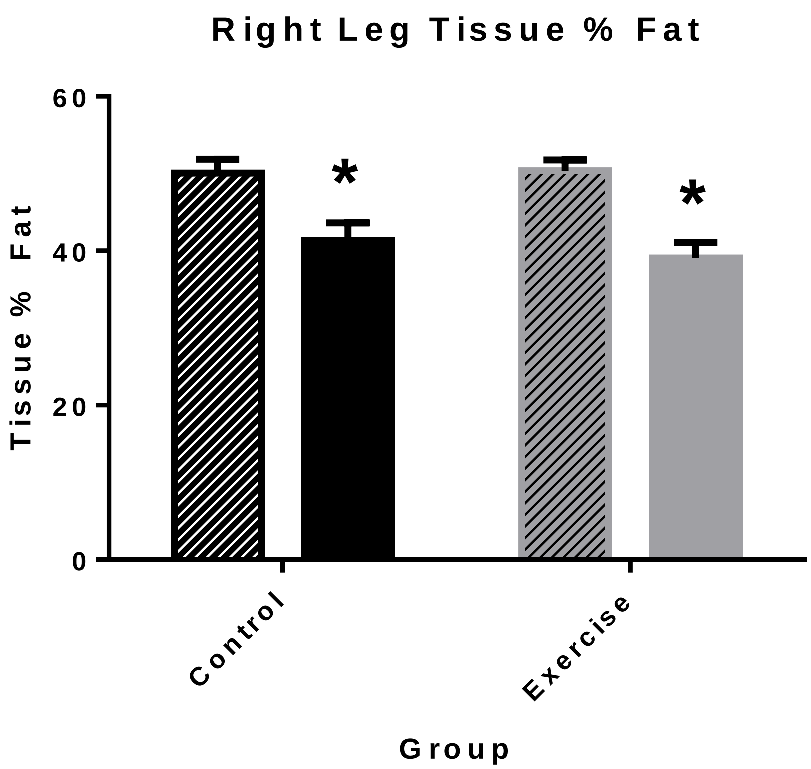


Figure 14: Right arm tissue % fat comparison over 6-month intervention of control group (CG) and exercise group (EXG). CG group with only gastric bypass, EXG group with gastric bypass and exercise. Patterned bars are pre-intervention, solid bars are post-intervention. *p<0.05 versus pre-intervention.

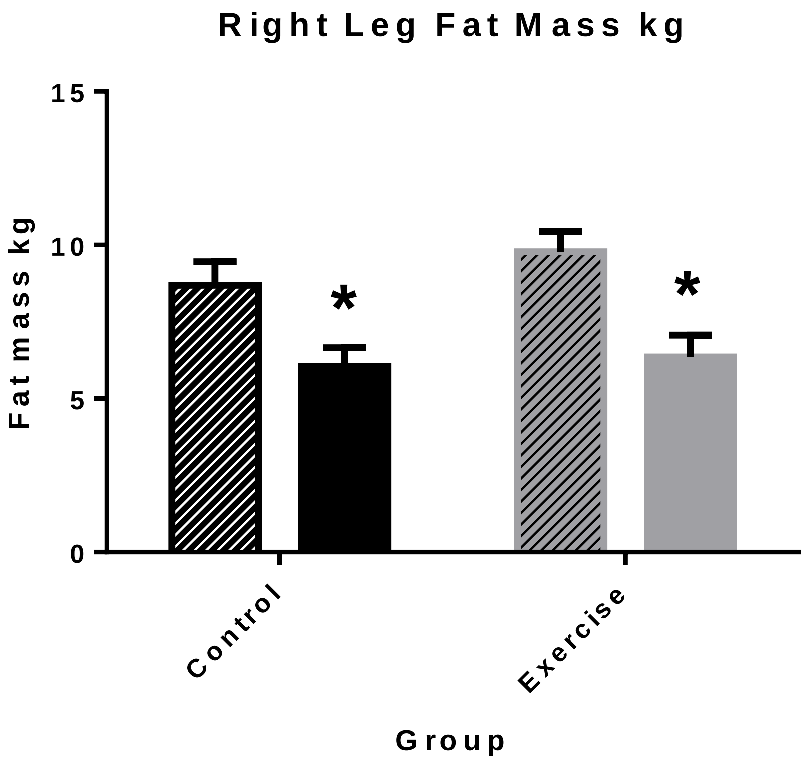


Figure 15: Right leg fat mass comparison over 6-month intervention of control group (CG) and exercise group (EXG). CG group with only gastric bypass, EXG group with gastric bypass and exercise. Patterned bars are pre-intervention, solid bars are post-intervention. *p<0.05 versus pre-intervention.

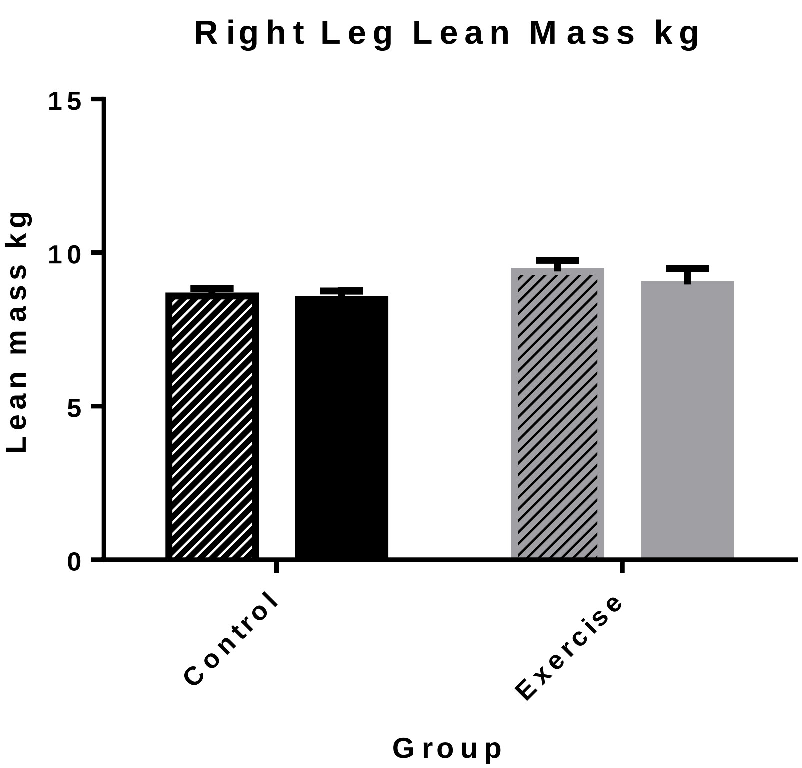


Figure 16: Right leg lean mass comparison over 6-month intervention of control group (CG) and exercise group (EXG). CG group with only gastric bypass, EXG group with gastric bypass and exercise. Patterned bars are pre-intervention, solid bars are post-intervention. No significant differences between or within groups were found.

Right arm segments

The right upper arm showed significant decreases over time in both groups for tissue % fat (Figure 18), region % fat, tissue mass, fat mass (Figure 17), lean mass (Figure 19), and total mass (P<0.001), and a significant increase in tissue % lean (P<0.001). Results are summarized in Table 8. Tissue % fat decreased 8.7 % (SE of diff. 2.5%) in the control group and 11.0% (SE of diff. 2.5) in the exercise group. Fat mass decreased 0.6 kg (SE of diff. 0.09 kg) in the control group and 0.8 kg (SE of diff. 0.09 kg) in the exercise group. Lean mass decreased 0.3 kg (SE of diff. 0.1 kg) in the control group and the exercise group decreased 0.4 kg (SE of diff. 0.1 kg). In contrast, BMC showed no significant change over time (P=0.307). There were no differences in percent change between groups.

Table 8: Right Upper Arm Result Comparisons

Right Upper Arm	Control				Exercise			
	Baseline	6 mo post	Absolute change	Percent change -%	Baseline	6 mo post	Absolute change	Percent change -%
Tissue % fat (%)	42.8	34.1*	-8.7 ± 2.5	-20.8 ± 5.6	44.4	33.4*	-11.0 ± 2.5	-24.8± 6.3
Tissue % lean (%)	55.9	63.7*	7.8 ± 2.4	14.4 ± 4.2	54.8	64.6*	9.8 ± 2.4	19.1 ± 5.0
Tissue (kg)	3.4	2.5*	-0.9 ± 0.1	-23.8 ± 3.0	4.3	3.2*	-1.1 ± 0.1	-27.1 ± 2.0
Fat mass (kg)	9.1	6.3*	-2.8 ± 0.4	-39.8 ± 4.8	9.8	6.4*	-3.4 ± 0.4	-44.2 ± 5.3
Lean mass (kg)	1.9	1.6*	-0.3 ± 0.1	-12.1 ± 4.4	2.4	2.0*	-0.4 ± 0.1	-13.0 ± 3.3
BMC (g)	85.1	83.9	-1.2 ± 3.5	0.2 ± 3.7	91.7	97.9	6.3 ± 3.5	7.7 ± 4.2

Baseline is the initial measurement; 6 mo post is the measurement taken 6 months after the baseline measurements.
***** (p<0.05) significantly different from baseline within the group.

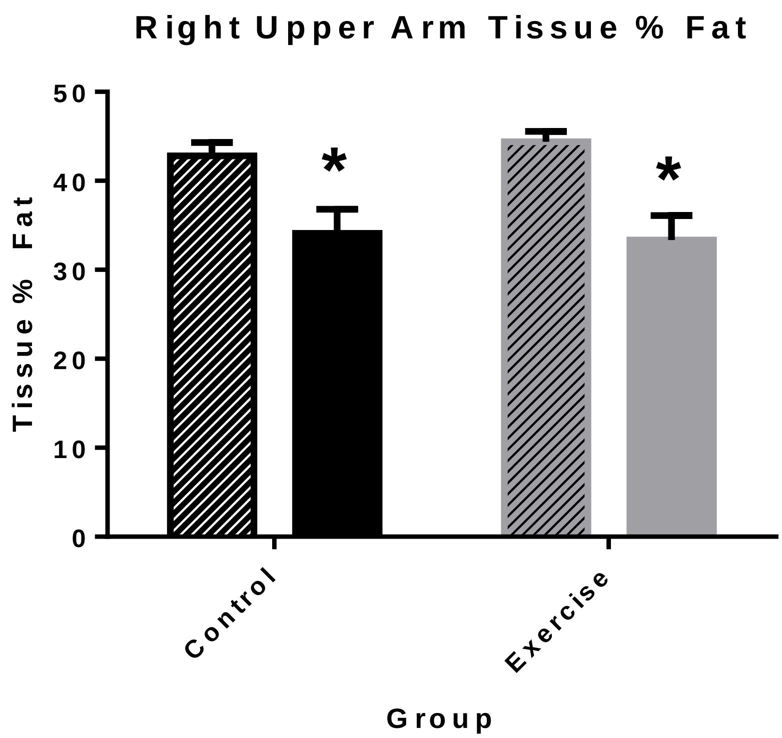


Figure 17: Right upper arm tissue % fat comparison over 6-month intervention of control group (CG) and exercise group (EXG). CG group with only gastric bypass, EXG group with gastric bypass and exercise. Patterned bars are pre-intervention, solid bars are post-intervention. *p<0.05 versus pre-intervention.

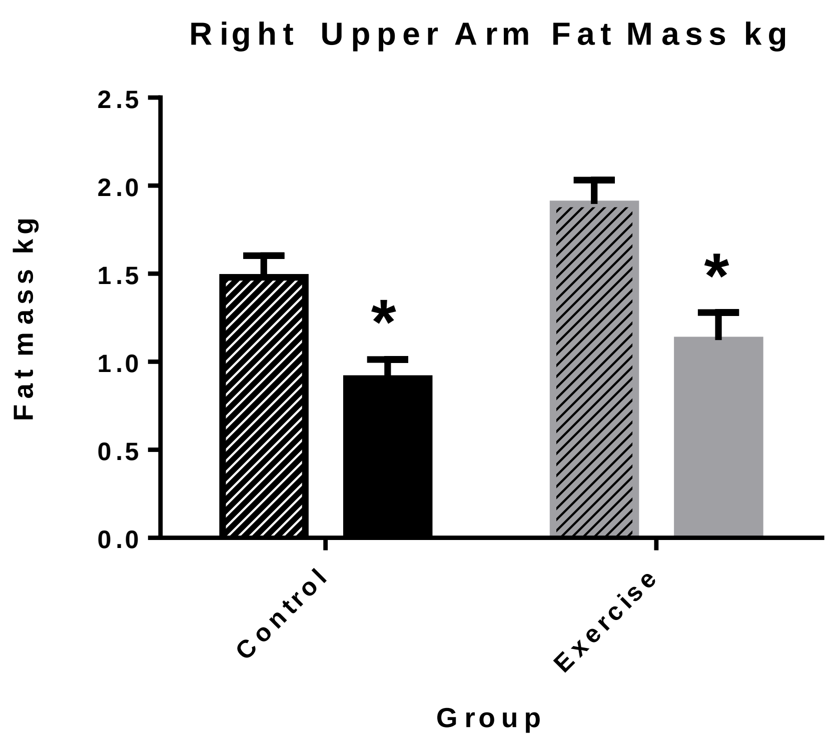


Figure 18: Right upper arm fat mass comparison over 6-month intervention of control group (CG) and exercise group (EXG). CG group with only gastric bypass, EXG group with gastric bypass and exercise. Patterned bars are pre-intervention, solid bars are post-intervention. *p<0.05 versus pre-intervention.

22).

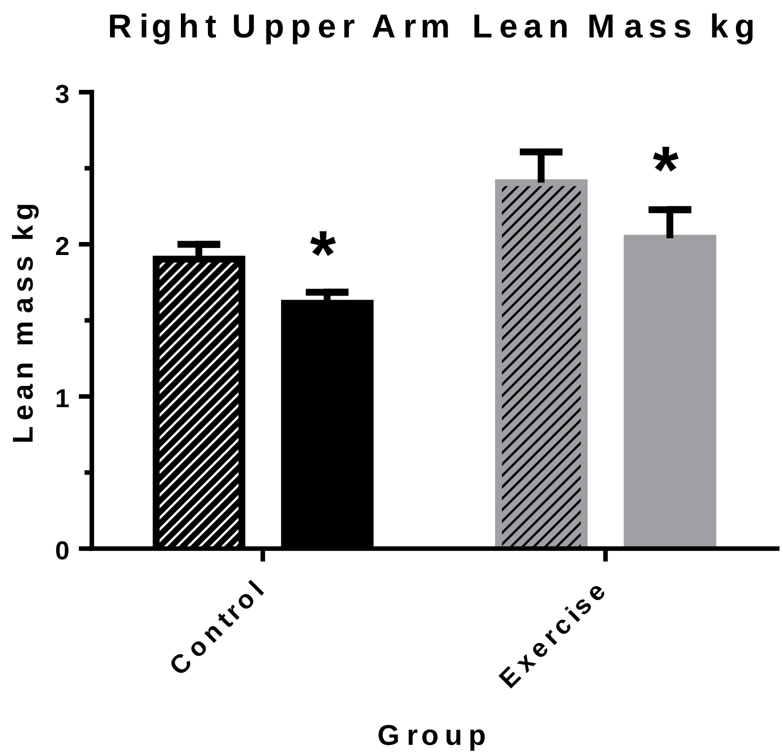


Figure 19: Right upper arm lean mass comparison over 6-month intervention of control group (CG) and exercise group (EXG). CG group with only gastric bypass, EXG group with gastric bypass and exercise. Patterned bars are pre-intervention, solid bars are post-intervention. *p<0.05 versus pre-intervention.

Both groups showed a significant decrease over time in right lower arm tissue % fat (Figure 20), region % fat, and fat mass (Figure 21) (P<0.001). Tissue mass (P=0.002) and total mass (P=0.002) also decreased significantly over time. Tissue % lean increased over time in both groups (P<0.001). Results are summarized in Table 9. Tissue % fat results indicated there may be an interaction effect, although post hoc testing showed no significance. Tissue % fat decreased 8.3% (SE of diff. 1.3%) in the control group and 11.8% (SE of diff. 1.2%) in the exercise group. Fat mass decreased 0.2 kg (SE of diff. 0.04 kg) in both the control and exercise groups. Lean mass (P=0.762) (Figure 22) and BMC (P=0.45) did not change significantly over time in either group; lean mass decreased 0.03 kg (SE of diff. 0.02 kg) in the control group and increased 0.02 kg (SE of diff. 0.02 kg) in the exercise group. There was a trend toward a significant difference (P=0.069) in the percent change of lean mass between groups; the control group decreased 3.4% (SEM 2.9%) but the exercise group increased 4.1% (SEM 2.8%) (Figure 22).

Table 9: Right Lower Arm Result Comparisons

Right Lower Arm	Control				Exercise			
	Baseline	6 mo post	Absolute change	Percent change -%	Baseline	6 mo post	Absolute change	Percent change -%
Tissue % fat (%)	41.2	32.9*	-8.3 ± 1.3	-22.0 ± 3.3	44.7	33.0*	-11.8 ± 1.2	-27.0 ± 3.6
Tissue % lean (%)	55.6	60.6*	5.1 ± 1.9	-11.4 ± 3.7	52.3	61.1*	8.8 ± 1.8	-17.6 ± 3.5
Tissue (kg)	1.4	1.2*	-0.2 ± 0.1	-12.1 ± 5.5	1.4	1.2*	-0.2 ± 0.1	-10.6 ± 3.8
Fat mass (kg)	0.6	0.4*	-0.2 ± 0.04	-31.8 ± 4.9	0.6	0.4*	-0.2 ± 0.03	-36.1 ± 3.1
Lean mass (kg)	0.8	0.8	-0.03 ± 0.02	-3.4 ± 2.9	0.8	0.8	0.02 ± 0.02	4.1 ± 2.8
BMC (g)	289.8	279.0	-10.9 ± 2.1	-2.3 ± 2.9	306.9	295.2	-11.7 ± 2.0	0.5 ± 1.8

Baseline is the initial measurement; 6 mo post is the measurement taken 6 months after the baseline measurements.

***** ($p<0.05$) significantly different from baseline within the group.

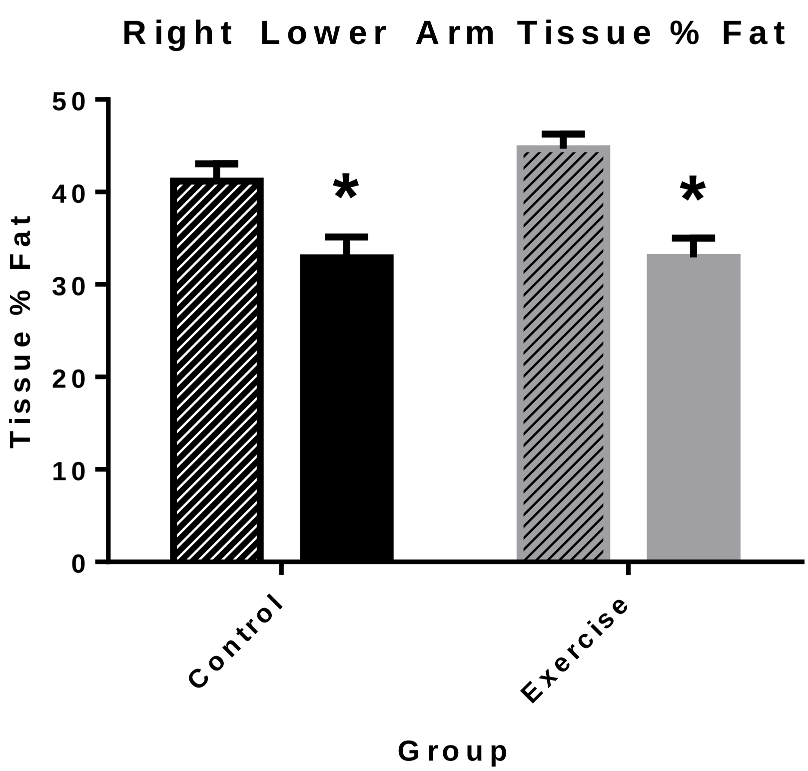


Figure 20: Right lower arm tissue % fat comparison over 6-month intervention of control group (CG) and exercise group (EXG). CG group with only gastric bypass, EXG group with gastric bypass and exercise. Patterned bars are pre-intervention, solid bars are post-intervention. *p<0.05 versus pre-intervention.

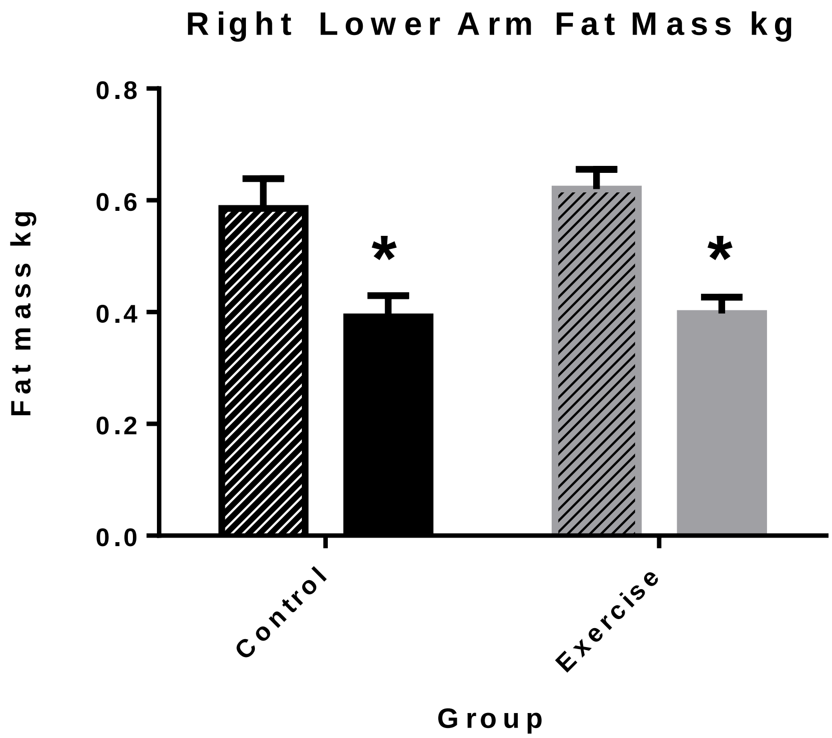


Figure 21: Right lower arm fat mass comparison over 6-month intervention of CG and EXG. CG group with only gastric bypass, EXG group with gastric bypass and exercise. Patterned bars are pre-intervention, solid bars are post-intervention. *$p<0.05$ versus pre-intervention.

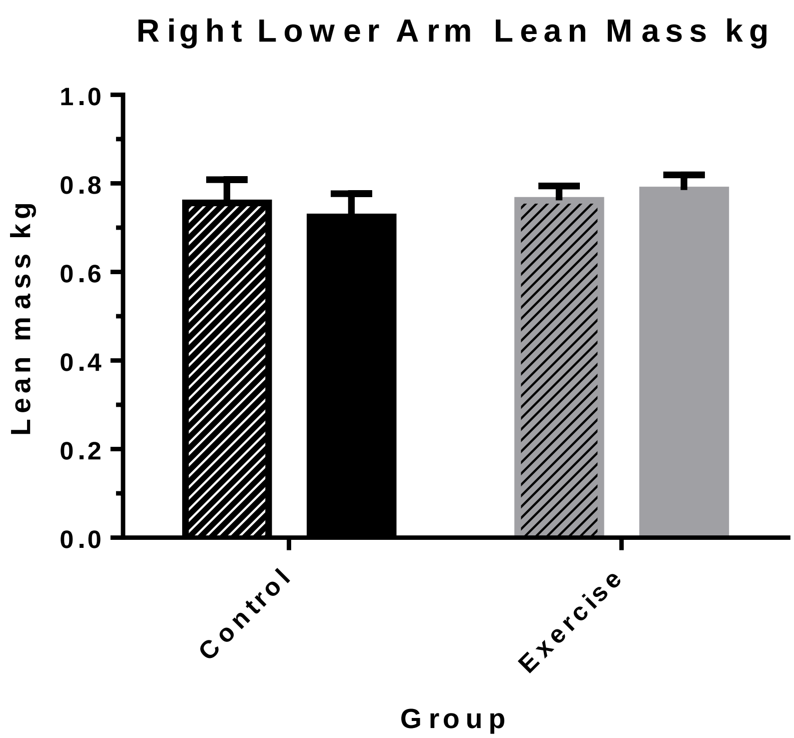


Figure 22: Right lower arm lean mass comparison over 6-month intervention of control group (CG) and exercise group (EXG). CG group with only gastric bypass, EXG group with gastric bypass and exercise. Patterned bars are pre-intervention, solid bars are post-intervention. No significant differences between or within groups were found..

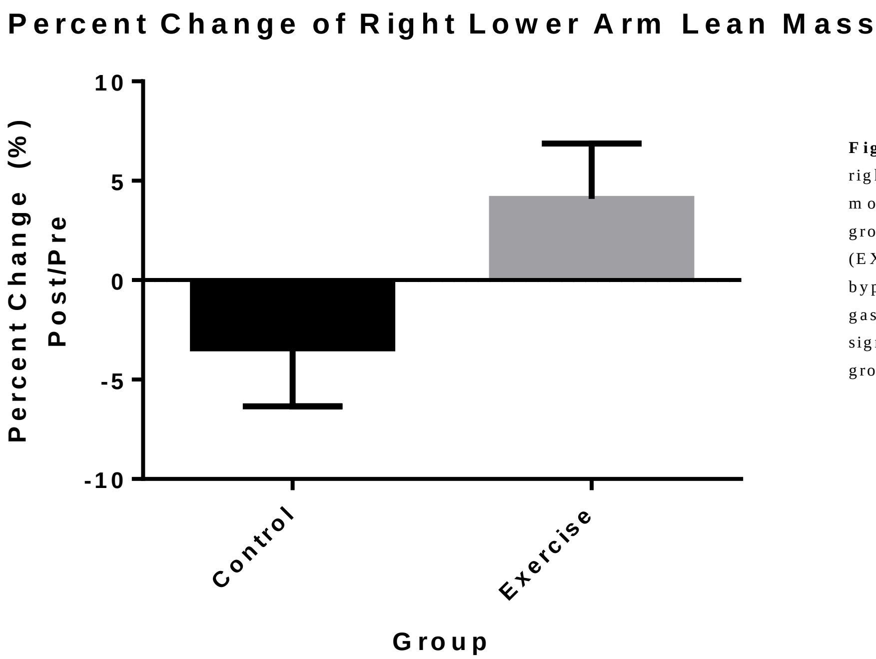


Figure 23: Percent change of right lower arm lean mass the 6 month intervention of control group (CG) and exercise group (EXG). CG with only gastric bypass surgery, EXG with gastric bypass and exercise. No significant differences between groups were found..

Right Leg Segments

The right upper leg showed evidence of significant decreases over time in both the exercise and control groups in tissue % fat (Figure 23), region % fat, tissue mass, fat mass (Figure 24), and total mass ($P<0.001$), and a significant increase over time in tissue % lean ($P<0.001$). Results are summarized in Table 10. Tissue % fat decreased 8.5% (SE of diff. 1.2%) in the control group and 9.8% (SE of diff. 1.2%) in the exercise group. Fat mass decreased 2.4 kg (SE of diff. 0.3 kg) in the control group and 2.8 kg (SE of diff. 0.3 kg) in the exercise group. Lean mass results showed a change over time ($P=0.008$) although post-hoc tests suggested it was not significant (Figure 25). Lean mass decreased 0.3 kg in both groups (control group SE of diff. 0.2; exercise group SE of diff. 0.1 kg). BMC did not show significant change over time in either group ($P=0.809$).

Table 10: Right Upper Leg Result Comparisons

Right Upper Leg	Control				Exercise			
	Baseline	6 mo post	Absolute change	Percent change -%	Baseline	6 mo post	Absolute change	Percent change -%
Tissue % fat (%)	55.0	46.5*	-8.5 ± 1.2	-16.2 ± 2.9	54.5	44.8*	-9.8 ± 1.2	-18.1 ± 2.1
Tissue % lean (%)	43.8	51.9*	8.0 ± 1.2	-18.5 ± 2.7	44.4	53.6*	9.2 ± 1.2	-21.4 ± 2.8
Tissue (kg)	13.5	10.8*	-2.7 ± 0.3	-19.3 ± 1.9	15.0	11.9*	-3.1 ± 0.3	-21.1 ± 2.0
Fat mass (kg)	7.6	5.2*	-2.4 ± 0.3	-32.1 ± 3.0	8.3	5.5*	-2.8 ± 0.3	-34.8 ± 2.7
Lean mass (kg)	5.9	5.6	-0. 3 ± 0.2	-3.2 ± 1.7	6.6	6.3	-0.3 ± 0.2	-4.3 ± 2.4
BMC (g)	345.0	336.1	-9.0 ± 12.4	-4.3 ± 2.4	374.5	379.2	4.8 ± 12.1	0.8 ± 4.0

Baseline is the initial measurement; 6 mo post is the measurement taken 6 months after the baseline measurements.

***** (p<0.05) significantly different from baseline within the group.

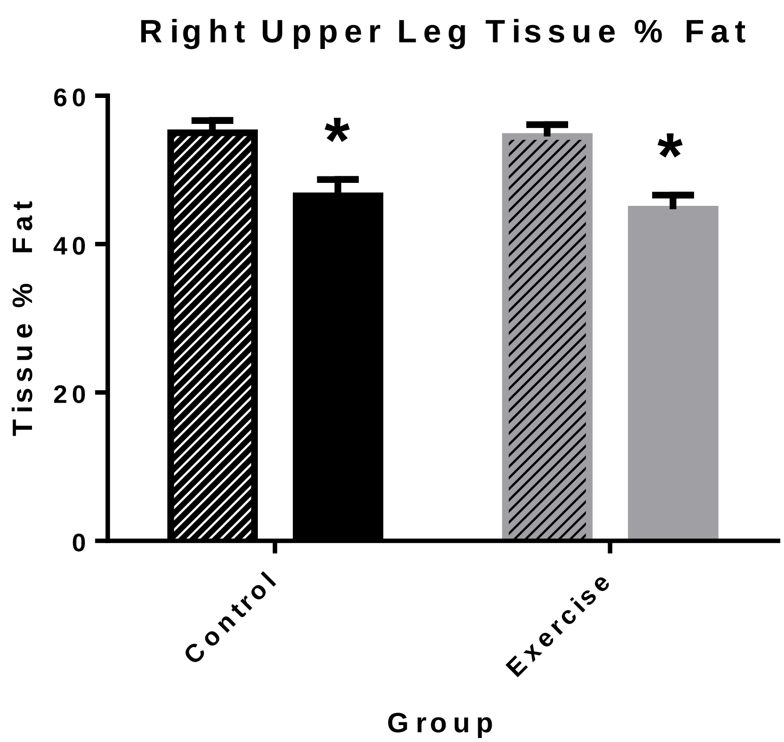


Figure 24: Right upper leg tissue % fat comparison over 6-month intervention of control group (CG) and exercise group (EXG). CG group with only gastric bypass, EXG group with gastric bypass and exercise. Patterned bars are pre-intervention, solid bars are post-intervention. *p<0.05 versus pre-intervention.

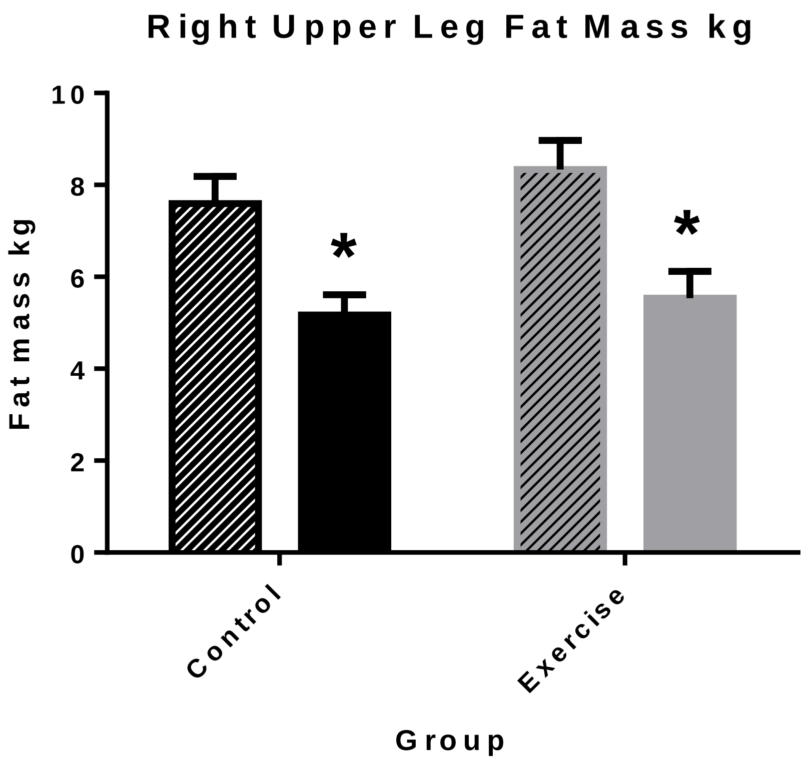


Figure 25: Right upper leg fat mass comparison over 6-month intervention of control group (CG) and exercise group (EXG). CG group with only gastric bypass, EXG group with gastric bypass and exercise. Patterned bars are pre-intervention, solid bars are post-intervention. *$p<0.05$ versus pre-intervention.

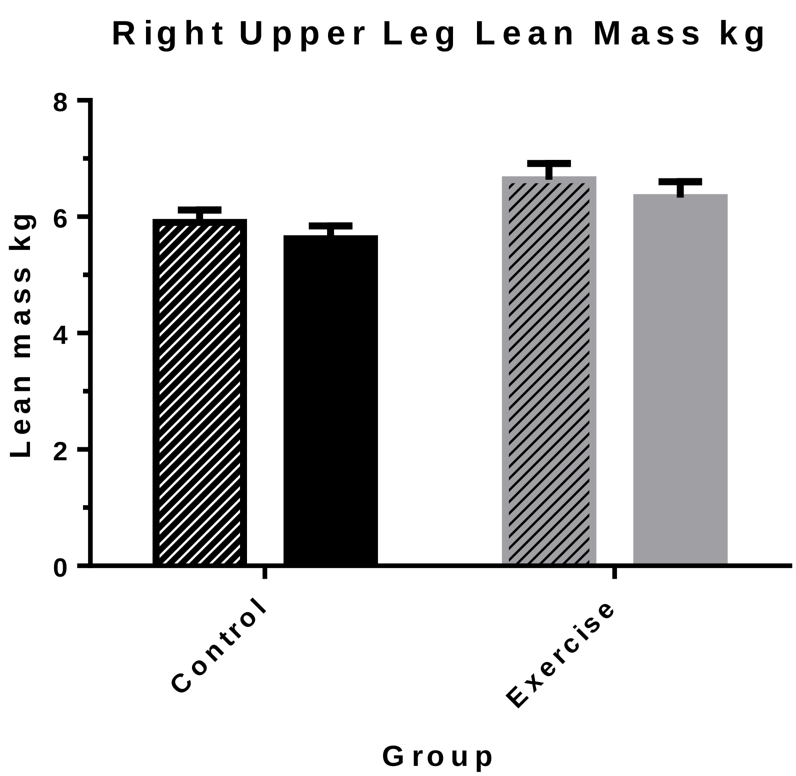


Figure 26: Right upper leg lean mass comparison over 6-month intervention of control group (CG) and exercise group (EXG). CG group with only gastric bypass, EXG group with gastric bypass and exercise. Patterned bars are pre-intervention, solid bars are post-intervention. No significant differences between or within groups were found.

The right lower leg showed significant decreases over time in tissue % fat (Figure 26), region % fat, tissue mass, fat mass (Figure 27), BMC, and total mass (P<0.001), and an increase in tissue % lean (P<0.001). Results are summarized in Table 11. Tissue % fat decreased 6.3% (SE of diff. 0.9%) in the control group and 7.1% (SE of diff. 0.8%) in the exercise group. Fat mass decreased 0.5 kg (SE of diff. 0.06 kg) in the control group and 0.6 kg (SE of diff. 0.06 kg) in the exercise group. Lean tissue (Figure 28) decreased significantly in the exercise group (P=0.009), 0.1 kg (SE of diff. 0.05 kg) but not in the control group (P=0.295), 0.05 kg (SE of diff. 0.05 kg), although there was no difference in the percent change between groups.

Table 11: Right Lower Leg Result Comparisons

Right Lower Leg	**Control**				**Exercise**			
	Baseline	**6 mo post**	**Absolute change**	**Percent change -%**	**Baseline**	**6 mo post**	**Absolute change**	**Percent change -%**
Tissue % fat (%)	40.7	34.3*	-6.3 ± 0.9	-16.8 ± 2.6	38.1	31.0*	-7.1 ± 0.8	-18.8 ± 2.1
Tissue % lean (%)	55.5	61.3*	5.8 ± 0.9	-14.4 ± 4.2	58.2	63.7*	5.5 ± 0.9	-19.1 ± 5.0
Tissue (kg)	4.4	3.9*	-0.5 ± 0.1	-11.5 ± 1.4	4.8	4.1*	-0.7 ± 0.1	-14.7 ± 1.6
Fat mass (kg)	1.9	1.4*	-0.5 ± 0.1	-26.3 ± 2.7	1.9	1.3*	-0.6 ± 0.1	-30.5 ± 2.4
Lean mass (kg)	8.6	8.5	-0.1 ± 0.3	-1.9 ± 1.7	9.4	9.0*	-0.4 ± 0.3	-4.8 ± 1.6
BMC (g)	289.8	279.0*	-10.9 ± 2.1	-3.8 ± 0.7	306.9	295.2*	-11.7 ± 2.0	-3.8 ± 0.6

Baseline is the initial measurement; 6 mo post is the measurement taken 6 months after the baseline measurements.

***** (p<0.05) significantly different from baseline within the group.

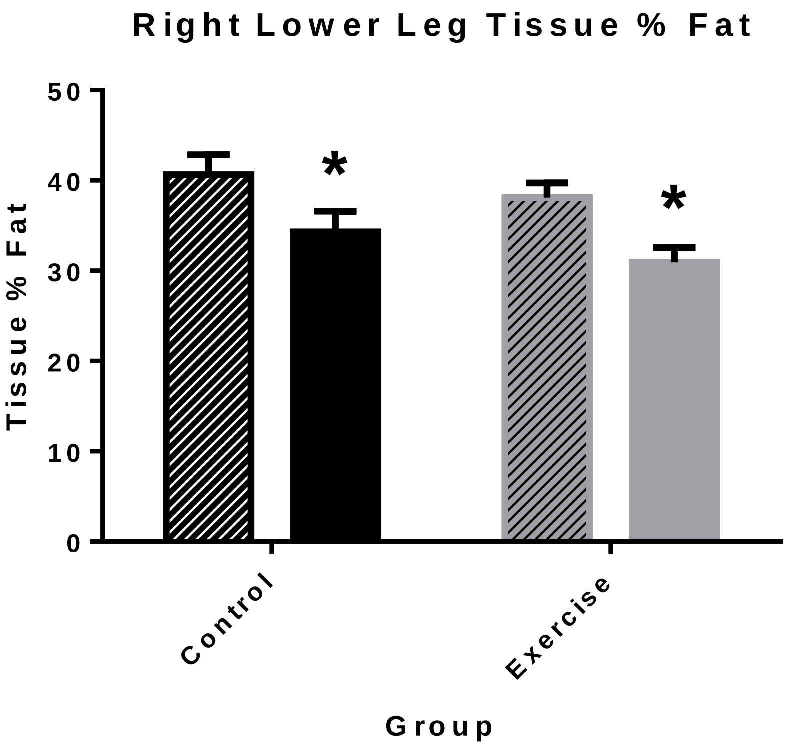


Figure 27: Right lower leg tissue % fat comparison over 6-month intervention of control group (CG) and exercise group (EXG). CG group with only gastric bypass, EXG group with gastric bypass and exercise. Patterned bars are pre-intervention, solid bars are post-intervention. *p<0.05 versus pre-intervention.

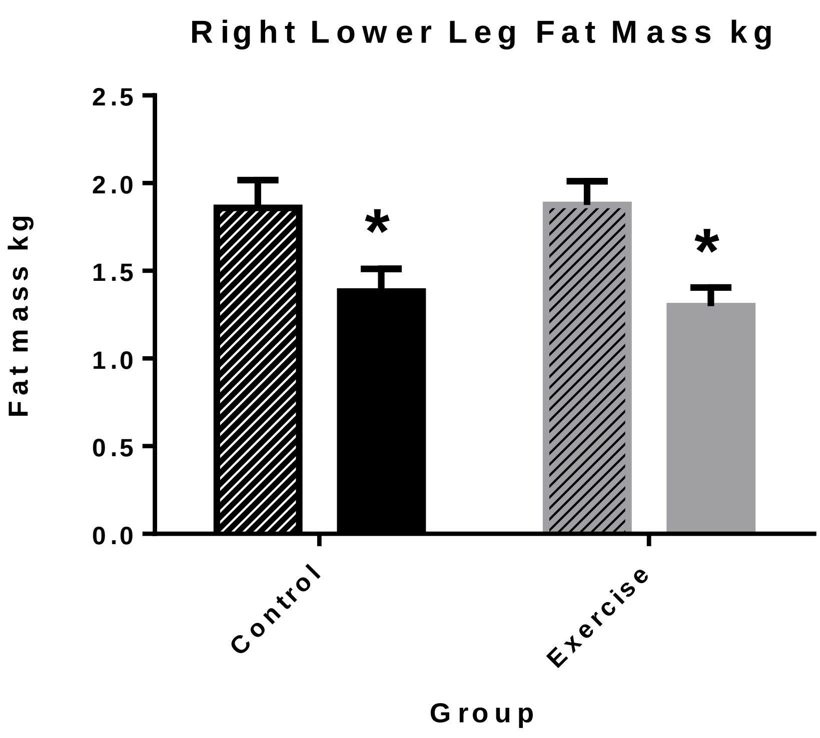


Figure 28: Right lower leg fat mass comparison over 6-month intervention of control group (CG) and exercise group (EXG). CG group with only gastric bypass, EXG group with gastric bypass and exercise. Patterned bars are pre-intervention, solid bars are post-intervention. *p<0.05 versus pre-intervention.

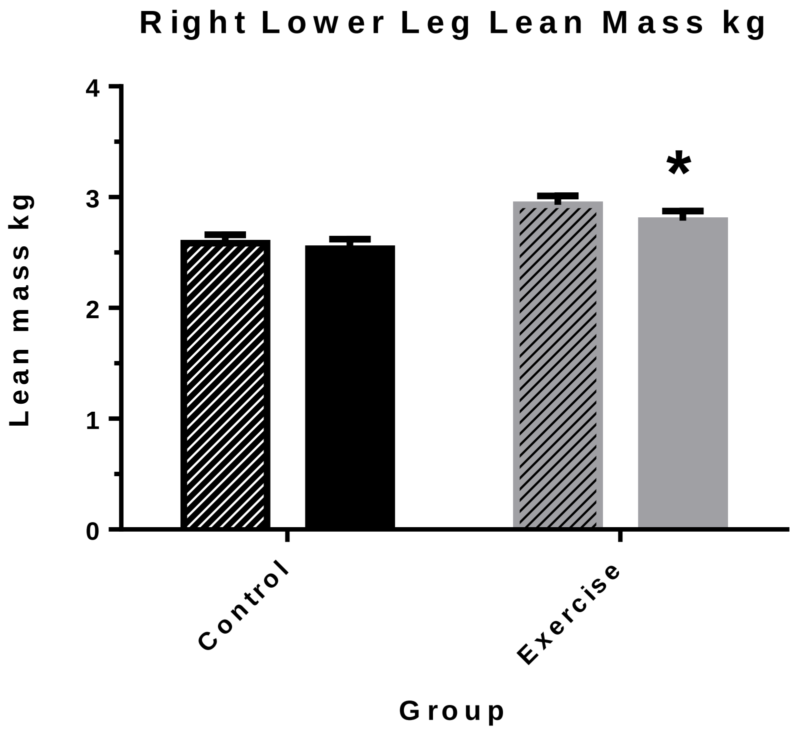


Figure 29: Right lower leg lean mass comparison over 6-month intervention of control group (CG) and exercise group (EXG). CG group with only gastric bypass, EXG group with gastric bypass and exercise. Patterned bars are pre-intervention, solid bars are post-intervention. *p<0.05 versus pre-intervention.

Differences in changes in lean mass between arm and leg

There was no significant difference in the percent change of lean mass between the control and exercise groups. There was also no significant difference in the percent change in lean mass between right arm and leg for the control (P=0.200) and exercise (P=0.378) groups (Figure 30).

There was a significant difference in percent change of lean mass in the exercise group's upper arm compared to upper leg (P=0.037) (Figure 29). The exercise group's upper arm decreased lean mass by 13.0% (SEM 3.3%) whereas the upper leg decreased 4.3% (SEM 2.4%). The control group showed a trend toward a difference in relative changes between the two limb segments (P=0.064). The control group's upper arm lean mass decreased 12.1% (SEM 4.4%) and the upper leg decreased 3.2% (SEM 1.7%). In both groups the upper arm had a greater relative decrease in lean mass than the upper leg.

In the lower arm and leg comparison (Figure 31), only the exercise group showed a significant difference in relative change in lean mass (P=0.009). The exercise group's lower arm lean mass increased by 4.1% (SEM 2.8%) whereas the lower leg lean mass decreased 4.8% (SEM 1.6%). The control group showed no difference in relative change in lean mass between the lower arm and lower leg (P=0.645).

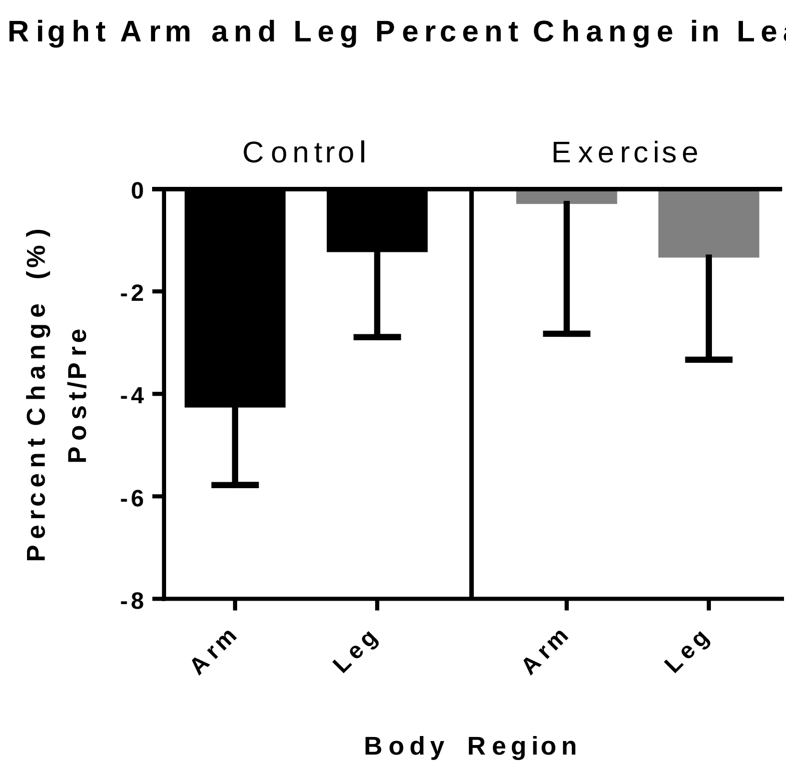


Figure 30: Comparison of the percent change in lean mass in the control group right arm and leg and the exercise group right arm and leg over 6-month intervention. Control group with only gastric bypass, exercise group with gastric bypass and exercise. No significant differences between body regions within groups were found.

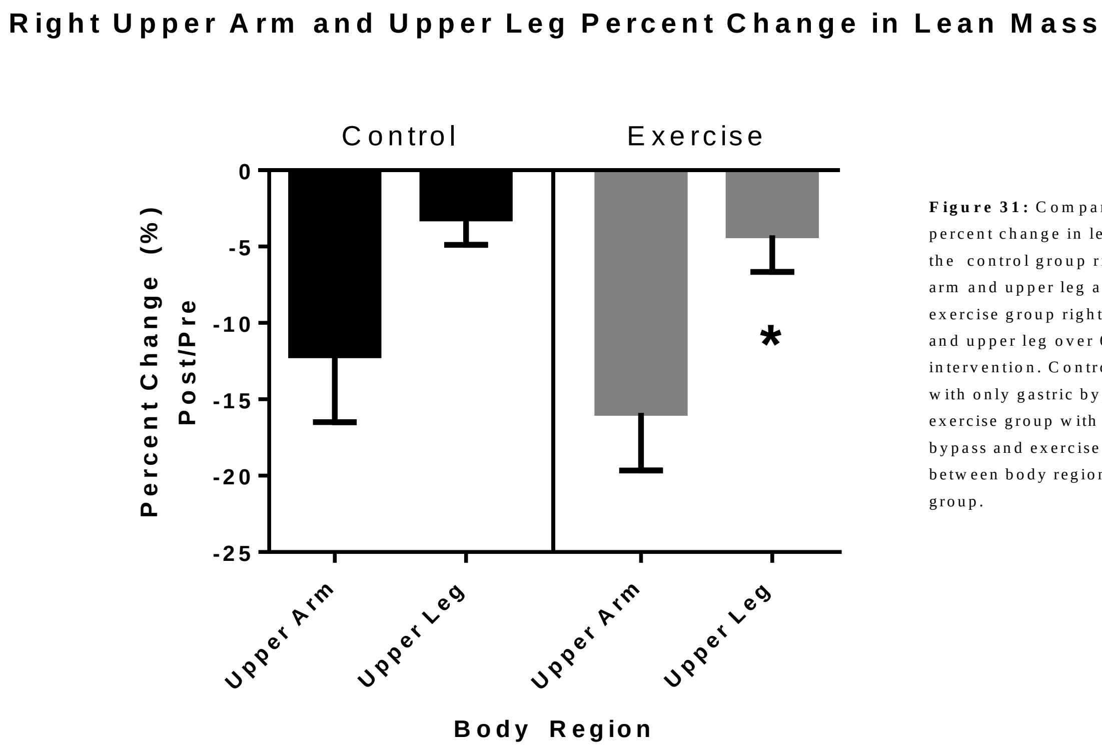


Figure 31: Comparison of the percent change in lean mass in the control group right upper arm and upper leg and the exercise group right upper arm and upper leg over 6-month intervention. Control group with only gastric bypass, exercise group with gastric bypass and exercise. *$p<0.05$ between body regions within group.

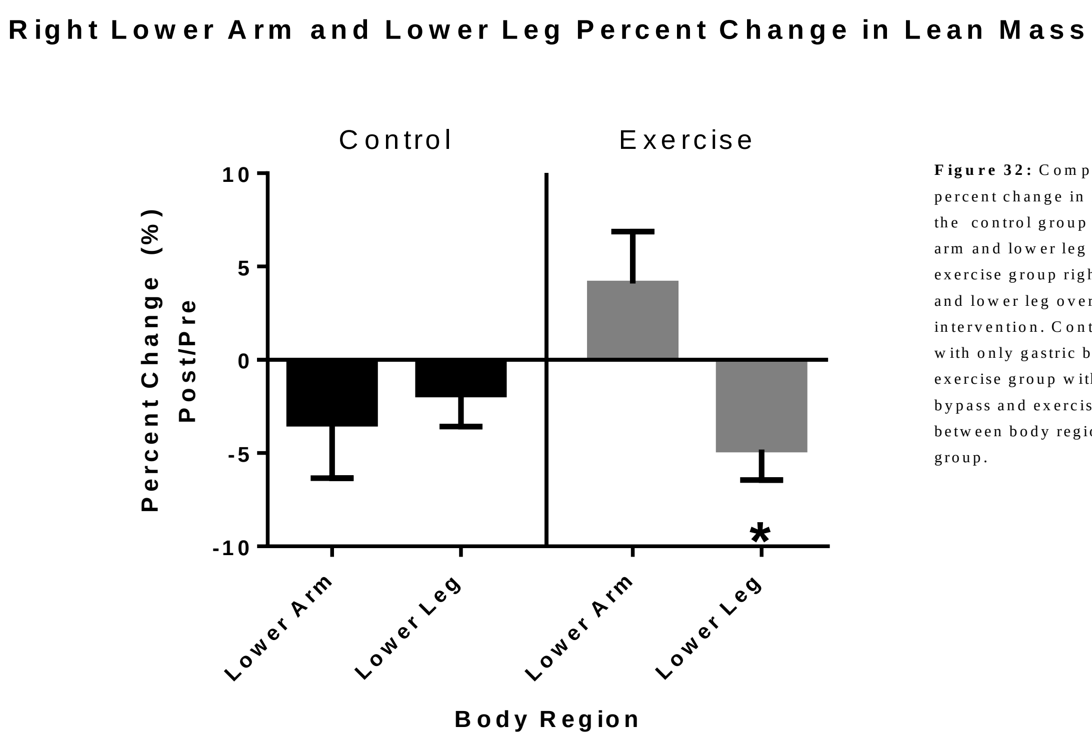


Figure 32: Comparison of the percent change in lean mass in the control group right lower arm and lower leg and the exercise group right lower arm and lower leg over 6-month intervention. Control group with only gastric bypass, exercise group with gastric bypass and exercise. *$p<0.05$ between body regions within group.

Chapter V: Discussion

This study examined the effects of a six month moderate intensity aerobic exercise intervention on lean mass in gastric bypass patients beginning 1-3 months after surgery. The purpose of this study was to examine the effects of exercise on lean mass and compare any changes in lean mass between the arm and leg. Overall, participants' body composition and weight changed as expected; weight, body fat percentage, fat mass and lean mass decreased. The only differences in percent change between groups were in the right total tissue mass, right trunk tissue mass (excludes bone mass) (Figure 8) and right trunk total mass (includes bone mass) in which the exercise group decreased more than the control group. This difference in percent change suggests that adding an aerobic exercise program 1-3 months post-gastric bypass surgery may help to reduce tissue mass, particularly in the trunk region, over the ensuing 6 months.

Further evidence of the possible benefits of an aerobic exercise program post-gastric bypass surgery was found in an interaction. Although the percent change between each group was not statistically different, there was an interaction by the two-way ANOVA in right arm BMC in which the control group decreased more than the exercise group (Figure 11). This suggests that the aerobic exercise program was beneficial to maintaining arm BMC although the clinical significance of this finding is unknown.

Studies that determine differences in lean mass between body regions are rare, particularly in the case of gastric bypass surgery. Chomentowski et al[17] looked at body region differences but the study was done on a diet-based weight loss intervention. Lower limb and trunk fat free mass decreased in the weight loss group but was maintained in the weight loss with exercise group. Upper limb lean mass did not change in either group, suggesting exercise may attenuate the loss of lean mass in the leg and trunk, but does not affect the arms; this, in theory, is the hypothesis posed in this study.

We hypothesized that aerobic exercise would attenuate the loss of lean mass. Further, it would attenuate the loss of lean mass in the legs, but have no effect on the loss of lean mass in the arms. Results showed lean mass only decreased in 2 body segments: the right upper arm in both groups (Figure 19) and the right lower leg in the exercise group only (Figure 28), thus suggesting both hypotheses are incorrect. There was no difference in the percent loss of lean mass between the exercise and control groups, suggesting that a 6 month moderate intensity aerobic exercise intervention that begins 1-3 months post-gastric bypass surgery may not affect lean mass.

In diet-induced weight loss, both aerobic exercise and resistance exercise can attenuate the loss of lean mass.[15,17,43] Due to the difference in rate and amount of weight loss, gastric bypass-induced weight loss does not seem to produce the same results. This study is consistent with findings from Stegen et al[39] who also found no difference in lean mass loss between the gastric bypass control and gastric bypass plus exercise (aerobic and resistance) groups. Interestingly, the results showed that although both groups lost lean mass, the exercise group did not lose any strength. The exercise group actually increased dynamic strength in the exercised muscle groups. Chomentowski et al[17] found evidence that exercise with weight loss prevents a loss of normal density lean tissue (commonly referred to as FFM) as compared to weight loss alone despite both groups losing lean mass (including normal density lean tissue and low density lean tissue) which may help explain the maintenance of strength Stegen et al[39] found in the gastric bypass plus exercise group. More research needs to be done, although this may be an indicator that the loss of lean mass associated with gastric bypass induced weight loss may not involve a decline in strength or functionality when combined with an exercise program.

Lean mass differences between body regions

This study is different from others because it looks at the differences in the changes in lean mass between arm and leg in gastric bypass patients. There were no differences in the percent decrease in lean mass between the right arm and leg in this study (Figure 30); however, there were significant differences between the right arm and leg segments in the exercise group. In the exercise group, the right upper arm had a greater percent decrease of lean mass than the right upper leg (13% and 4.3% respectively) (Figure 29). This may be due to the use of each body segment; disuse of a muscle leads to atrophy, whereas adequate loading prevents atrophy.[44] The upper leg muscles were loaded regularly, i.e. for standing, sit-to-stand, walking, and other activities of daily living. In contrast, the loss of lean mass in the upper arm was conceivably due to a reduced load and/or less use. The right upper arm in the exercise group decreased tissue mass by 27%; 63.6% of that loss was fat mass, thus reducing the load. The exercise group also showed evidence of an increase in lean mass in the right lower arm but a decrease in right lower leg lean mass (Figure 31). Although the increase in lean mass in the right lower arm was not statistically significant, there was a statistically significant difference between the lower arm and leg. The decrease in lower leg lean mass was small (0.1 kg decrease) but statistically significant and may be explained by biomechanical differences in movement after weight loss. Obese individuals tend to walk with more ankle movement and less knee movement than lean individuals.[45,46] As weight is lost, during walking the ankle moves less, resulting in less use of the lower leg muscles, and the knee movement increases, consequently increasing the use of upper leg muscles[47,48], which also helps explain the maintenance of lean mass in the upper leg.

The control group also decreased lean mass more in the lower leg than the lower but the difference was not statistically significant. Tissue mass decreased less in the control group than the exercise group, which may have resulted in smaller biomechanical changes in movement patterns. Hence a lesser amount of change in body segment lean mass than the exercise group.

BMC

BMC was not a main component in this study, but there were some interesting findings worth noting. Research shows that BMC decreases with weight loss;[49] a 1-2% total body bone loss is typically expected with a 10% reduction in weight although gastric bypass patients tend to lose more.[50] In this study, the right side total showed a mean decrease in BMC of 6.5%, likely due to the decreased bone load with weight loss.[51] Research also suggests that the decrease of BMC is (in part) due to malabsorption of key nutrients.[49,50] Segmentally, the only significant change in BMC was a decrease in the right arm in the control group over time. The exercise group maintained right arm BMC, which supports other findings of exercise's ability to attenuate the loss of BMC associated with weight loss.[50] The clinical significance of the loss of BMC in the right arm is unknown.

Weight loss

Weight loss during the 6 month period of this study is comparable to findings previously published in the literature. Many studies measured weight changes from before surgery to 4-6 months post-surgery, thus covering the period of the most rapid weight loss.[6,14,52] However, this study begins 1-3 months after surgery due to DXA's weight restrictions, catching only the cusp of rapid weight loss. Over the 6 month intervention in the current study, participants lost approximately 19.9% of their body weight, which is similar to 4-month interventions beginning one week pre-surgery by Stegen et al[39] and Costello et al[19] (19.0% and 19.7% respectively).

Carey et al[5,6] found similar results within the time frame (18.4% at 3 months), but a greater decrease in body weight by 6 months post-surgery (28.2%). The discrepancy between the current study and Carey et al[5,6] is due to the difference in time frame. The current study did not include pre-surgery data; rather the 6 month intervention began 1-3 months post-surgery, potentially missing the period of greatest weight loss.

Tissue % fat

Body fat percentage has been shown to decrease along with weight loss. Results from this study provided evidence of an 11.9% decrease in tissue % fat, which falls along the high side of previous reports in the literature (7%[19]-9.5%[39] decrease at 4-months post-surgery, to 7.9% at 6 months post-surgery[6]). Most studies only clarify body fat percentage as a ratio of fat mass to fat free mass. In this study tissue percent fat refers to the ratio of fat mass to lean mass; bone mass is not included. When comparing region percent fat (which includes bone, i.e. body fat percentage) to tissue percent fat, the latter tends to be higher in gastric bypass patients because of the associated decrease in BMC. This may account for the disparity in results.

Fat mass

Fat mass loss in this study was on the low end of the range of fat mass loss published in the literature. The results of this study showed a mean loss of fat mass of 18.6 kg or 38.7% body fat whereas Stegen et al[39], a 4 month study, found a similar absolute decrease of 18.5 kg. Relatively, Stegen et al saw a smaller decrease of fat mass from the initial body fat (29.5%). The relative difference between the two studies suggests in the first 1-3 months post-surgery, there is a greater rate of fat loss (29.5% decrease in 4 months) than in a 6 month intervention beginning between months 1-3 post-surgery (38.7% decrease in 6 months). This variance in the rate of fat mass loss is consistent with findings from Carey et al[5,6], Guisti et al[14], and Wadstrom et al.[52]

Lean mass

In this study, the mean decrease of right side total lean mass for all participants was 0.9 kg or 3% (Figure 3). Thus we can assume that total body lean mass loss was 1.8 kg or 3%. This is significantly lower than amounts reported in the literature. Participants in Carey et al's study lost 4.9% lean mass in the first month, 12.7% by the 3rd month, and finally capped lean mass loss of 17.9% at 6 months post-surgery (Table 1).[5,6] At 6 months post-intervention Wadstrom et al[52] saw a 14.6% decrease of lean mass, whereas the lowest the author found in the literature of gastric bypass surgery was 9.2%.[19] Again, this difference may be in part due to the time frame of the intervention around the surgery date. Lean mass loss is greatest at the period of greatest weight loss, which occurs in the first month post-surgery, which was not included in the current study due to weight restrictions on the DXA.

Suggestions for further research

One of the major limitations in this study was the time at which participants began the intervention post-surgery (1-3 months). Although recovery time from surgery was necessary, initiating the intervention closer to the same time relative to participants' surgery date would have provided less intra-study variance and inter-study variance. The varying rate of weight and lean mass loss in the first 3-6 months post-surgery may have been a confounding factor in this study.

More research needs to be done to better understand the loss of lean mass with gastric bypass surgery. Studies may want to include long term (6 months or longer) resistance training interventions, combined resistance and aerobic training. Another direction may be to include pre-surgery exercise interventions to determine if the amount of initial lean mass influences the loss of lean mass post-surgery.

Obesity is linked to many co-morbidities although this study included only those individuals without co-morbidities. It would be interesting to explore what kind of effects diabetes or metabolic syndrome would have on the loss of lean mass.

Some research points to muscle quality in terms of low density lean tissue (LDLT) and normal density lean tissue (NDLT). In one study,[17] NDLT did not decrease although total lean mass did. Perhaps the loss of lean mass is merely a loss of LDLT—the lower quality lean mass. Because of its increased lipid content, the impact of LDLT on basal metabolic rate (BMR) may be less than the impact of NDLT on BMR. If muscle quality is a bigger contender in weight loss maintenance than the amount of lean mass, this could be clinically significant. Future research should clarify the quality of lean mass that is lost and whether it is clinically significant.

Conclusion

Gastric bypass surgery results in significant weight loss, and as the literature suggests, significant lean mass loss. Lean mass is a key component to BMR and ambulation, both of which play a role in long term weight loss maintenance. Investigators have not yet found an intervention that is successful in attenuating the loss of lean mass resulting from gastric bypass surgery. The 6 month moderate intensity aerobic exercise intervention beginning 1-3 months post-surgery used in this study was also unsuccessful. The results suggest this intervention did not affect lean mass at all. More research needs to be done in this field as well as to differentiate regional losses of lean mass and determine its clinical relevance.

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Appendix: IRB Approval

EAST CAROLINA UNIVERSITY
University & Medical Center Institutional Review Board Office
4N-70 Brody Medical Sciences Building· Mail Stop 682
600 Moye Boulevard · Greenville, NC 27834
Office **252-744-2914** · Fax **252-744-2284** · www.ecu.edu/irb

Corrected approval letter. Approval date from the continuing review letter was missing.

Notification of Continuing Review Approval

From: Biomedical IRB
To: Joseph Houmard
CC:

Gabriel Dubis
Date: 11/15/2012
Re: CR00000624
UMCIRB 07-0715
Physical Activity Following Surgery-Induced Weight Loss

I am pleased to inform you that at the convened meeting on 11/14/2012 of the Biomedical IRB , this research study underwent a continuing review and the committee voted to approve the study. Approval of the study and the consent form(s) is for the period of 11/14/2012 to 11/13/2013.

The Biomedical IRB deemed this study Greater than Minimal Risk.

Changes to this approved research may not be initiated without UMCIRB review except when necessary to eliminate an apparent immediate hazard to the participant. All unanticipated problems involving risks to participants and others must be promptly reported to the UMCIRB. The investigator must submit a continuing review/closure application to the UMCIRB prior to the date of study expiration. The investigator must adhere to all reporting requirements for this study.

The approval includes the following items:

Name	Description	Modified	Version
Brief Protocol Version 4	Study Protocol or Grant Application	10/17/2011 4:38 PM	0.01
Exercise History Post.pdf	Surveys and Questionnaires	8/24/2011 2:20 PM	0.01
Exercise History Pre.pdf	Surveys and Questionnaires	8/24/2011 2:21 PM	0.01
Full Protocol Version 4	Study Protocol or Grant Application	10/17/2011 4:39 PM	0.01
Informed Consent Follow-up	Consent Forms	12/15/2011 2:57 PM	0.04
Informed Consent Genetics	Consent Forms	10/17/2011 3:29 PM	0.01
Informed Consent Version 7	Consent Forms	12/15/2011 2:57 PM	0.03
Single flyer.doc	Recruitment Documents/Scripts	8/24/2011 2:04 PM	0.01

The following UMCIRB members were recused for reasons of potential for Conflict of Interest on this research study: None

The following UMCIRB members with a potential Conflict of Interest did not attend this IRB meeting: None

IRB00000705 East Carolina U IRB #1 (Biomedical) IORG0000418
IRB00003781 East Carolina U IRB #2 (Behavioral/SS) IORG0000418 IRB00004973