EFFECTS OF A 12-WEEK PERIODIZED RESISTANCE TRAINING PROGRAM ON MUSCLE STRENGTH, MUSCLE QUALITY, AND PHYSICAL ACTIVITY AFTER ROUX-EN-Y GASTRIC BYPASS SURGERY

by

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ABSTRACT

While several researchers have reported reductions in fat free mass (FFM) and muscular strength following Roux-en-Y gastric bypass (RYGB) surgery, changes in muscle and muscular strength following RYGB have received little attention. A lack of understanding about changes in FFM and muscular strength following RYGB is concerning because on average, individuals elect RYGB after they are 40 years of age, a time when loss of muscle and strength begin a natural decline. Since resistive exercise training has been used to mitigate age-related losses in FFM and strength, this study proposes to determine if a periodized, resistance training program following RYGB (a) increases muscle mass as assessed with MRI-derived thigh muscle cross-sectional area (CSA) and increases muscle quality (MQ); and (b) increases leg strength leading to more time engaged in physical activity (PA).

A convenience sample of women having undergone RYGB were recruited *(N* = 18) and randomly placed into an intervention group (IG; *n* = 11) and a control group (CG; *n* = 7). A total of 16 women completed the study. Body composition was assessed using air displacement plethysmography to determine fat mass (FM), fat free mass (FFM), and percent body fat (%BF). Height was measured to determine body mass index (BMI). Unilateral quadriceps 1Repetition Maximum (RM) strength of the right leg was measured using selecterized leg extension equipment. Bilateral, lower body strength was measured using 3RM, 40 degree leg press. Muscle CSA was measured before and after 12 weeks of resistance training using magnetic resonance imaging (MRI). Muscle quality was calculated by dividing quadriceps strength and lower body strength by quadriceps CSA and whole thigh CSA, respectively. Physical activity (PA) was measured using accelerometers.

Repeated measures ANOVA was used to analyze outcomes with significance set at $p < 0.05$. The 12-week periodized resistance training intervention was shown to significantly increase strength and MQ in the IG. However, no change in quadriceps or whole thigh CSA was observed. Most indices of PA did not change significantly (total steps per day, moderate to vigorous physical activity, and sedentary time), but a significant time and interaction effect was observed for light physical activity (LPA; $p < 0.05$). Improvements in strength and MQ are important for physical function and quality of life and offer protection against the aging process. Due to the conflicting results for muscle CSA with other research, we recommend additional studies examining muscle CSA in the future. We also suggest additional research employing objective techniques to measures PA in those having undergone RYGB.

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CHAPTER 1

INTRODUCTION

The prevalence of obesity has increased dramatically in the last 30 years. The number of adults in the United States who are classified as being obese (BMI ≥ 30) has doubled from approximately 15% in 1980 to nearly 34% in 2004 (Flegal et al., 2010; Shields et al., 2011). Almost 33% of all men and 36% of all women fall into the obese classification and 6% of these are classified as morbidly obese (BMI ≥ 40) (Ogden et al., 2012). To combat the rise in obesity and the related comorbid health conditions, health professionals are developing techniques to reduce excess body weight. One such technique has been the development of bariatric weight loss surgery.

Bariatric Weight Loss Surgery

The advent of bariatric weight loss surgery occurred in the middle of the 20th century. Some early techniques that were successful for weight loss ultimately resulted in severe medical complications and had to be abandoned or revised (Buchwald, 2001; Jaunoo & Southall, 2010). Early surgical techniques have evolved into the five bariatric procedures used today, all of which have been shown to effectively improve body composition and health (Buchwald, 2001; Jaunoo & Southall, 2010). Of the five procedures, Roux-en-Y gastric bypass (RYGB) is the most prevalent procedure, resulting in significant weight loss and reductions in comorbid conditions.

Over 120,000 bariatric procedures are performed each year in the U.S., of which over half are Roux-en-Y gastric bypass (Buchwald, 2009; Livingston, 2010). Roux-en-Y is both a restrictive and malabsorptive procedure. Weight loss is achieved by limiting caloric intake through reduction of the size of the stomach while also limiting caloric and nutrient uptake by bypassing the most absorptive section of the small intestine (Buchwald, 2002).

The positive outcomes from this surgery have been well documented (Adams et al., 2012; Buchwald et al., 2004; Christou et al., 2004) and include loss of excess body weight and improvements in obesity-related comorbid conditions such as insulin resistance, type 2 diabetes, and dyslipidemia (Adams et al., 2012; Bloomgarden, 2010; Christou et al., 2004). Despite the positive health benefits from surgical weight loss, one negative outcome appears to be a significant loss of fat free mass (FFM) and skeletal muscle mass (SM) (Chaston, Dixon, & O'Brien, 2007; Levitt et al., 2010; Lyytinen, Liikavainio, Pääkkönen, Gylling, & Arokoski, 2013). The loss of FFM and SM, both considered lean tissues, may have serious negative implications for mobility, weight regain, and physical function, especially as one ages.

Loss of Lean Tissues

Many researchers have sought to quantify changes in lean tissues as well as body fat following bariatric surgery, including RYGB. Significant losses in FFM, lean tissue (LT), and skeletal muscle (SM) have been reported (Carey, Pleigo, Raymond, Brook, & Skau, 2006; Carlin et al., 2013; Chaston, Dixon, & O'Brien, 2007; Ciangura et al., 2010; Das et al., 2003; Hue et al., 2008; Lyytinen et al., 2013). Comparison of lean tissue outcomes following RYGB is difficult because many different techniques are used to measure body composition. Some researchers use techniques based on two-component body composition models while other researchers use techniques based on either three-or-four component body composition models. As a result, some studies report FFM (body mass minus fat mass), others report LT (body mass minus fat mass and bone mass), and still others use strategies to quantify SM. It is the assessment of changes in skeletal muscle following bariatric surgery that is the focus of the current study.

The focus is on skeletal muscle because skeletal muscles are directly responsible for generating muscular strength and total body mobility. Assessment of FFM following RYGB, as has been done by a number of researchers (Carey, Pleigo, Raymond, Brook, & Skau, 2006; Carlin et al., 2013; Chaston et al., 2007; Das et al., 2003), has revealed that FFM, most of which is assumed to be SM, occurs following bariatric surgery (O'Brien, McPhail, Chaston, & Dixon, 2006). Only a few studies have specifically sought to quantify SM losses (Levitt et al., 2010; Lyytinen et al., 2013; Periera, Marchini, Carniero, Arasaki, & Zanella, 2012; Tamboli et al., 2010). Therefore, there is a need to quantify changes in SM following bariatric surgery and to explore strategies to mitigate the loss of skeletal muscle following bariatric surgery.

Loss of Strength

Examination of SM is of interest since a loss of SM frequently results in a loss of muscular strength (Hue et al., 2008) that negatively impacts physical activity (PA) and physical function (PF) (Bond et al., 2008; Stegan, Derave, Calders, Van Laetham, & Pattyn, 2009). In addition, decreases in muscle cross-sectional area and strength are also related to frailty, falls, morbidity, and mortality (Misic, Rosengren, Woods, & Evans, 2007) and declining strength in midlife is highly predictive of physical function later in life (Park et al., 2006).

The association between strength and SM reflects the fact that muscle cross-sectional area accounts for approximately 40% of the strength of skeletal muscle (Narici, Roi, Landoni, Minetti, & Cerritelli, 1989) while neurological and morphological characteristics account for the remainder (Aagard et al., 2001). While age-related losses of muscle cross-sectional area and muscular strength are well documented, there has been less attention paid to changes in muscle cross-sectional area and muscular strength following bariatric surgery. Stegen et al. (2009) and Hue et al. (2008) are two of the groups of researchers who have reported that individuals who have undergone bariatric weight loss surgery experience a significant loss of strength. Several researchers have suggested that postsurgery strength losses are likely due to the significant loss of skeletal muscle in the months following surgery (Levitt et al., 2010; Lyytinen et al., 2013; Periera et al., 2012; Tamboli et al., 2010).

More research is needed to examine SM, including muscle cross-sectional area, and muscular strength following bariatric surgery. If the natural age-related decline in SM and strength is compounded by losses following bariatric surgery, methods such as resistance training should be explored to mitigate the losses.

Muscle Quality

Muscle quality (MQ), an indicator of the quality or ability of muscle to produce force per given cross-sectional area, is important for mobility, performing activities of daily living, as well as general physical function such as rising from a chair or lifting objects (Misic et al., 2007; Park et al., 2006). Muscle quality has also been used as an outcome measure to evaluate the efficacy of resistance training, since muscle quality is the quotient of strength divided by muscle volume (Castro, McCann, Shaffrath, & Adams, 1995; Marcus, Addison, & Lastayo, 2012; Misic et al., 2007).

Some evidence suggests that resistance trained individuals have greater force production per cross-sectional area (Castro et al., 1995; Frontera, Meredith, O'Reilly, Knuttgens, & Evans, 1988); however, some researchers have reported decreases in MQ with resistance training (Sale, Martin, & Mooz, 1992). Obviously more research is needed in this area.

There is also a need to better understand the impact of RYGB on muscle quality. Since patients having undergone RYGB have been shown to lose a significant proportion of muscle cross-sectional area (Lyytinen, Liikavainio, Pääkkönen, Gylling, & Arokoski, 2013), their muscle quality might also be diminished. It has been argued that MQ is the most important component of physical function, especially in the elderly (Goodpastor et al., 2006; Misic et al., 2007). Therefore, if RYGB patients experience significant SM losses, these patients may be at increased risk for reductions in muscle quality. However, no research has directly assessed muscle quality in RYGB patients and little work has been done to determine if resistance training can improve RYGB patient's muscle quality and associated physical function variables.

Physical Activity

Physical activity (PA) is an important component of physical function and contributes to a healthy life. Increasing daily physical activity has a multitude of positive effects including improvements in ADLs, weight maintenance, and cardiovascular and metabolic health (Bloomgarden, 2010; Bond et al., 2008; Warburton Nicol & Bredin, 2006). Participating in at least the recommended levels of physical activity should be an essential component of the postbariatric lifestyle for RYGB patients. Currently, the recommendation by the American College of Sports Medicine (ACSM) to prevent weight gain is between 150 and 250 minutes of moderate exercise per week and 200 to 300 minutes of moderate PA for long-term weight loss (Donnelly et al., 2009).

Although there are relatively few studies that have quantified PA in bariatric weight loss populations, there is considerable variability in the reported PA values. Early studies used subjective, self-report data instead of objective measures (Jacobi, Ciangura, Couet, & Oppert, 2011) with the result that PA values increased following bariatric surgery. At least one study has provided evidence that bariatric patients significantly inflate self-report PA time compared to objective, accelerometer data (Bond et al., 2010). Therefore, there is a need for more research using objective measures of PA to better understand PA patterns postbariatric surgery.

In addition, there is a need to determine if resistive training, postsurgery impacts PA. Currently, there are no data on the effects that resistance training may have on PA following RYGB. There is a great deal of evidence showing the relationship between declining strength, especially in the aged, and declining physical function and increased mortality (Hairi et al., 2010; Hicks et al., 2012), but there is little supporting evidence that shows improved strength leads to more time spent engaged in physical activity (Chandler, Duncan, Kochersberger, & Studenski, 1998; Hunter, Thompson, & Adams, 2000; Wong, Chaouachi, Chamari, Dellal, & Wisloff, 1998). Consequently, research examining the effects that resistance training may have on PA should be undertaken.

Summary

In conclusion, little research has assessed skeletal muscle variables and strength following RYGB. More specifically, no studies to date have assessed MQ in this population and few studies have assessed the impact that resistance training has on skeletal muscle variables or PA following RYGB. This study proposes to use a resistance training modality and assess the effects on muscle cross-sectional area, strength, MQ, and PA in patients having undergone RYGB.

Statement of the Problem

Loss of muscle cross-sectional area typically leads to losses in strength and muscle quality, which can have negative implications for weight loss, mobility, ADLs, and physical activity. This study sets out to determine if resistance training can increase muscle cross-sectional area, muscular strength, and muscle quality in women 8 weeks after undergoing Roux-en-Y gastric bypass surgery, a time when muscle protein turnover is quite high. This study also sets out to determine if changes in strength and muscle quality from resistance training will increase time spent involved in PA as well as the intensity of physical activity.

Study Purpose

The purposes of this project were to (a) determine the effects of a periodized resistance training program on strength, muscle quality, and muscle cross-sectional area in women 8 weeks post RYGB surgery, and (b) to determine if a resistance training program improved physical activity.

Significance Statement

Data from this study will provide a better understanding of the effect of resistance training on strength, muscle quality, muscle cross-sectional area, and physical activity following Roux-en-Y gastric bypass weight loss surgery. This information may help physicians and health practitioners develop strategies to improve outcomes following RYGB. Unique to the methodology of this study is (a) the use of magnetic resonance imaging to measure muscle cross-sectional area; (b) a homogeneous population (100% female participants who underwent Roux-en-Y gastric bypass surgery); and (c) a 12-week periodized resistance training program developed for muscle hypertrophy (first 6 weeks) and strength (last 6 weeks). There are very limited or no data addressing the impact that resistance training may have on strength, muscle quality, muscle cross-sectional area, and daily physical activity; therefore, the results from this study will add to the understanding of the role that resistance training has on skeletal muscle and physical activity following RYGB surgery. Such information is particularly relevant since so many middle-aged people, who are already experiencing age-related loss of skeletal muscle mass, are seeking bariatric surgery.

Research Questions

The following questions will help to guide this research investigation:

1) What effect does a 12-week, periodized resistance training have on muscle cross-sectional area, strength, and muscle quality in women following RYGB weight loss surgery? 2) Does a 12-week periodized resistance training program increase the time women spend engaged in physical activity or the intensity of their physical activity as measured by triaxial accelerometry?

Delimitations, Limitations, and Assumptions

The following delimitations apply to the current study. All of the participants are Caucasian females from the Salt Lake Valley, Utah, which may not be representative of other groups within other regions of the country and the results may not be applicable to males. Two other delimitations are the resistance training protocol used and the duration of the study. For the purposes of this study, a 12-week periodized program was used. The resistive loads were selected to first maximize muscle hypertrophy and secondly to develop muscular strength. Other protocols and program durations could and should be used in future research.

One limitation to this study is that there is very little research on resistive exercise following RYGB and skeletal muscle function. Therefore, relevant literature could not be used to guide the resistive training program planning. Another limitation to the study was the fact that the training could not begin until several weeks after surgery. Previous research has shown that the first few weeks postsurgery is the time period when the rate of loss of FFM is greatest. Therefore, subjects in the current study were not rapidly losing FFM, which may have influenced the changes in FFM and SM observed in the current study.

Lastly, daily physical activity for both the control or intervention groups was not measured throughout the 12 weeks of the study. If the intervention participants or the control group participants increased or decreased their physical activity levels, the internal validity of study would be compromised.

A number of assumptions were also made to facilitate the completion of the current study. It was assumed that:

1. Magnetic resonance imaging is a valid and reliable measurement for determining skeletal muscle cross-sectional area.
2. Strength assessments are a valid and reliable method for measuring change in muscle function.
3. Participants wore the activity monitor as prescribed and appropriately noted errors in monitor placement or wear time.
4. The use of accelerometry did not alter a participant's regular daily physical activity habits.
5. Participant data would meet the assumption of Homogeneity of Variance.

CHAPTER 2

REVIEW OF LITERATURE

Introduction

The purpose of this review of literature chapter is to provide background and a foundation for examining the influence of resistance training on body composition indices, muscular function, and physical activity patterns in bariatric surgery patients. The chapter is presented in four sections. The chapter begins with an overview of the obesity trends and briefly discusses available approaches to weight loss and weight maintenance including bariatric weight loss surgery (BS). The second section of the chapter examines the literature relative to changes in body composition following weight loss including BS. Emphasis will be placed on examining losses of body fat and lean tissues including changes in muscle cross-sectional area (CSA), strength, and muscle quality (MQ) following weight loss. The third section focuses on examining the possible consequences of lost muscle/lean tissue. The fourth and final section of the review examines the potential benefits that a periodized resistance training (RT) program may have on the variables influenced by losses from muscle/lean tissue following weight loss procedures, and especially following surgical weight loss procedures such as Roux-en-Y gastric bypass (RYGB).

Obesity and Obesity Treatments

The number of people in the United States who are classified as obese has increased rapidly in recent years. In 1991, only 17.1% of the adult U.S. population was categorized as obese (BMI >30.0) with 11.7% of men and 12.2% of women falling into this category (Mokdad et al., 1999). By 1998, there was a 6% increase in over-all obesity with similar increases for both men and women. In 2008, 34.4% of the U.S. population between the ages of 20 and 79 were classified as obese, with 32.6% of men and 36.2% of women falling into this category (Shields, Carroll, & Ogden, 2011). Fortunately, this trend seems to be leveling off, at least in women. Between 1999 and 2008, Flegal et al. (2010) reported no significant increase in the prevalence of obesity in women. Men, however, did show a significant increase over the same time period, but data indicated that the trend was slowing (Ogden, Carroll, Curtain, Lamb, & Flegal, 2010). Increases in the number of people who are classified as obese is of concern because obesity is associated with a variety of adverse health conditions.

Chronic diseases, including hyperlipidemia, coronary and cerebral artery disease, hypertension, and type 2 diabetes are all associated with obesity (Bray, 2004; Cawley & Meyerhoefer, 2012; Ferrante, 2007; Withrow & Alter, 2011). The sheer magnitude of the body weight with obesity can also lead to musculoskeletal problems such as osteoarthritis and joint pain (Bray, 2004). Chronic diseases combined with musculoskeletal issues can lead to visual impairments, greater risk of coronary artery disease, and physical discomfort, all of which can greatly impair physical function (Clark & Mungai, 1997; Stenholm et al., 2008). These comorbid conditions are also costly.

Obesity-related comorbidities result in higher costs for individuals and the health care system. Healthcare costs in the U. S. associated with obesity have been calculated to be as high as 168 billion U. S. dollars (Cawley & Meyerhoefer, 2012). Obese individuals typically have health care costs that are 30% greater than their healthy weight (BMI = 18.5-25 kg/m^2) counterparts (Withrow & Alter, 2010), prompting the search for strategies to treat obesity and its comorbidities.

Traditional methods for combating weight gain such as diet, exercise, or a combination of both have been shown to have marginal, short-term success, with eventual weight regain (Skender et al., 1996; Zelasko, 1995), while surgical weight loss interventions have proven quite effective. For example, at a National Institute of Health Consensus Conference, examination of the data prompted the suggestion that bariatric surgery is "the only effective treatment for patients with medically severe (morbid) obesity" (Brolin, 1996).

Bariatric Weight Loss Surgery

Bariatric surgery was developed in the 1950s as a method of stimulating weight loss in obese individuals (Buchwald, 2002) by decreasing the caloric intake side of the energy balance equation. The first surgery was a malabsorptive procedure known as the jejunoileal bypass developed by Varco and Kremen as well as by Linner and Nelson (Buchwald, 2002). With malabsorptive procedures, a section of the small intestine, typically the duodenum and a section of the jejunum, is 'bypassed' to reduce nutrient absorption. In the 1960s, the jejunoileal bypass was replaced with the Roux gastric bypass, the first malabsorptive/restrictive procedure (Eldar et al., 2011). A restrictive procedure involves reducing the size of the stomach, thus limiting the volume of food that can be ingested (Buchwald, 2002). Combining both the malabsorptive and restrictive components of weight loss surgery leads to significant decreases in the caloric intake side of the energy balance equation resulting in weight loss.

There are five bariatric procedures used today: gastric bypass (RYGB), gastric banding (GB), sleeve gastrectomy (SG), biliopancreatic diversion (BPD), and duodenal switch (DS). Each is classified as either restrictive, malabsorptive, or a combination of both (Buchwald, 2004; Jaunoo & Southall, 2010). Gastric banding and SG are purely restrictive in nature. With the gastric banding procedure a band is placed on the upper portion of the stomach separating the new gastric pouch from the main body of the stomach. Gastric banding differs from SG in that with SG, nearly three-quarters of the main body of the stomach is excised, leaving a small gastric pouch for food storage (Buchwald, 2002). The malabsorptive procedures, such as BPD and DS, reduce the size of the stomach, although not to the degree of the restrictive procedures. Malabsorption of nutrients occurs by diverting food away from the proximal portion of the small intestine, the duodenum and the proximal portion of the jejunum where most nutrient absorption typically occurs. The loss of nutrient absorption leads to weight loss (Buchwald, 2002; Eldar, Heneghan, Brethauer, & Schauer, 2011; Hansen et al., 2006). Combining both the malabsorptive and restrictive components of weight loss surgery compounds the decreases in the caloric intake side of the energy balance equation, resulting in substantial weight loss (Buchwald & Oien, 2009; Kohn, Galanko, Overby, & Farrell, 2009; Odstricil et al., 2010).

The prevalence of bariatric weight loss surgery reflects a number of factors: First, bariatric surgery results in greater weight loss than conventional treatments (Chaston, Dixon, & O'Brien, 2007; Nagle, 2010). Conventional treatments such as diet, behavioral and pharmaceutical interventions tend to result in weight losses of approximately 12kg (Chaston, Dixon, & O'Brien, 2007) while weight loss from gastric bypass have been reported to average 30kg, representing a loss of more than 80% of excess weight (Hansen, Tarquati, & Abumrad, 2006; Hatoum & Kaplan, 2013; Jaunoo et al., 2010). Second, bariatric surgery has been shown to improve or reverse obesity-related comorbid conditions within weeks of surgery (Eldar, Heneghan, Brethauer, & Schaur, 2011; Hallersund et al., 2012; Jaunoo & Southall, 2010; Olbers et al., 2012; Sjöstrom et al., 2004; Sjöstrom et al., 2007). Lastly, weight lost with bariatric surgery tends to be maintained for years. While all bariatric weight loss procedures effective at stimulating weight loss, the focus of this dissertation will be on the Roux-en-Y gastric bypass procedure.

Roux-en-Y Gastric Bypass Surgery

Roux-en-Y gastric bypass is the most prevalent form of bariatric surgery in North American, accounting for 51% of the 220,000 bariatric procedures performed in 2008 (Buchwald, 2009). Worldwide, 46.6% of the 340,768 bariatric surgeries performed were RYGB (Buchwald & Oien, 2013).

The restrictive portion of RYGB is accomplished by constructing a small pouch in the upper portion of the stomach. This reduces the volume of the stomach from approximately 3 pints to about the size of an egg, limiting the intake of foods and liquids. This portion of the surgery leads to a 94% reduction in caloric intake (-2062 +/- 271 kcal/day) 5 months following surgery. The decrease in caloric intake is attenuated to approximately 89% (-1418 +/- 171 kcal/day) 14 months after the initial RYGB procedure (Odstrcil et al., 2010).

The malabsorptive portion of the procedure is accomplished by bypassing the most absorptive section of the small intestine, the duodenum and the jejunum. Surgically, the distal portion of the jejunum is connected to the small pouch created from the stomach; thus, the duodenum and a portion of the jejunum are bypassed (Buchwald, 2002; Odstricil et al., 2010). Bypassing the most absorptive section of the small intestine results in significant reduction in both nutrient and calorie absorption (-124 +/- 57kcal/day and -172 +/- 60 kcal/day at 5 and 14 months, respectively). The combined restrictive and malabsorptive nature of RYGB results in significant and dramatic changes in body composition (Odstrcil et al., 2010) as well as body weight changes.

Another factor that aids in favorable body composition changes following RYGB is the postsurgery diet. Patients are directed to eat a diet high in proteins and fats and very low in carbohydrates. The combination of low caloric intake and low carbohydrate meals leads to a state of ketosis which in turn promotes lipolysis and loss of body fat. The low caloric intake is also thought to contribute to a loss of FFM.

Weight Loss and Body Composition Changes

Numerous researchers have published data supporting the use of RYGB for reducing body weight. Most research focuses on short-term changes (6 months) (Carlin et al., 2013; Chaston et al., 2007; Ciangura et al., 2010; Hallersund et al., 2012; Miller, Nicklas, You, & Fernandez, 2009; Olbers et al., 2012;; Tamboli et al., 2010; Werling et al., 2012). The most rapid weight loss following RYGB can be seen in the first 6 to 12 months with a tendency to slow over time (Carey, Pleigo, Raymond, & Skau, 2006; Tamboli et al., 2010). Significant loss in body weight following RYGB has been reported only a few months after surgery. Lost body weight of 25.9kg, 23.8kg, and 26.6kg have been reported just a few months after RYGB (Carey et al., 2006, Stegen, Derave, Calders, Van Laethem, & Pattyn, 2009; Trakhtenbroit et al., 2009), illustrating the dramatic impact RYGB has in the short-term. Average body weight losses at the 12-month postsurgery period range from 37kg to 52kg (Carlin et al., 2013; Ciangura et al., 2010; Hattoum & Kaplan, 2013; Levitt et al., 2010; Miller et al., 2009; Tamboli et al., 2010; Yan et al., 2008).

Longitudinal studies have also reported significant positive changes in body weight following RYGB (Adams et al., 2012; Sjöström et al., 2004; Yan et al., 2008). Adams et al. (2012) showed that weight loss 6 years post-RYGB was about 37kg, a significant reduction from baseline values (95% CI). The Swedish Obese Subject Study, with a cohort of over 1700 participants, reported a mean loss of approximately 28kg 10 years from baseline compared to controls who increased body weight by nearly 2 kg (Sjöström et al., 2004). At the end of 5 years, Yan et al. (2008) reported that patients maintained their lost body weight of ~40kg.

These data show that RYGB reduces body weight in both the short and long term. Researchers who have used different methods, such as percent of total body weight, also report significant losses.

Percent of Weight Loss

Studies reporting BS-induced weight loss as a percentage of total body weight have shown significant results with reported losses of 26.2% of initial body weight 6 months postsurgery and 34.2% 12 months postsurgery (Miller et al., 2009). Longitudinal data on 1156 obese subjects between the ages of 18 and 72 years also showed reductions in body weight of 34.9% 2 years following surgery and 27.7% 6 years after RYGB

(Adams et al., 2012). Data by Sjöström et al. (2004) and Christou, Look, and MacLean (2006) showed very similar results with a significant decrease in percentage of weight 10 years postsurgery.

Weight Loss as a Percentage of Excess Weight

Some researchers have presented RYGB-induced weight losses as a percentage of excess weight. Conceptually, excess weight is the initial body minus the ideal body weight and in the literature, ideal body weight (IBW) is calculated with the following formula (Miller, 1985):

Males: IBW = 50 kg + 2.3 kg for each inch over 5 feet.

Females: IBW = 45.5 kg + 2.3 kg for each inch over 5 feet.

Once ideal body weight is determined, the percent excess weight loss (%EWL or EWL) can be calculated (Deitel, Gawdat, & Melissas, 2007):

$$\%\text{EWL} = \frac{\text{preoperative weight} - \text{current weight}}{\text{preoperative weight} - \text{ideal weight}} \times 100$$

Greater than 50%EWL is the benchmark for defining success following RYGB (Friere, Borges, Alvarez-Liete, & Correia, 2012; Yan et al., 2010). According to the 50% EWL standard RYBG surgery is quite successful (Miller et al., 2009; Yan et al., 2010) with post-RYGB EWL ranging from 52% (Yan et al., 2010) to nearly 70% (Buchwald et al., 2004; Christou et al., 2004).

Although loss of excess weight is dramatic within 12 to 24 months postsurgery, research has also shown weight regain often occurs. In a 10-year study of patients who underwent RYGB, Christou, Look, and MacLean (2006) showed a trend of weight regain beginning 2.5 years postsurgery. They reported that at 11.4 years after RYGB, EWL had fallen to 67.6 ± 1.3% from the high of 88.6 ± 1.3% at year 2.5. Adams et al. (2012) and Sjöström et al. (2004) also showed a similar trend with subjects regaining 7.2% of their excess weight between years 2 and 6 and 7.3% between years 2 and 10, respectively.

Changes in Body Composition

Although weight loss and EWL are two frequently used metrics for evaluating bariatric surgery, a number of researchers have examined changes in body composition following RYGB surgery. Most frequently, a two-component model has been used to describe body composition (Lukaski, 1987). The two components of body composition are FM and fat free mass (FFM), with fat frequently reported as percent fat.

Changes in % Body Fat

Tracking changes in percentage of body fat is quite useful, especially since it is the high body fat and not just body weight, which is associated with inflammation and comorbidities. Percent fat values for patients pre-RYGB can be quite high averaging >50%. Reported decreases in percent body fat have been shown to range from 5.5% to ~7% just a few months following RYGB surgery (Stegen et al., 2009; Trakthenbroit et al., 2009) to a loss in percent fat of ~12% to 17% 1 year after surgery (Das et al., 2003; Levitt et al., 2010; Miller, Nicklaus, You, & Fernandez, 2009; Tamboli et al., 2010; Trakhtenbroit et al., 2009).

Changes in Fat Mass

Still other researchers have elected to report changes in body fat as fat mass (FM) rather than percent fat. In 15 severely obese women (mean BMI = 46.77kg/m^2) body composition was assessed using real-time bioimpedance analysis. The mean baseline FM was 65.9 kg with mean FM losses of -16.1kg, -33.6kg and -37 kg, reported at 3, 9, and 24 months postsurgery. All of the postsurgery FM values represented a significant loss in FM compared to baseline (Trakhenbroit et al., 2009). Other researchers have reported significant loss of fat mass (~26kg) 6-12 months following RYGB (Carey et al., 2006; Ciangura et al., 2010).

Changes in Fat Free Mass

Although the goal of bariatric surgery is reduction in fat mass and significant losses of fat mass have been reported by many researchers. Some researchers have also assessed FFM, reporting significant losses, but such reports are much less frequent than reports on changing fat mass. Assessing FFM losses may be an important metric in measuring the safety of bariatric weight loss procedures (Chaston, Dixon, & O'Brien, 2007), since loss of FFM can be associated with lower metabolic rate (Carey, Pliego, & Raymond, 2006), mobility, and quality of life (Villareal et al., 2011; Wadden et al., 1997).

A comprehensive review by Chaston et al. (2007) compared loss of FFM between three bariatric procedures: biliopancreatic diversion (BPD), RYGB, and laparoscopic gastric banding (LAGB). When outcomes from the three surgical methods were reviewed, RYGB showed the greatest loss in FFM reported as percent fat free mass (%FFM). For RYGB, there was a %FFM loss of 31% compared to 25.6% for BPD and 17.5% for LAGB. According to the Chaston et al. review, loss in FFM ranged from 21.2% to 36.3%. However, others have reported greater variability in FFM percent losses (14-36%) (Benedetti et al., 2000; Chaston et al., 2007; Metcalf, Rabkin, Rabkin, Metcalf,

& Lehman-Becker, 2005; Trakhtenbroit et al., 2009). As noted by Chaston et al. (2007), their review only included two studies with a total of 49 participants, leading these researchers to point out that given the low number of study participants, more research is warranted.

Changes in Lean Soft Tissue

In addition to reporting changes in FFM following BS, some researchers have reported changes in lean soft tissue (LST) following BS. The assessment of LST is only possible with select body composition assessment techniques. While various methods (hydrostatic weighing, bioimpedance analysis, skinfolds, and air-displacement plethysmography) that use two component models will result in the calculation of FM and FFM, using other methodologies (dual energy x-ray absorptiometry [DXA]) or combining methodologies (air-displacement plethysmography + total body water), three-component body composition models have been used to report FM and subdivide FFM into bone (lean hard tissue) and LST. Unfortunately, no consensus on the definition of LST exists in the scientific community (Heymsfield et al., 2005); therefore, for the purpose of this manuscript, LST will be operationally defined as soft tissues (not bone with its high mineral content) composed of a high percentage of protein, therefore excluding fat. The dominant constituent of LST, is skeletal muscle and LST mass differs from FFM in that LST mass does not include bone mass as is true for FFM.

Studies using DXA 12 months post-RYGB have reported significant LST losses of 16% (Ciangura et al., 2010), 18% (Levitt et al., 2010), and 19% (Tamboli et al., 2010) compared to baseline values. In addition, both Tamboli and Ciangura report regional losses in LST. Tamboli reported losses of 19%, 17%, and 24% at 12 months for total

LST, extremities, and nonabdominal trunk regions, respectively. At 12 months postsurgery, Ciangura reported a 19% loss for total LST with a 14% loss for extremities. The losses in LST have been assumed to represent losses in SM since skeletal muscle is the major soft tissue in the extremities.

Tamboli et al. (2010) used an analysis of urinary 3-methylhistidine (30MeH), a marker of myofibrillar proteolysis, to support the hypothesis that losses in LST represent a loss of SM. Since myofibrillar proteins are dominant in skeletal muscle, increased proteolysis of myofibrillar protein as indicated by increased 30MeH in the urine would indicate a loss of skeletal muscle. In their study, 3-MeH rose sharply in the first 6 months following surgery, the same time period that yielded a significant decrease in LST (Tamboli et al., 2010).

Another analysis was used to provide further insight as to the impact of RYGB on the skeletal muscle in the extremities. Specifically, Ciangura et al. (2010) used DXA scan data and an equation developed by Kim et al. (2002) to quantify SM. A significant mean loss of 5.6 kg of skeletal muscle was observed 12 months after RYGB.

Changes in Muscle Cross-Sectional Area

Ultrasound, a technique that can be used to quantify muscle cross-sectional area (CSA), has been used to further our understanding of the influence of RYGB on skeletal muscle. However, only two studies to date have measured skeletal muscle CSA following RYGB. Significant decreases in rectus femoris (25.2%), vastus lateralis (21.3%), and vastus medialis (26.6%) CSA were reported 8.8 months following RYGB in 16 subjects (*n* = 13 females and 3 males) (Lyytinen et al., 2013). Periera et al. (2012) showed even larger losses (34%) of quadriceps CSA 6 months following RYGB and nearly 30% loss in CSA of the upper limb (anterior brachium), a change from 32±6 mm to 21±6mm and 27±7mm and 15±5mm, respectively.

MRI imaging is another technique that is used to quantify muscle CSA; however, no studies on postsurgery RYGB patients have been published. Therefore, there is a need for the research using MRI with BS populations.

Some of the decrease in muscle CSA following RYGB that has been observed with ultrasound loss of skeletal muscle following RYGB may also reflect age-related loss of skeletal muscle. About 80% of patients who undergo bariatric surgery are in their fifth decade of life (Buchwald et al., 2009), the point at which skeletal muscle mass begins a steady decline in both men and women (Janssen et al., 2000). Therefore, it is important that research with more participants and well-matched control groups be conducted, if we are to better understand the impact of RYGB surgery on skeletal muscle.

Outcomes from Loss of Skeletal Muscle

If RYGB surgery significantly reduces FFM and exacerbates age-related skeletal muscle losses, the consequences could be significant for patients electing RYGB surgery. The following section of this review examines some of the possible consequences of losses of FFM, particularly skeletal muscle.

Decreased Strength

The relationship between skeletal muscle mass and strength is well documented (Aagard et al., 2001; Folland & Williams, 2007; Narici, Roi, Landoni, Minnetti, & Cerritelli, 1998). Strength has been shown to be correlated to the size of a skeletal muscle or muscle group with approximately 40% of the variability in strength accounted for by skeletal muscle CSA. The remaining 60% is accounted for by other factors, including increased in neural adaptation, increased inhibition of antagonists, and muscle morphology (Narici et al., 1998).

Several studies have shown that there is a significant loss of strength following bariatric weight loss (Handrigan et al., 2010; Hue et al., 2008; Stegen et al., 2009). Results from a 2008 study showed significantly lower within-group isometric leg extensor strength ($p < .01$) 1 year following Duodenal switch (DS) surgery and a 23% greater loss in leg extensor strength compared to subjects who lost weight via caloric restriction (diet) (Hue et al., 2008). A later study showed morbidly obese men who underwent DS lost 33% of leg extensor strength 12 months postsurgery compared to baseline values. It was also shown that there was a linear relationship between weight loss and strength across time, indicating that as weight loss increased maximal force also fell (Handrigan et al., 2010). In the only study using RYGB patients, it was reported that dynamic muscular strength variables, as well as static hand grip strength, were significantly reduced 4 months after RYGB (Stegen et al., 2009). The presumption is that the loss of strength was tied to losses in SM, but this study did not measure the composition of the weight loss, so it is unclear how much of the total weight lost was SM.

Since more than 80% of individuals who undergo bariatric surgery are over 40 years of age and it is during the 5th decade of life that the age-related decline in both strength and muscle mass begins to accelerate (Janssen et al., 2000), it is important to determine the influence loss of muscle from BS has on strength. The significant losses in muscle and strength following RYGB may exacerbate the progressive declines that occur with aging, particularly the aging of sedentary individuals. Since losses of muscle and strength are known to lead to decreased physical functioning and physical activity, additional examination of skeletal muscle and strength following RYGB is warranted.

Decreased Muscle Quality

Muscle quality is defined as strength divided by unit mass (area or volume) and is an index of muscle function. While muscle size is the greatest contributor to strength other intrinsic muscular characteristics influence muscular performance or muscle quality (MQ). These other factors include fiber type composition and their adaptation to physical activity (Folland & Williams, 2007), pennation angle (Aagard et al., 2001; Narici et al., 1998) and connective tissue performance (Kjaer, 2004). By precisely quantifying muscle CSA using high-quality imaging techniques (i.e., MRI or CT) and measuring strength, it is possible to determine changes in MQ; however, determining which intrinsic characteristics are responsible for the changes is more difficult.

While little work has been done to examine MQ following BS, several researchers have documented age-related changes in MQ. Delmonico et al., (2009) reported a 16% decline in midthigh muscle strength in the elderly (-13.4%) over a 5-year period. The loss in strength was disproportionate (2-5 times greater) compared to the loss of muscle CSA. This indicates that factors other than muscle CSA were likely to blame. In a cross-sectional longitudinal study examining MQ, Metter et al. (1999) showed an age-associated decline in MQ when assessed using CSA or FFM. They went on to point out the age-associated change in MQ varied depending on how muscle mass was measured and based on the study design. Newman et al. (2003) also showed an age-related decline in MQ, explaining that most of the variance in strength was accounted for by declines in MM, but that age and body fat both had an inverse association with lower MQ.

The significance of a decrease in muscle quality is that decreases in muscle quality are associated with decreases in physical function (PF) (Hicks et al. 2012), and the ability to perform activities of daily living (ADLs) (Misic, Rosengren, Woods, & Evans, 2007). In the literature on aging, moderately high correlations between MQ and physical function tests such as ascending and descending stairs, timed up-and-go, timed walk test, and a timed obstacle walk test have been observed (Misic et al., 2007). Lower MQ is also associated with reduced walking speed and a decrease in the ability to rise from a chair and climb stairs (Hunter et al., 2000; Mänty et al., 2012; Schot et al., 2003). Lower MQ has also been shown to be associated with an increased incident of falls, reduced quality of life, and a greater incidence of morbidity and mortality (Metter et al., 2002; Moncada, 2011; Ozcan et al., 2005; Schaap, Koster, & Visser, 2012). Lastly, low levels of PF result in dependency on others for care (Misic et al., 2007).

While the above data are from the literature on aging, there is also some research that has examined muscle quality in obese individuals, revealing that obesity also seems to be associated with lower muscle quality. According to Cooper et al. (2014), MQ is inversely related to BMI in both young and older subjects. Individuals with BMI values and body fat percentages in the obesity range have been reported to have reduced MQ (Koster et al, 2011; Park et al., 2006).

Decreased Physical Function

Unfortunately, there has been limited research examining the impact of loss of muscle from bariatric surgery on indices of physical function; therefore, this review will rely upon literature that has focused on the loss of muscle and strength associated with aging and use obesity-specific and BS-specific research where available.

Low PF has been shown to be associated with loss of muscle mass and strength (Cawthon et al., 2009; Manty et al., 2012; Metter et al., 2002; Misic et al., 2007; Moncada, 2011; Ozcan et al., 2005; Schaap, Koster, & Visser, 2012) as well as decreases in muscle density (higher intramuscular fat) (Cawthon et al., 2009; Visser et al., 2002). Low muscle mass and strength, in turn, have been shown to be associated with higher incidents of falls, reductions in ADLs, loss of independence, reduced quality of life and physical performance, and greater incidence of morbidity and mortality (Cawthon et al., 2009; Manty et al., 2012; Metter et al., 2002; Misic et al., 2007; Moncada, 2011; Ozcan et al., 2005; Schaap, Koster, & Visser, 2012) especially later in life (Ditroilo, Forte, Benelli, Gambarara, & De Vito, 2010; Hicks et al., 2012; Hunter et al., 2000; Mänty et al., 2012; Schot et al., 2003).

Daily physical activity is another measure of physical function and while the daily activity of overweight and obese individuals has not been studied relative to muscle mass, a number of researchers have reported that obese individuals do not meet the ACSM physical activity guidelines for weight maintenance and they are far less physically active than their normal-weight (Davis, Hodges, & Gillham, 2006) and over-weight counterparts (Cooper et al., 2000; Tudor-Locke et al., 2010). In addition, the obese are more sedentary between bouts of activity (Baruth, Sharpe, Hutto, Wilcox, & Warren, 2013; McManus, Chu, Yu, & Hu, 2011) than normal weight individuals.

There also appear to be significant negative trends in physical activity when comparing individuals within differing BMI classifications. The greater the BMI, the lower number of steps per day and time spent in moderate and vigorous activity. Normal weight individuals are shown to attain just over 7,000 steps per day, spend 25.7 minutes per day in moderate activity, and 7.3 minutes per day in vigorous activity. Comparatively, overweight individuals take an average of 6,879 steps per day and spend 25.3 minutes in moderate activity and 5.3 minutes of vigorous activity and obese individuals take an average of 5,784 steps per day and spend 17.3 minutes in moderate activity and 3.2 minutes in vigorous activity (Tudor-Locke et al., 2010).

Obese individuals have also been shown to be less active than their over-weight and normal-weight counterparts during nearly every time point of the week, including weekdays (279.1 ± 77.5 vs. 391.3 ± 139.4 counts/min; $p < .001$), weekends, (222.3 ± 93.9 vs. 386.2 ± 177.5 counts/min; $p < .001$), and evenings (221.1 ± 126.3 vs. 380.8 ± 220.7 counts/min; $p < .005$) (Cooper et al., 2000).

While the loss of body fat following BS might be predicted to allow for more daily physical activity, studies addressing PA patterns following surgical weight loss have reported mixed result. The lack of clarity on the influence of BS on daily physical activity may reflect differences in the methodologies used to assess physical activity.

Most of the initial reports of increased physical activity following bariatric surgery have used self-report data or questionnaires to quantify physical activity (Bond et al., 2008; Jacobi et al., 2011; Karason, Lindroos, Stenlöf, & Sjöstrom, 2000) which tend to over-report PA (Bond et al., 2010). Other researchers using objective measures (accelerometers and pedometers) to determine physical activity have reported no change in PA and that PA of bariatric patients remains below recommendations for health. Bond et al. (2010) showed subjects who had undergone bariatric weight loss surgery engaged in less MVPA (26.4 ± 23.0 min/d vs. 52.4 ± 24.7 min/d) and fewer activity counts per hour (13,799 ± 3758 vs. 19,462 ± 4259) compared to controls, and unpublished data by

Ouellette and colleagues (2014) showed subjects do not change their physical activity patters after surgical weight loss.

Because PA is such an important component of weight management and health, the scientific community needs to further examine the influence of BS on daily physical activity. In addition, while the decrease in daily physical activity with age has been partially attributed to decreases in skeletal muscle mass, the relationship between skeletal muscle mass and daily physical activity in obese and BS patients has not been examined.

Resistance Exercise Training

For the aged and other groups of individuals who have lost skeletal muscle mass, regular resistive exercise has been shown to decrease muscle mass loss and improve physical function and may be even increase daily physical activity. Although there has been some research to suggest that using RT to increase muscular strength may increase daily PA (Hunter et al., 2000), no such research exists on the effects of RT for post-bariatric surgery patients.

Given the potential negative consequences of decreases in skeletal muscle mass, strategies to minimizing losses in skeletal muscle mass following BS should be employed to minimize negative outcomes. The following section provides background information on resistance training and how participating in resistance training might be used to minimize the loss of skeletal muscle and muscular strength following BS.

Resistance Training Background

Resistance training (RT) involves using weights, cables, machines, and other pieces of equipment to vary the volume, load, and intensity of exercises in order to stimulate muscle growth and strength development. The following sections will discuss how RT is associated with changes in strength, CSA, and muscle quality.

RT and Increases in Strength

Strength is a well-documented and important RT adaptation, resulting in increased sports performance (Folland & Williams, 2007; Wong, Chaouachi, Chamari, Dellal, & Wisloff, 2010), injury prevention (Fleck & Falkel, 1986), and physical function (Chandler, Duncan, Kockersberger, & Studenski, 1998; Hicks et al., 2012). Increased strength from RT is multifactorial, representing both morphological and neurological changes (Bird et al., 2005; Cormie, McGuigan, & Newton, 2011; Folland & Williams, 2007; Kraemer et al., 2003; McCall et al., 1996; Seyness et al., 2007).

The morphology of muscles can change in multiple ways and contribute to muscular strength in a variety of ways. Fiber type, fascicle length, pennation angle, and cross-sectional area are all examples of morphological aspects of skeletal muscle (Cormie et al., 2011; Farup et al., 2012; Folland & Williams, 2007) and each makes a different contribution to the development of muscular strength.

One of the morphological characteristics of skeletal muscle that has been studied relative to the expression of muscular strength is pennation. Pennation refers to the angle individual muscle fibers are arranged relative to the tendon and the line of pull of the whole muscle. Pennation angle is the angle formed between the muscle fiber and the line of pull of the muscle (i.e., the tendon). An increase in pennation angle results from increases in DNA transcription of myofibrillar proteins such as actin and myosin. The angle must change in order to accommodate the greater myofibrllar volume which in turn results in larger whole muscle CSA and greater force production (Aagard et al., 2000; Cormie et al., 2011). Although an increase in pennation angle acts to reduce the force production of individual fibers (Aagard et al., 2001; Folland & Williams, 2007; Ikegawa et al., 2008), due to the less effective angle of pull on the tendon (Cormie et al., 2011), the increase in pennation increases the CSA of the whole muscle, allowing more fibers to connect to the tendon per tendon area (Cormie et al., 2011; Folland & Williams, 2007). The increased number of fibers connected to the tendon results in an increase in parallel cross-bridges that more than compensates for any decrease in force production of individual fibers due to the less effective angle of pull on the tendon. The overall result is an increase in maximal force produced by the whole muscle in response to resistance training-induced increases in pennation angle.

Neurological changes also occur in response to RT, but they are much more difficult to quantify. Morphological changes, such as pennation angle and skeletal muscle CSA, consequent to RT can be measured using sophisticated imaging techniques. However, definitive evidence of neurological adaptations to RT such as increased motor unit recruitment (MUR) is more difficult due to a lack of sophisticated measurement techniques (Folland & Williams, 2007). Therefore, we must rely upon less precise techniques that support the idea that neurological changes are taking place.

Evidence that neurological factors account for strength gains is supported by the disproportionate increase in strength compared to muscle CSA during the early phases of a RT program (Folland & Williams, 2007; Gabriel, Kamen, & Frost, 2006). Two of the primary neurological adaptations that may account for the increase in strength are increased motor-unit recruitment and agonist-antagonist interaction.

Early increases in strength have been attributed, in part, to increased motor-unit recruitment (MUR) or the number and size of motor-units that are actively recruited during muscular work (Folland & Williams, 2007; Gabriel et al., 2006; Moritani & de Vries, 1979; Seynnes et al., 2007). While we cannot measure specific MU activity, we can measure frequency and amplitude of neuroelectrical activity using electromyography (EMG).

Motor units are recruited based on the size principle with smaller type I fibers being recruited before larger type II fibers. Measurement of MUR using surface electromyography (SEMG) has shown increased SEMG amplitude and strength without a concomitant increase in muscle hypertrophy (Folland & Williams, 2007; Gabriel et al., 2006; Ramsey et al., 1990). Improvements in activation of higher-threshold motor-units and larger type II muscle fibers have also been observed shortly after the initiation of an RT program. Type II fibers are capable of generating greater force and can result in significant strength gains (Cormie et al., 2011). Other neurological factors, such as motor-unit firing frequency or rate-coding, have also been shown to improve strength (Brooks, Fahey, & Baldwin, 2005; Gabriel et al., 2006; Ramsey et al., 1990). Together, these neurological factors result in significant strength gains without concomitant muscular hypertrophy.

Another neurological adaptation that seems to occur with RT is a better coordination in the activation of the agonist and antagonist muscles. To move a heavy load characteristic of RT, the agonist muscle must produce sufficient force to overcome the load while assisted by synergist muscles. At the same time, the antagonist muscle action must be attenuated. If antagonist muscle action does not decrease appropriately, the agonist must not only overcome the load, but also the opposing force created by the antagonist muscle. Resistance training has been shown to reduce antagonistic actions, thus improving overall strength (Cormie et al., 2006).

Folland and Williams (2007) point out that in addition to decreasing antagonistic activation, the capacity to improve agonist activation is dependent upon the muscle group(s) involved in the contraction, muscle length and joint position, as well as the complex nature of the muscle action involved.

RT and Increases in CSA

Although changes in muscle morphology and neurological factors contribute to strength, the greatest single contributor to strength is the cross-sectional area (CSA) of the individual muscle fiber (Cormie et al., 2011). It has been reported that 40% of the variability in strength of a muscle fiber is due to fiber CSA (Narici et al., 1989) and RT is known to be a potent stimulus for increasing CSA (Bird et al., 2005; Kraemer et al., 2003; Kraemer & Ratamess, 2005; Rennie et al., 2004).

Each skeletal muscle is comprised of many fasciculi or bundles of muscle fibers. Therefore, the use of a rope as an analogy for a skeletal muscle helps with understanding the functioning of a skeletal muscle. The fasciculi of the skeletal muscle are analogous to the strands of a rope. Each individual strand of the rope is capable of resisting a particular force. The diameter of each strand dictates its strength (i.e., smaller strands are weaker than larger strands). The cumulative effect of all the strands of the rope determines the capacity of the rope to resist force. With a skeletal muscle, each of the fibers in a fasiculus is capable of exerting force to overcome resistance. A larger number of individual fibers contracting translates into a larger resistance that can be overcome by the whole skeletal muscle. Increasing the size of each muscle fiber or increasing the overall number of muscle fibers is known as muscle hypertrophy and will lead to a greater muscle CSA. Consequently, muscle hypertrophy and the associated increase in overall muscle CSA is thought to account for a significant increase in strength (Aagard et al., 2001; Cormie et al., 2011; Folland & Williams, 2007).

Skeletal muscle hypertrophy is the result of a combination of three factors: 1) an increase in muscle fiber CSA, 2) an increase in muscle fiber number (hyperplasia), and 3) an increase in the amount of connective tissue within and around skeletal muscle (Bird et al., 2005; Folland & Williams, 2007; Shoenfeld, 2010).

In order for skeletal muscle hypertrophy to occur, the resistance or load must be of sufficient magnitude, duration, and/or volume. Under proper loading, the size and number of the contractile proteins, actin and myosin, within a muscle fiber increases. This increase occurs due to an increase in protein turnover in favor of protein synthesis (Shoenfeld, 2010), resulting in enlargement of the CSA of the muscle fibers. As muscle fiber CSA increases, so too does the CSA of the muscle since the muscle is comprised of groups of muscle fibers (Bird et al., 2005; Folland & Williams, 2007; Shoenfeld, 2010; Tarpenning, Wiswell, Hawkins, & Marcel, 2001).

Hypertrophy of individual muscle fibers is not the only explanation for an increase in the CSA of the whole muscle. Hyperplasia can also potentially contribute to increases in muscle CSA (Cormie et al., 2011; Seynnes et al., 2007). Hyperplasia refers to an increase in number of muscle fibers and is thought to be due to satellite cell proliferation (Bird et al., 2005; Kreamer & Ratamess, 2005; Rennie, Wackerhage, Spangenburg, & Booth, 2004) from hormonal stimulation in response to mechanical damage created with muscle loading (Kreamer & Ratamess, 2005; Rennie et al., 2004; Shoenfeld, 2010).

The increase in muscle size from satellite cells is due to at least five factors. First, muscle fibers are multinucleated with a "constant nuclear-content-to-fiber-mass ratio." This means that as satellite cells proliferate, they must either increase the size of the existing muscle fiber to accommodate the increase in nuclei or add an increasing number of "nuclear domains" in order to carryout mRNA translation and protein synthesis (Shoenfeld, 2010). Second, satellite cells express regulatory factors that aid in repair and growth of skeletal muscle fibers, which results in hypertrophy (Cornelison & Wold, 1997; Kraemer & Ratamess, 2005). Third, there is some evidence that satellite cells fuse with existing muscle fibers or with one another, resulting in an increase in the CSA of the whole muscle (Folland & Williams, 2007; Rennie et al., 2004). Lastly, increases in connective tissues associated with skeletal muscle may also contribute to an increase in the CSA of the whole muscle (Bird et al., 2005; Folland & Williams, 2007; Shoenfeld, 2010). Increases in endomysial connective tissue have been reported with chronic resistance training and in untrained controls exposed to resistance training (MacDougall, Sale, Elder, & Sutton, 1982), while increases in collagen have been reported in animal studies (Stone, 1988). Although the proportion of hypertrophy attributed to connective tissue is low (~13%) (MacDougall et al., 1982) it is reasonable to conclude that adaptation of connective tissue through RT does contribute to overall hypertrophy.

Increases in whole muscle CSA appear to be the result of an increase in the size of both type 1 and type 2 fibers (Aagard et al., 2001; Cormie et al., 2011; MacDougall, Eldar, Sale, Moroz, & Sutton, 1980). While type 2 fibers are capable of generating greater force production than type 1 fibers, force development is proportional to the CSA of a muscle fiber irrespective of fiber type (Cormie et al., 2011).

RT and Increased MQ

As discussed previously, MQ is a function of muscular strength related to the size of the muscle. Since resistance training is a potent stimulus for skeletal muscle hypertrophy (Bird, Tarpenning, & Marino, 2005; Donnelly et al., 1993; Folland & Williams, 2007; Kraemer et al., 2003; McCall, Byrnes, Dickinson, Pattany, & Fleck, 1996; Seynnes, de Boer, & Narici, 2007), resulting in an increase in muscle CSA, it is reasonable to assume that RT will increase MQ. Similarly, the RT-related increase in muscle strength also supports the concept that RT will result in an increase in MQ. While no studies have reported MQ changes in bariatric patients after RT, there are many RT studies with elderly populations. Tracy et al. (1999) reported significant increases in MQ in elderly men and women who engaged in a 9-week RT program (14 and 16%, respectively). Similar results were reported by Pinto and colleagues (2014) who showed a mean increase of 14.8% in MQ in elderly females who engaged in a RT program for 6 weeks.

RT and Increased PF/PA

The relationship between strength and physical function (PF) has been chronicled in elderly populations, but not in BS patients. Studies have shown that increases in lower extremity strength has a significant and positive effect on indices of physical function. Using linear regression, Chandler et al. (1998) showed a significant association between gains in strength and skills performance ($\beta = 1.35$; $p = .0009$) and gait speed ($\beta = 0.08$; $p = .02$) while Villareal et al. (2011) showed positive increases from baseline physical performance values for those who exercised (15% increase) and those who exercised and dieted (21% increase) compared to those who only dieted (12% increase).

Other studies have looked into the relationship between strength gains and physical activity (PA). Several studies have shown a positive correlation between strength and PA (Hunter, Wetzstein, Fields, Brown, & Bamman, 2000; LeCheminant et al., 2014; Rantanan et al., 1999), while others have not (Hughes et al., 2001; Lemmer at al., 2001: Rangan et al., 2011). Research using heterogeneous populations has shown mixed results. LeCheminant et al. (2014) showed postpartum women who engaged in 18 weeks of RT did become more physically active than those who engaged in 18 weeks of flexibility training. However, Rangan et al. (2011) showed that 8 months of RT alone did not impact energy expenditure from PA (EEPA), but aerobic training (AT) and combined AT/RT did have a significant influence on PA. Similarly, Lemmer et al. (2000) showed that 24 weeks of RT had no effect on EEPA in any group (young, old, male, or female).

Based on the existing literature, the lack of agreement suggests that there is a need for more research examining the impact of RT on daily PA. There is a particular paucity of research examining the impact of RT on BS patients and so more work is needed that focuses on the effect that RT has on PA in bariatric weight loss patients. Physical activity is an important component of weight maintenance and improved health. As such, strategies for improving greater PA in bariatric weight loss patients should be explored.

Summary

Obesity and its many comorbid conditions are at an all-time high in North America and around the world, resulting in higher morbidity and mortality, lower quality of life, and higher health care costs for an already over-burdened health care system. To counter the rise in obesity and its associated diseases, the medical community has developed several surgical weight loss interventions that have proved to be quite effective at reducing excess weight and reversing or improving associated medical conditions such as type 2 diabetes, hypertension, and hyperlipidemia.

While surgical weight loss has very positive results, one possible negative outcome has been suggested (Chaston et al., 2006). In the months following weight loss surgery, there is evidence to suggest that there are significant losses in FFM (Chaston et al., 2006) and this loss comes primarily from skeletal muscle (O'Brien et al., 2006). Only two studies have quantified losses in skeletal muscle CSA following Roux-en-Y gastric bypass surgery (Lyytinen et al., 2013; Periera et al., 2012), both showing significant losses in thigh muscle CSA. Both of these studies, however, used ultrasound and not the more accurate MRI imaging.

While some researchers have reported losses in muscular strength following RYGB weight loss surgery, the number of studies in the literature is quite small and inadequate. This dearth of information means there is a need for more research in this area of medicine. Lastly, the assessment of MQ has been used to examine the impact of losses of both skeletal muscle CSA and muscular strength on the physical function and daily physical activity of aging individuals; however, the same research has not been completed with RYGB patients.

If bariatric surgery does result in the loss of muscular strength and muscle CSA as indicated by some researchers, preventive methods should be employed to attenuate decreases in muscular strength and CSA following RYGB. Resistance Training represents a potential preventive strategy, since it is well documented that high-volume, high-intensity resistance training increases muscular strength, muscle CSA, and MQ in healthy young adults as well as aging individuals. High-volume, high-intensity resistance training has also been observed to increase many indices of physical function in aging individuals; however, the impact of RT on daily physical activity is less well studied and the existing research is contradictory.

Given the paucity of information as well as the contradictory nature of some of the published information on bariatric patients, there is a need to examine the impact of high-volume, high-intensity RT on bariatric patients. Implementing a high-volume, high-intensity resistance training program with bariatric patients would allow for expanding understanding of a potential strategy for enhancing muscle size, muscle quality, and physical activity following BS.

CHAPTER 3

METHODS

Study Design

This study was a randomized repeated-measures design. Approval for the study was obtained from the Institutional Review Board (IRB) at the University of Utah.

Research Participants

Eighteen females between the ages of 25 and 60 years with a BMI > 30 kg/m^2 but <50 kg/m^2 were recruited from bariatric surgery clinics in the Salt Lake Valley. Based on past literature (Stegen et al., 2009) for the muscular strength variable, a power analysis using Gpower3.0 with a strong effect size was used to determine that 14 subjects would be needed to identify a muscular strength treatment effect. A total of 18 participants were recruited to account for subject attrition and 16 completed the study, 9 in the IG and 7 in the CG.

Verbal recruitment took place at pre-operative group meetings and involved a brief description of the study. Potential subjects were given the opportunity to speak directly with the PI to: 1) provide verbal instructions, 2) obtain Informed Consent (IC), and 3) administer a medical history questionnaire to insure that inclusion criteria (Appendix A) were fulfilled. Once the PI had a signed IC, each participant was contacted 6 weeks following surgery to confirm their willingness to participate. Individuals that were interested in becoming subjects were scheduled for an MRI, body composition appraisal, and strength testing between 8 and 10 weeks postsurgery.

Subjects were excluded if they reported any of the following conditions, since these might have interfered with completion of the study and or negatively biased study results:

1-Active cancer

2-History of myocardial infarction, coronary bypass surgery, angioplasty, or stroke

3-Type 1 and 2 diabetes

4-Claustrophobia, or other established contraindications to MRI imaging

5-Postsurgical anemia

6-Current smokers or those having smoked in the past 6 months

7- Musculoskeletal defects that limit activity

8- Currently engaged in a resistance training program

Once an individual qualified for entry into the study and had completed the MRI, body composition appraisal, and muscular strength testing she was randomly placed into either the Control group (CG) or Intervention group (IG).

Study Procedures

Assessments for both the IG and CG followed the order shown in Figure 1. For both the IG and CG participants, the T1 tests were completed between weeks 8 and 10 following surgery, with participant surgery recovery being the determining variable. After the CG members completed T1 testing, they were instructed to not change their physical activity behaviors until after the T2 testing. For the IG group, resistance training was initiated within 48 hours following T1 testing. The resistance training was continued

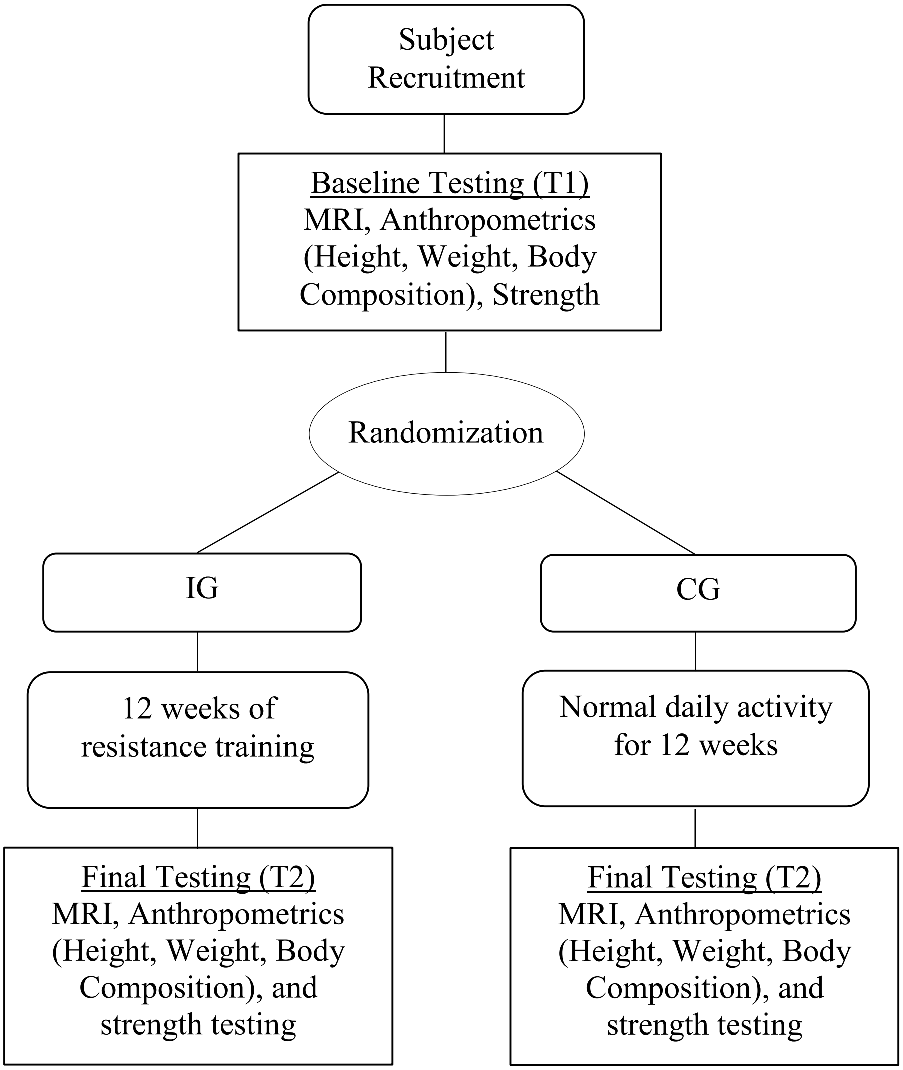

Figure 1. Flow chart for study procedures.

for 12 weeks and the T2 tests for the IG were administered 48-72 hours after the final RT session.

All tests were completed on the same day. MRI was completed first to prevent the possibility of activity-related factors (muscle blood flow, etc.) resulting in image artifact. The anthropometric tests were administered next to prevent distortions due to fluid shifts and potential sweating associated with the muscular strength warm-up and testing. The last of the assessments was the muscular strength testing.

Magnetic Resonance Imaging

Magnetic Resonance Imaging (MRI) was used to assess cross-sectional area of the right thigh at the midpoint between the greater trochanter of the femur and the proximal aspect of the patella using a 3T Tri MR scanner with a 12-channel head coil (Siemens, Erlanger, Germany).

All T1 MRI scans were completed within a 48-hour period prior to beginning the study (Peterson et al, 2011). For the IG, T2 MRI scans were conducted no sooner than 48 hours after the completion of the resistance training portion of the study to reduce potential MRI distortion due to inflammation and the influx of intracellular water that may result from resistance training. In addition, to ensure that the effects of training were captured, the T2 scans for the IG were taken no more than 72 hours following the last training session. For CG participants, the T2 scans were completed within 72 hours of the completion of the 12-week control period.

Cross-sectional area of the quadriceps and of the whole thigh musculature was analyzed using a custom-written image analyzing software (Met lab; Mathworks, Inc., Natick, MA) on a desktop computer. Each of the four distinct quadriceps muscles (vastus lateralis, vastus medialis, vastus intermedius, and rectus femoris) and of the whole thigh region (quadriceps, hamstring and adductor groups as well as sartorius and gracilis) was identified from the images independent of skin, the femur, and subcutaneous, as well as some intermuscular fat. Each muscle or muscle group within the scan was manually traced using a computer hand-held mouse. The manual tracing procedure allowed for individual muscles and whole muscle group CSA to be automatically computed (Figures 2 and 3).

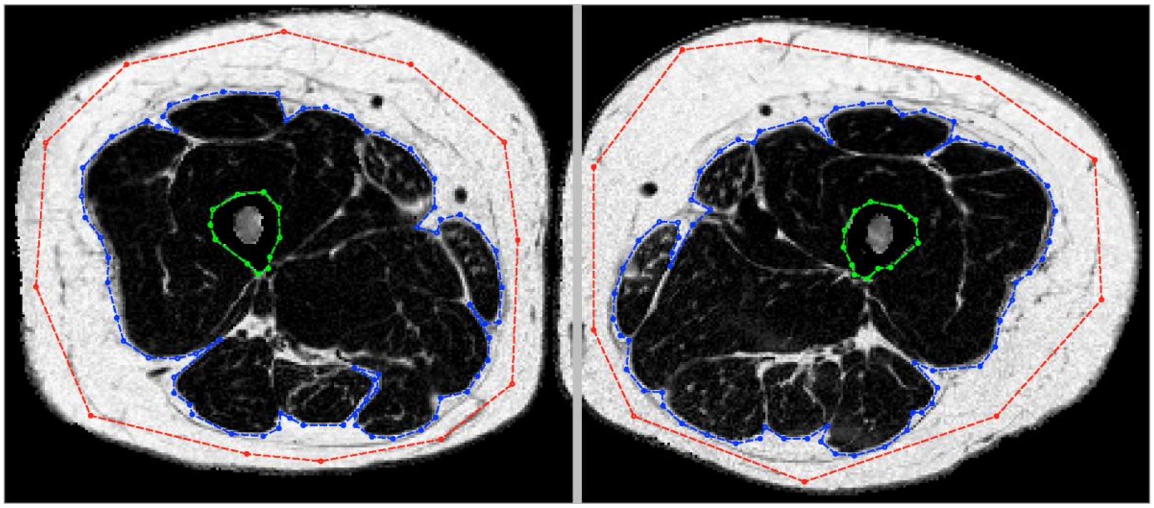

Figure 2. MRI of whole thigh CSA – baseline. Left side image is right thigh of IG subject. Inner dashed lines used to measure WTCSA. The dashed red line (in the middle of the white area of the scan) denotes the superficial edge of subcutaneous adipose tissue; the deeper blue dashed line represents the outer border of the thigh skeletal musculature. The area inside this blue line is the WTCSA. The dashed line near the center of the image has been drawn to indicate the border the femur.

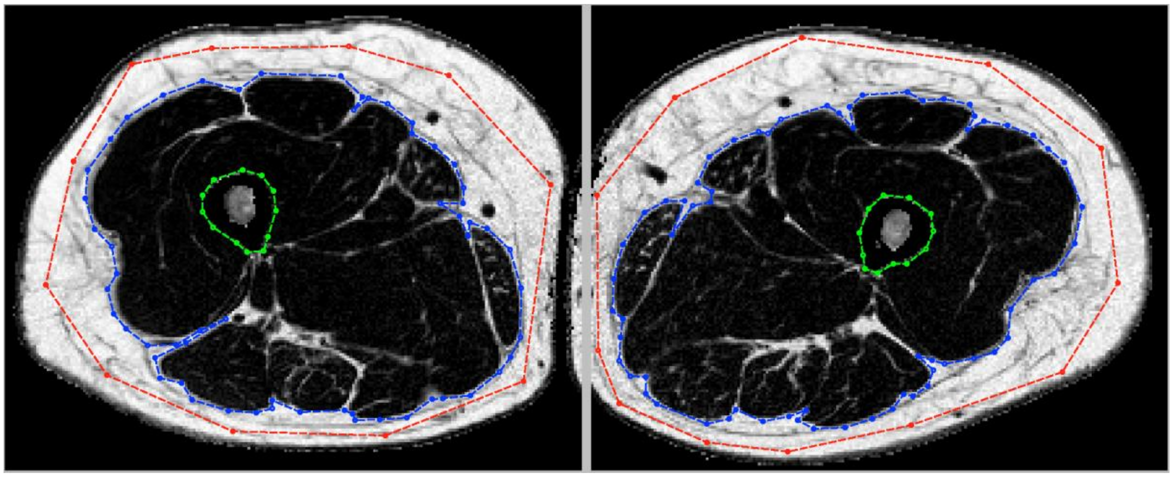

Figure 3. MRI of whole thigh CSA - week 12. Left side image is right thigh for IG subject. There has been a noticeable reduction in subcutaneous adipose tissue (white outer area).

To enhance the reliability of the scan analyses, the same individual performed the analyses for both the T1 and T2 scans for both the CG and IG. In addition, the MRI technician performing the muscle tracings was blinded to the relationship between subject images and subject grouping (CG vs. IG) throughout the entire study.

For data analysis, four 10mm cross-sectional area slice images of the right thigh were analyzed and three of these images were averaged for CSA calculations. The actual cross-sectional area was calculated by counting the number of pixels falling on the area of scan designated as muscle; therefore, the contribution of fat and other noncontractile connective tissues was excluded from CSA calculations. The number of pixels counted was multiplied by the area value of a pixel to yield actual muscle CSA (Jubrias et al., 1997). Interclass correlation (ICC) and validity statistics using these techniques has been shown to be quite high (0.99 and 100.7%, respectively - see Lastayo et al. (2009).

Anthropometrics

Subject height was measured using a wall-mounted measuring tape and recorded to the nearest 0.5 cm. Weight was measured using a digital scale and recorded to the nearest 0.1 kg. Height and weight were used to calculate body mass index (BMI) [weight(kg)/height(m)^2].

Body composition was measured using air displacement plethysmography (ADP) (BodPod, Life Measurement, Inc., Concord, Calif.) Lung volume was determined using standard prediction equations based on height. The Siri equation was used to predict %fat. Fat free mass was calculated by subtracting fat mass from total body mass. Air displacement plethysmography was selected to assess changes in body composition based on the work of Minderico et al. (2006), who demonstrated that when compared to dual energy x-ray absorptometry (DEXA), there were no differences in body composition changes over time between each method.

The body composition variables, %fat, FM, and FFM were not primary outcome measures for this study. They were used for descriptive statistics and to provide study participants with information that may be of interest to them.

Muscular Strength Testing

Prior to administering the muscular strength tests, subjects were given the opportunity to perform several low intensity (2-3 sets of 4-6 reps) practice sets with each machine (leg extension and leg press). These sets served as a warm-up and for the participants to familiarize themselves with the resistance training equipment (Hill-Haas, Bishop, Dawson, Goodman, & Edge, 2006). Subjects were provided instruction relative to proper technique of each exercise and performance of the exercises was supervised.

A 1RM leg extension (LE) (Häkkinen et al., 1998) using the right leg was conducted to determine right leg quadriceps strength. Following the 1RM leg extension test, a 3RM muscular strength test was conducted on a 40 degree plate loaded leg press (LP) (Hammer Strength, Irvine, CA), using both legs simultaneously (Lawton, Cronin, & McGuigan, 2013). A 3RM test was selected for the leg press exercise since the women participants in the IG were resistive training novices. A 3RM test reduces the magnitude of the loads necessary and therefore can be executed more safely that a 1RM test.

Using dynamic muscular strength testing to assess maximal values required several attempts, especially with novice lifters. The warm-up sets were used to derive starting loads for the 1RM and 3RM testing. Once the warm-up sets were completed, the 1RM testing for leg extension began. Participants attempted to complete a 1RM using a weight that was predicted to be the maximal weight that could be lifted. After a 3-5-minute recovery interval, the subject attempted a higher load. This procedure continued until a 1RM was completed with good form. During this procedure, subjects performed no less than two, but no more than five trials to determine maximal strength (Robinson et al., 1995; NSCA's Essentials of Personal Training, Baechle & Earle, 2004). The same procedure of using multiple trials was repeated for the 3RM leg press test.

The T1 values for both the 1RM leg extension and the 3RM leg press were also used in individualizing the loads used during the initial training sessions for members of the IG. In addition, T1 values for both the 1RM leg extension and the 3RM leg press served as baseline values from comparison with the T2 values recorded after the 12-week RT program (Stegen et al., 2009).

Muscle Quality

Muscle quality, calculated by dividing the 1RM muscular strength by CSA for the right thigh, is a strategy for evaluating changes in strength that take into account differences in individual muscle size. MQ, as a normalized assessment variable, is a good predictor of muscular function when compared to over-all strength (Peterson et al., 2011). Changes in muscle quality can be measured by changes in CSA. However, disproportionate changes in strength to CSA can show reductions or improvements in muscle quality more so than changes in strength alone (Delmonico et al., 2009). If improvements in strength are observed with little or no change to muscle CSA, it may be concluded that the quality of the muscle tissue has improved, especially if neuromuscular strength adaptations are taken into account by assessing muscular strength after a 3-week adaptation period (Folland & Williams, 2007; Narici et al., 1989).

Physical Activity

Actigraph GT3X (Pensacola, FL) tri-axial accelerometers was used to measure physical activity (PA) before and after the 12-week RT intervention. The current study followed the protocol as seen in the National Health and Nutrition Examination Survey (NHANES) 2003-2004 as described by Matthews et al. (2008) where subjects wore the accelerometers during waking hours and removed them during sleeping hours. Accelerometers were worn on the right hip for 8 consecutive days at the beginning of the study and for 8 consecutive days after the conclusion of the study. While 3-5 days of wear time is recommended for adults, we chose 8 consecutive days of wear time to account for possible missed days. Four weekdays and 1weekend day were analyzed for the purpose of this study (Trost, McIver, & Pate, 2005). Accelerometers were set to collect data at 60-second epochs in accordance with the recommendations for adults (Trost et al., 2005). Cut-points between 1952 and >5725 counts per minutes (CPM) were used to determine moderate to vigorous physical activity (MVPA) (Freedson et al., 1998).

High interinstrument reliability (between different Actigraph) has been shown for Actigraph monitors for total activity counts, steps, and time spent in sedentary (0-499 counts per minute), light (500-1951 counts per minute), moderate (1952-5724 counts per minute), and vigorous (≥ 5725 counts per minute) intensity activities (McClain, Sisson, & Tudor-Locke, 2007). Validation of the Actigraph GT3X for measuring physical activity has been described by Kelly and colleagues (2013) when compared to oxygen consumption.

Accelerometry data from the first day of wear-time, reflective of a familiarization period, were eliminated to reduce the effects of reactivity of accelerometer use by the subjects. To ensure at least 10 hours of wear time (Rich et al., 2013), subjects placed accelerometers on their clothing as they dressed each morning then removed the accelerometer each night before bed. Data collection less than 10 hours each day was eliminated. All subjects were asked to continue their normal daily activities during the study.

Resistance Training

The IG completed 12-weeks of periodized resistance training. The word periodized refers to planning of specific periods of training for different purposes. The RT program design was divided into three periods. Period 1, the first 2 weeks of the study, was designed to allow adaptation to RT while keeping delayed onset muscle soreness (DOMS) to a minimum (Cheung, Hume, & Maxwell, 2003). During Period 1, three training sessions were held each week. Period 2, weeks 2 through 7, consisted of progressively higher volume workouts (3-4 sets 15 to 10 reps with addition of more exercises). The high volume design of Period 2 was to stimulate muscle hypertrophy. During the first 4 weeks of Period 2, training occurred three times per week. Starting with the fifth week of Period 2, the number of days per week of training was reduced by one day. The rationale for moving to 2 training days per week was two-fold: First, three subjects involved in pilot work requested a reduction in days per week because of time limitations. In an effort to prevent subject dropout, a compromise was made to begin a 2 day per week regimen. Second, volume load for lower body RT exercises was quite high. A 2 day per week regimen allowed for greater recovery and, as a result, greater performance during the following workout (Gentil & Bottaro, 2013; Wernbom, Augustsson, & Thomeé, 2007).

Period 3 consisted of the remaining 5 weeks of the 12-week training program. Period 3 was designed to maintain muscle mass and to stimulate maximal strength gains by increasing the loads for the exercises and decreasing the number of repetitions of each exercise (Kraemer et al., 2003; Fry, 2004).

Sets, repetitions, and weight for both the leg extension and leg press were initially set as a percentage of 1RM (i.e., a set of 15 repetitions completed with a load of approximately 65% of 1 RM while a set of 8 repetitions requires setting the load at 80% of 1RM). The 1RM value for the leg extension was available from the T1 testing. Since the T1 leg press consisted of a 3RM, a formula was used to determine a leg press 1RM. With the following formula, the total weight lifted during the 3RM test was used to predict 1RM for the leg press:

Predicted 1RM: 1-RM = weight lifted (lb) / [1.0278 - (reps to fatigue * 0.0278)] (Brzycki, 1993).

During the training sessions, if the number of repetitions for a calculated 1RM workload could be easily performed, the load was increased for maximum effect while keeping the number of repetitions at the prescribed level for a given week. The 1RM load determination was used for only the leg extension and leg press exercises; all other lower body exercise loads were determined based on the number of repetitions that could be completed based on the written RT program. In other words, the number of repetitions for each exercise was established for each week of training and the loads were adjusted accordingly so that maximal efforts were achieved for each set of exercises.

Workout sessions lasted approximately 60-80 minutes. Each RT session began with 5-10 minutes of warming up and dynamic stretching followed by 50-60 minutes of resistance exercise. The resistance training portion of the study incorporated core exercises as defined by the National Strength and Conditioning Association (NSCA). Lifts included squats, lunges, leg press, leg curl, leg extension, lat pull down, shoulder press, bench press, and bent or seated rows. The focus of this study was on lower body adaptation. Each training session concluded with a 5-10-minute cool-down period using a stationary bicycle.

CG group members did not participate in a training program. Instead they were instructed to continue their normal daily activities during the 12-week study.

Statistical Analysis

All dependent variables were checked for normal distributions within both the control and intervention group using histograms and the Shapiro-Wilk test for normality. To test for equality of error variances between the control and intervention group on each dependent variable, Levene's test was employed. Alpha levels to determine statistical significance were adjusted using the Bonferroni method because of analysis of multiple dependent variables.

Initial body weight is frequently reported with BS studies since initial body weight has been shown to be associated with bariatric surgery outcomes (Chen et al., 2009; Wood et al., 2014). To determine if initial or presurgery body weight influenced the outcome variables measured in association with the RT intervention for the current study, 2 x 2 mixed design ANCOVA tests for each dependent variable were completed using group (control, experimental) and time (baseline, posttest) factors and a presurgery weight covariate. In addition, 2 x 2 mixed design ANOVA tests for each dependent variable were completed using group (control, experimental) and time (baseline, posttest) factors with no covariate variable. The effect of interest was the statistical significance of the group × time interaction and neither the ANOVA or ANCOVA analyses resulted in statistically significant interaction effects. Therefore, presurgery weights were not used as a covariate for any of the outcome variables reported in Chapter 4.

Since variability in wear-time between the T1 and T2 test periods could impact the PA data, a 2 x 2 ANOVA test was employed to examine differences in wear-time between the CG and IG across time points. There were no statistically significant main effects seen for group or time on wear-time ($p > 0.05$); therefore, no wear-time covariate was used for analysis of the PA data.

For statistically significant effects, Cohen's delta ($d = x_1 - x_2 / s_{\text{pooled}}$) was used to determine the effect size and practical significance of each pair-wise comparison. Effect sizes were classified as small if $d \leq 0.2$, medium if $d \cong 0.5$, and large if $d \geq 0.8$ (Cohen, 1988). Because of multiple analyses on multiple dependent variables, alpha level was corrected at $p \leq 0.01$ to protect against Type I error. All analyses were carried out using IBM's SPSS v23.0 statistical software package (Armonk, NY, USA).

CHAPTER 4

RESULTS AND DISCUSSION

In an effort to combat obesity and its comorbidity conditions (Bray, 2004; Cawley & Meyerhoefer, 2012; Ferrante, 2007; Withrow & Alter, 2011), bariatric surgical procedures have been used to stimulate weight loss. Despite successful weight loss for many patients, questions regarding associated losses of skeletal muscle and strength (Chaston et al., 2006) as well as weight regain have arisen (Adams et al. 2012; Sjöström et al., 2004). Since loss of skeletal muscle and accompanying muscular strength impacts physical activity in aging populations, it is possible that a loss of skeletal muscle and muscular strength could contribute to inadequate physical activity and a reduced weight loss following BS or the reduced physical activity might contribute to weight regain in bariatric surgery patients. Therefore, the current study was designed to examine the potential for resistive exercise training to maintain or perhaps increase skeletal muscle mass, FFM, muscular strength, and physical activity in postbariatric surgery patients.

This chapter presents results from the study starting with descriptive characteristics of the study participants followed by the results of analyses examining differences in FFM, muscle CSA, strength, muscle quality, and physical activity between the intervention (IG) and control (CG) participants. The chapter will close with a discussion of the major findings, how they are related to the research questions posed in this study, as well as other related research.

Descriptive Statistics

Eighteen White females between the ages of 28 and 60 years (44.9 ± 10.2 years) volunteered for the study. Their mean weights at presurgery, at the initiation of the study (T1) and at the study conclusion (T2), can be seen in Table 1. While 18 participants began the study, during the course of the study, 2 women in the IG dropped out, resulting in 16 women completing the study (9 in the intervention group and 7 in the control group). The smaller *n* that occurred as the study progressed is reflected in Table 2 compared to Table 1.

Although previous research has suggested that initial body weight is associated with the weight loss achieved following BS, for the current study, using initial body weight as a co-variate did not influence the ANOVA values. Therefore, only the ANOVA outcomes will be presented.

Over the course of the 12-week study, there were 30 RT sessions with an 89% adherence rate by the IG. On Day 1 of the RT program, IG subjects performed a volume of 60 total repetitions for their legs (2 sets x 15 reps of LP and 2 sets x 15 reps for leg curl at loads near 65% of 1RM). By week 7 the IG was performing a volume of 170 repetitions on exercises such as LP, machine squats, LE, leg curl, and lunges. On the final day of the study, the IG was performing 45 repetitions (3 sets x 2-4 reps of near maximal loads).

The baseline (T1) descriptive data for the group as a whole as well as the IG and CG participants are presented in Table 2. A one-way ANOVA was used to compare baseline variables between the IG and CG. The two groups were not significantly

Table 1. Presurgery Weight for T1

	Group	Presurgery	T1	T2	Diff Pre to T1	Diff Pre to T2
Wt (kg)	IG	131.3 (± 2.6)	108.7 (±13.0)	94.1 (±13.4)	-22.6	-37.2
	CG	136.1 (±17.3)	113.6 (±15.4)	99.6 (±12.7)	-22.5	-36.5

Note: Comparison of changes in body weight for study groups ± *SD*. Diff Pre to T1 and Diff Pre to T2 is the absolute difference in weight in kgs.

Table 2. Participant Characteristics

	T1 (***n*** = 18) All subjects ***M***(±***SD***)	T1 (***n*** = 11) IG ***M***(±***SD***)	T1 (***n*** = 7) CG ***M***(±***SD***)
Age	44.9(±10.2)	47.0(±10.8)	41.6(±8.7)
Height (cm)	169.0(±6.0)	168.7(±5.1)	169.4(±6.6)
Weight (kg)	110.6(±15.5)	108.7(±15.9)	113.4(±15.4)
% body fat	48.9(±6.5)	49.0(±7.3)	48.9(±5.4)
FM (kg)	55.0(±14.1)	54.2(±15.0)	56.3(±13.6)
FFM (kg)	55.6(±3.9)	54.5(±4.1)	57.3(±3.3)
BMI(kg/ht^2)	38.9(±5.6)	38.3(±5.9)	39.9(±5.3)

Note. IG, intervention group; CG, control group; FM, fat mass; FFM, fat free mass; BMI, body mass index [wt(kg)/ht(m)^2]. No between-group differences ($p < .05$) were present at T1.

different at T1 in regards to age, height, BMI, percent body fat (%BF), fat mass (FM), or fat free mass (FFM) ($p > .05$).

Except for BMI in the intervention group, the Shapiro-Wilk test for normal distributions revealed no statistical significance within either the control or intervention group on any dependent variable ($p > 0.01$). Because BMI approximated a normal distribution in the control group and repeated measures ANOVA is robust to slight deviations from normality, no transformation on BMI was made. Additionally, for each ANOVA test, Levene's test for equality of error variances revealed no statistical significance between the control or intervention group ($p > 0.01$). Mauchley's test for sphericity was not conducted because there were only two levels of the within-subject factor.

Anthropometric Variables

As anticipated, there was a significant time effect for body weight ($F(1, 15) = 279.5$; $p < .001$; $d = .99$), percent body fat ($F(1, 15) = 79.4$; $p < .001$; $d = 1.1$), FM ($F(1, 15) = 171.9$; $p < .001$; $d = 1.1$), and BMI ($F(1, 15) = 273.0$; $p < .001$; $d = 1.0$) over the course of the study with both the both the IG and CG experiencing significant decreases (Table 3). There were no interaction effects for any of the anthropometric variables.

Subjects in both groups lost significant FM, although the CG lost slightly more (16 ± 4.0kg) FM than IG subjects (13.6 ± 4.3kg). Figure 4 portrays the similarity in the loss of FM for the two groups, the large variability within each group, as well as the lack of an interaction effect.

A significant time effect for loss in percent body fat (%BF) and BMI were observed, as was a large degree of variability in individual responses; however, no

Table 3. Absolute and Relative Changes of Anthropometric Characteristics After 12 Weeks of Resistance Training (IG $n = 9$; CG $n = 7$).

		Week 12	Absolute change	Relative change (%)	Time (*p* value)	Interaction (*p* value)
Wt (kg)	IG	94.1(±13.4)	-15.7(±3.4)	-14.3	$p < .001$	$p = 0.3$
	CG	99.6(±12.7)	-13.9(±3.7)	-12.2	$p < .001$	
% Body fat	IG	42.3(±7.7)	-6.8(±2.2)	-13.8	$p < .005$	$p = 0.4$
	CG	40.6(±8.0)	-8.3(±4.5)	-17.0	$p < .05$	
FM (kg)	IG	40.5(±12.9)	-14.3(±3.6)	-26.0	$p < .001$	$p = 0.8$
	CG	41.2(±13.1)	-15.1(±5.4)	-26.8	$p < .001$	
BMI	IG	32.7(±4.2)	-5.5(±1.2)	-14.4	$p < .001$	$p = 0.4$
	CG	35.0(±4.4)	-4.9(±1.3)	-12.3	$p < .001$	

Note. FM, fat mass; BMI, body mass index [wt(kg)/ht(m)^2]. Comparison of changes for study groups at the study conclusion as mean values ± *SD*. *p* values for time and interaction are displayed (significance set at $p < .05$).

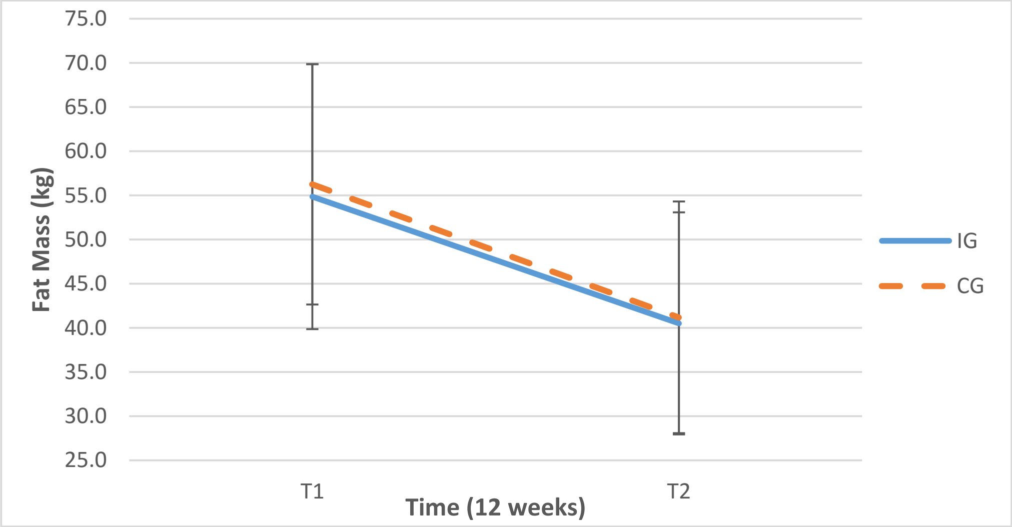

Figure 4. Loss of fat mass. T1 to T2 in RYGB weight loss subjects

interaction effect for either variable occurred (Table 3).

Surprisingly, previous research indicated significant FFM losses with BS. Our initial repeated measure ANOVA for FFM (see Table 4) did not result in either a time effect ($F = 4.1$; $p = .08$) or an interaction effect ($F(1, 15) = .01$; $p = .9$; $d = .04$). To further examine the FFM values, the T1 and T2 values for the individuals in the two groups were plotted. Considerable variability in the individual FFM values over the course of the study is apparent. The IG individual data, plotted in Figure 5, illustrates that 2 subjects gained FFM, 1 stayed about the same, and 6 lost FFM. The CG individual

Table 4. Baseline, Absolute, and Relative Changes for Fat Free Mass After 12 Weeks of Resistance Training Including the Outlier (**n* = 16) and Excluding the Outlier (*n* = 15).

	Group	T1	T2	% Change	Time (*p* value)	Interaction (*p* value)
FFM (kg)*	IG	55.0(±4.4)	53.6(±3.9)	-2.4	$p = .08$	$p = 0.9$
	CG	57.3(±3.3)	58.5(±5.7)	3.5	$p = 0.4$	
FFM (kg)	IG	55.0(±4.4)	53.6(±3.9)	-2.4	$p = .08$	$p = 0.3$
	CG	57.4(±3.6)	57.6(±5.8)	2.1	$p = 0.7$	

Note. FFM, Fat free mass. Comparison of changes in FFM by study group with (*) and without outlier at the study conclusion as mean values ± *SD*. *p* values for time and interaction are displayed (significance set at $p < .05$).

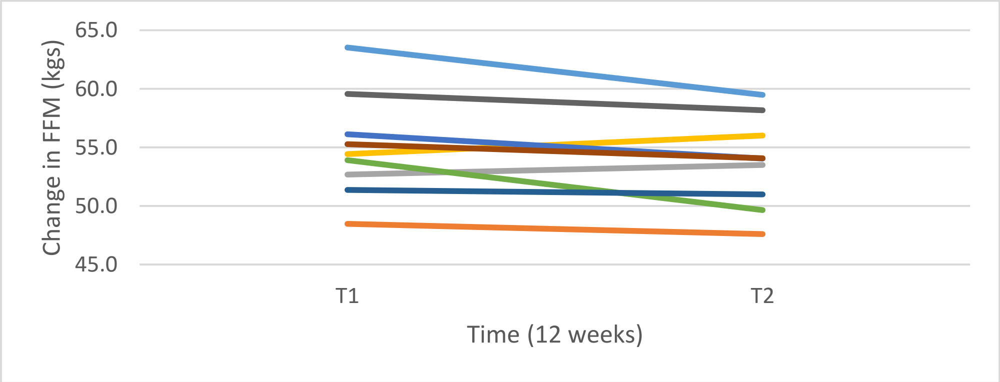

Figure 5. Change in FFM in the IG by individual (*n* = 9)

data, plotted in Figure 6, illustrates that 4 subjects increased FFM while 3 lost FFM. One of the CG experienced an increase in FFM that was greater than 2.5*z* fulfilling the criteria of an outlier. The FFM repeated measures ANOVA was completed with all subjects (Figure 7) and again without the outlier (see Table 4). The analysis results for the CG without the outlier (1.2 ± 3.7kg; $F = 3.9$, $p = .04$) were very similar to the repeated measures ANOVA when the outlier was included (0.2 ± 3.0kg; $F = 3.9$, $p = .07$); therefore, the data for all of the CG subjects were used for all further analyses.

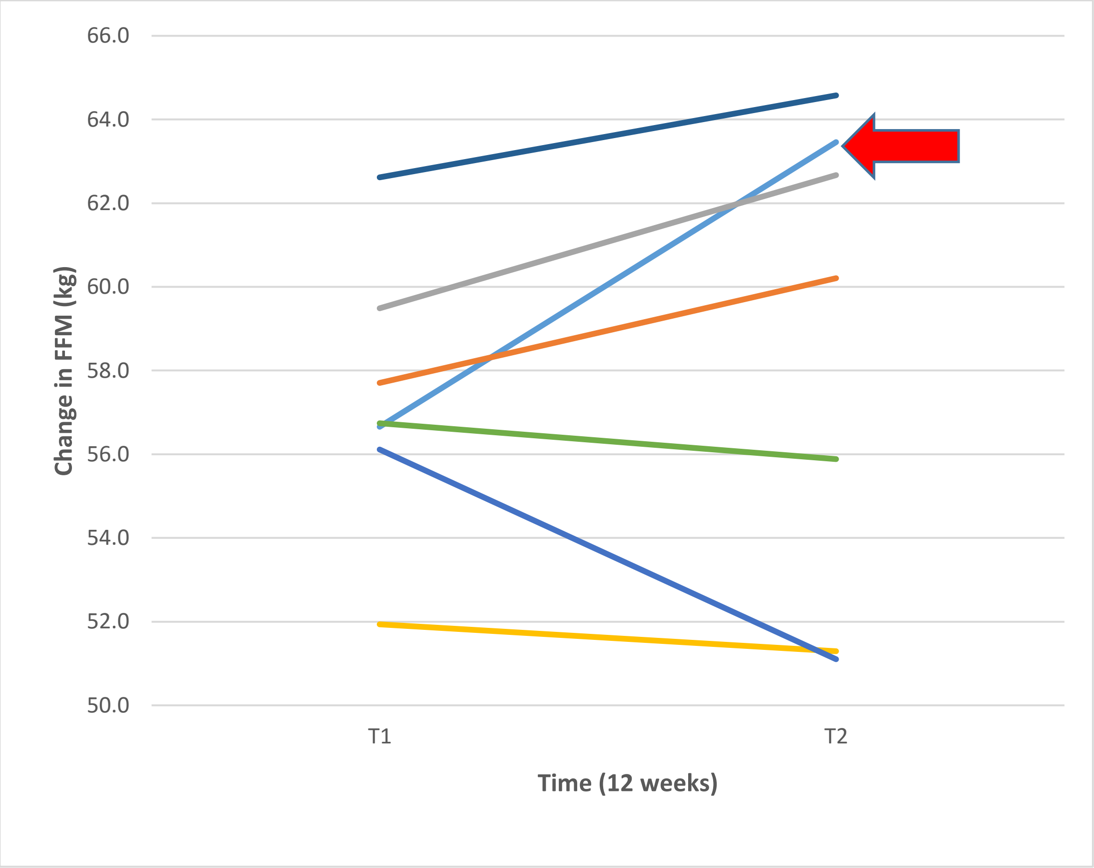

Figure 6. Change in FFM for CG with outlier. Arrow indicates subject with dramatic rise (>2 *SD*) in FFM over the course of the study ($n = 7$).

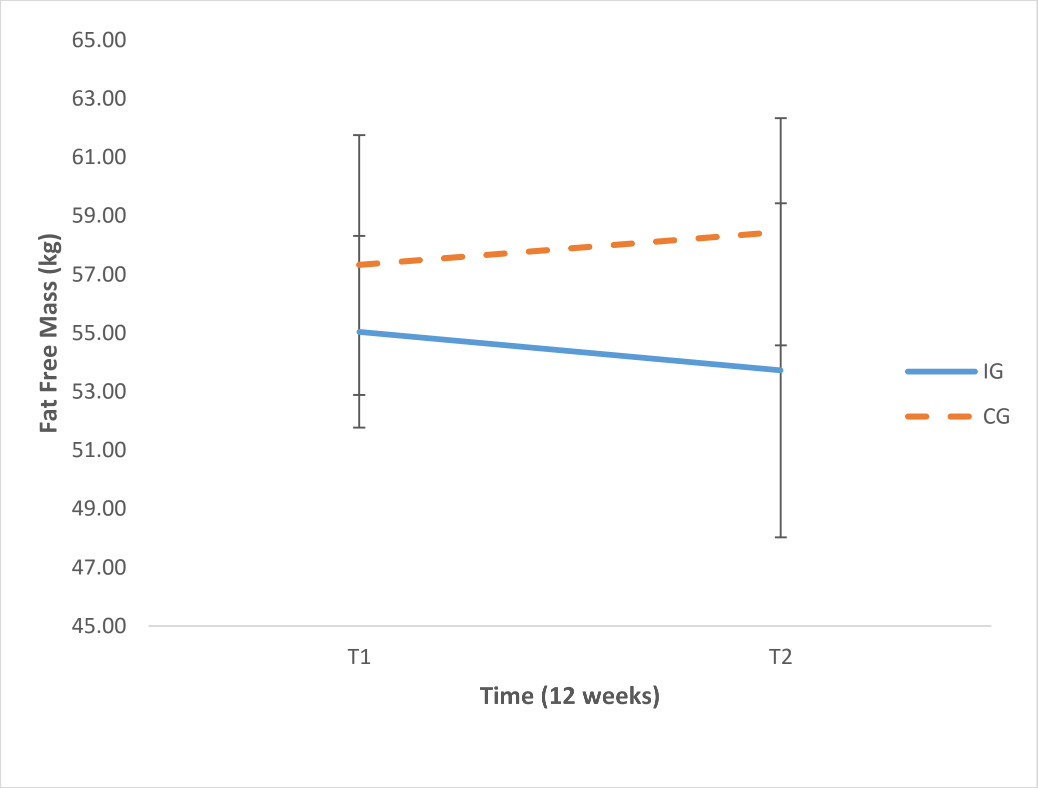

Figure 7. Overall change in FFM. Change in the mean FFM over 12 weeks measured via air displacement plethysmography. All subjects included (*n* = 16).

Skeletal Muscle Variables

Table 5 presents both T1 and T2 values for leg press strength (LP), leg extension strength (LE), quadriceps muscle cross-sectional area (QCSA), whole thigh muscle cross-sectional area (WTCSA), and muscle quality based on strength from the leg press divided by the CSA of the whole thigh (MQLP) and muscle quality based on strength from the leg extension divided by the CSA of the quadriceps muscles. Diagrams for each of the skeletal muscle variable are also included.

Table 5. Changes in Muscle Variables After 12 Weeks of Resistance Training (n = 16)

	Group	T1	T2	Time (p value)	Interaction (p value)
LP (kg)	IG	163.4(±34.4)	222.8(±42.4)	$p < .001$	$p < .001$
	CG	131.1(±33.5)	126.3(±37.9)	$p = .2$	
LE (kg)	IG	32.5(±6.0)	38.3(±6.4)	$p = .006$	$p < .01$
	CG	26.9(±5.3)	26.2(±5.5)	$p = .6$	
QCSA (cm^2)	IG	53.8(±6.4)	53.3(±6.5)	$p = .3$	$p = .3$
	CG	52.3(±6.6)	50.8(±7.2)	$p = .1$	
WTCSA (cm^2)	IG	114.6(±13.3)	110.7(±13.9)	$p = .08$	$p = .07$
	CG	112.5(±14.4)	109.6(±15.4)	$p = .2$	
MQ LP	IG	1.4(±0.4)	2.1(±0.6)	$p < .01$	$p < .005$
	CG	1.2(±0.3)	1.2(±0.3)	$p = .6$	
MQ LE	IG	0.62(±0.2)	0.74(±0.2)	$p < .005$	$p < .05$
	CG	0.51(±0.07)	0.52(±0.1)	$p = .8$	

Note. IG, intervention group; CG, control group; LP, leg press; LE, leg extension; QCSA, Quadriceps cross-sectional area; WT CSA; whole thigh cross-sectional area; MQ, muscle quality (strength/CSA). Comparison of T1 and T2 values presented as mean ± *SD*. LP and WTCSA were calculated using the Brzycki formula, (1993) (see below). Differences over time (12-week study duration) and interaction for the IG and CG are presented (significance set at $p < .05$).

Leg Press Strength

LP strength increased by 59.4kg, as seen in Figure 8. This change accounted for an increase of 36% from T1 to T2 for the IG. The CG, however, saw a nonsignificant decrease in strength of -4.8kg accounting for a change -3.7% (see Table 5 and Figure 8). There was only a 19% difference in LP strength between the group at T1, but the difference in LP strength at T2 between groups was 96.5kg or 55.4%, resulting in a significant interaction effect (*F*(1, 15) = 118.3; $p < .001$; $d = 2.4$).

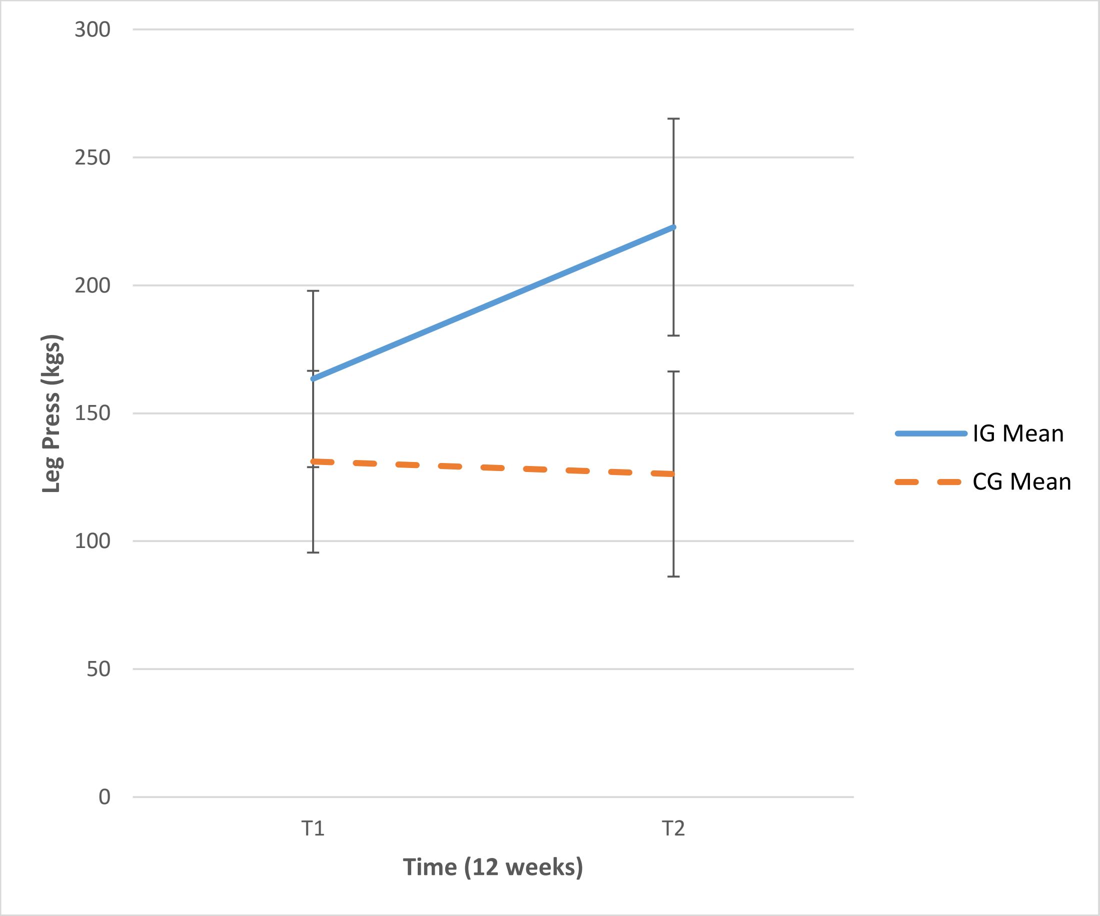

Figure 8. Interaction effect for LP strength. The effect of a 12-week resistance training intervention on leg press strength for the intervention group compared to the control group. Group × Time interaction for leg press (LP) strength was significant ($p < 0.001$).

Leg Extension Strength

At baseline, there was a 17% difference in strength between groups. The IG improved their LE strength significantly from T1 to T2 with a gain of 18% ($p = .006$) while the CG showed a 3% loss in strength ($p > .05$). A difference of 12.1kg or 32% was observed (Table 5) between the T2 values for the two groups, resulting in a significant interaction effect for leg extension (LE) strength (Figure 9) ($F(1, 15) = 9.3$; $p < .01$; $d = 2.0$).

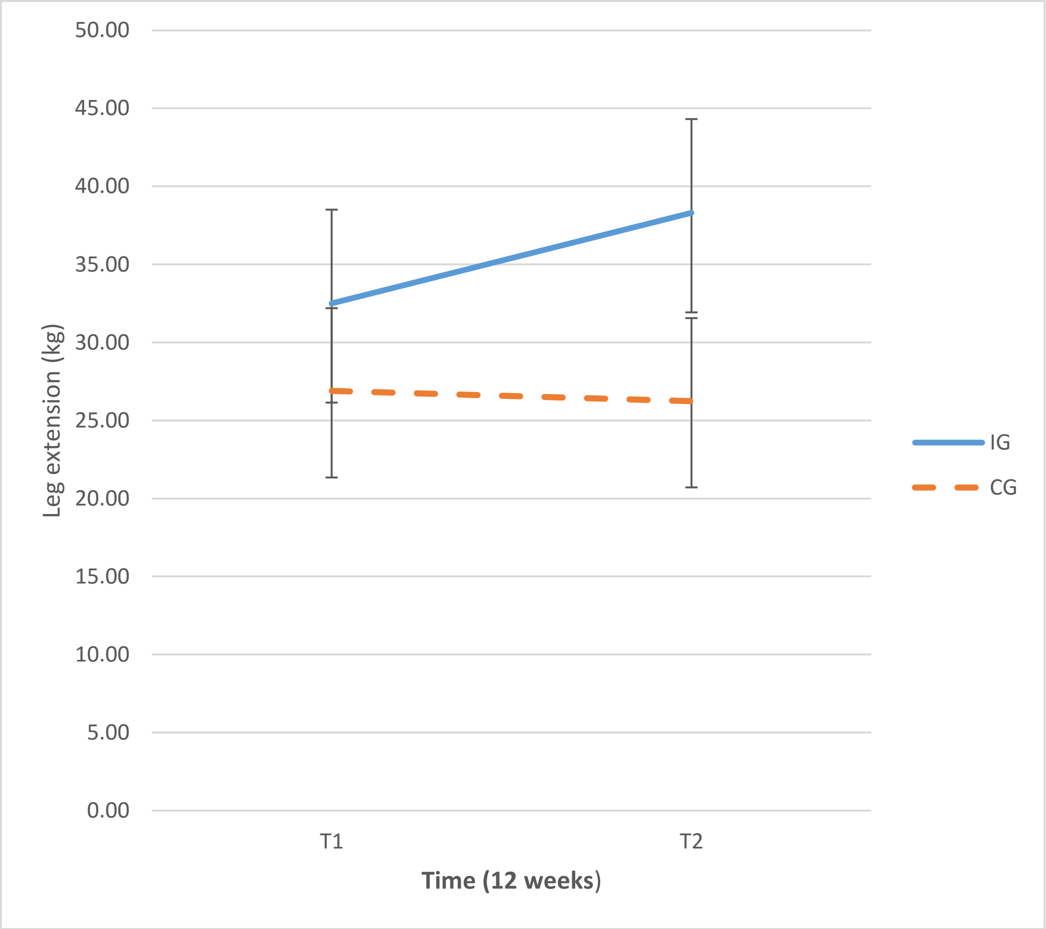

Figure 9. Interaction effect for LE strength. The effect of a 12-week resistance training intervention on leg extension strength for the intervention group compared to the control group. Group × Time interaction for leg extension (LE) strength was significant ($p < 0.01$).

Muscle Cross-Sectional Area

Mean cross-sectional area for the quadriceps (QCSA) measured via MRI was not significantly different between groups at T1 or T2 and no interaction effect was observed (*F*(1, 15) = 1.0*;* *p* = .3; *d* = .36). The IG lost 0.5cm^2, less than 1/10th of a percent, of QCSA. The CG lost 1.5cm^2 or approximately 3% of quadriceps CSA (Table 5).

Changes in whole thigh cross-sectional area (WTCSA) are also presented in Table 5. There was no time effect for WTCSA over the course of the study and no interaction effect was observed. Reproductions of the T1 and T2 MRI of one IG subject are represented in Figures 2 and 3.

Muscle Quality

Muscle quality for leg press (MQLP), calculated as the quotient of strength divided by the cross-sectional area of the whole thigh (WTCSA), increased by 50% for the IG group while no change was observed for the CG (0.0%) (Table 5). The IG improved MQLP 54.5% compared to controls, resulting in a significant interaction effect (*F*(1, 15) = 58.7; *p* <.005; *d* = 1.9) (Figure 10).

A significant time effect was observed for muscle quality for the leg extension (MQLE) in the IG. However, no time effect was observed in the CG. The increase in MQLE in the IG was 19% compared to 2% for the CG. This large increase in strength in the IG was dramatic compared to the very small increase in strength for the CG. These dramatic differences in strength resulted in a significant interaction effect that is illustrated in Figure 11 (*F*(1, 15) = 7.9; *p* < .05; *d* = .86) while the numerical values can be seen in Table 5.

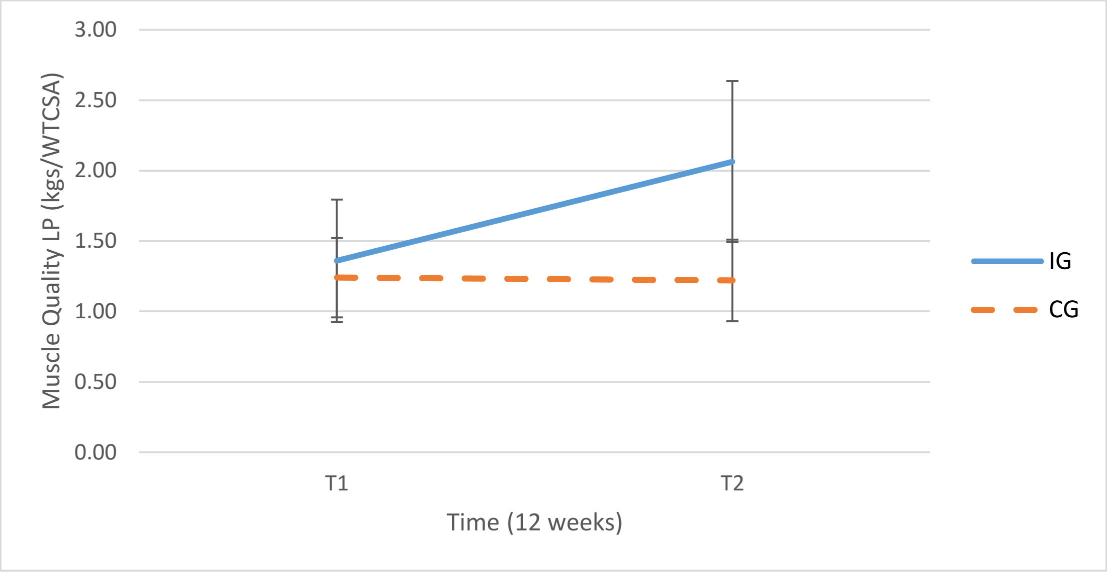

Figure 10. Interaction effect for MQLP. The effect of a 12-week resistance training intervention on leg press muscle quality (MQLP) for the intervention group compared to the control group. Group × Time interaction for MQLP was significant ($p < 0.005$).

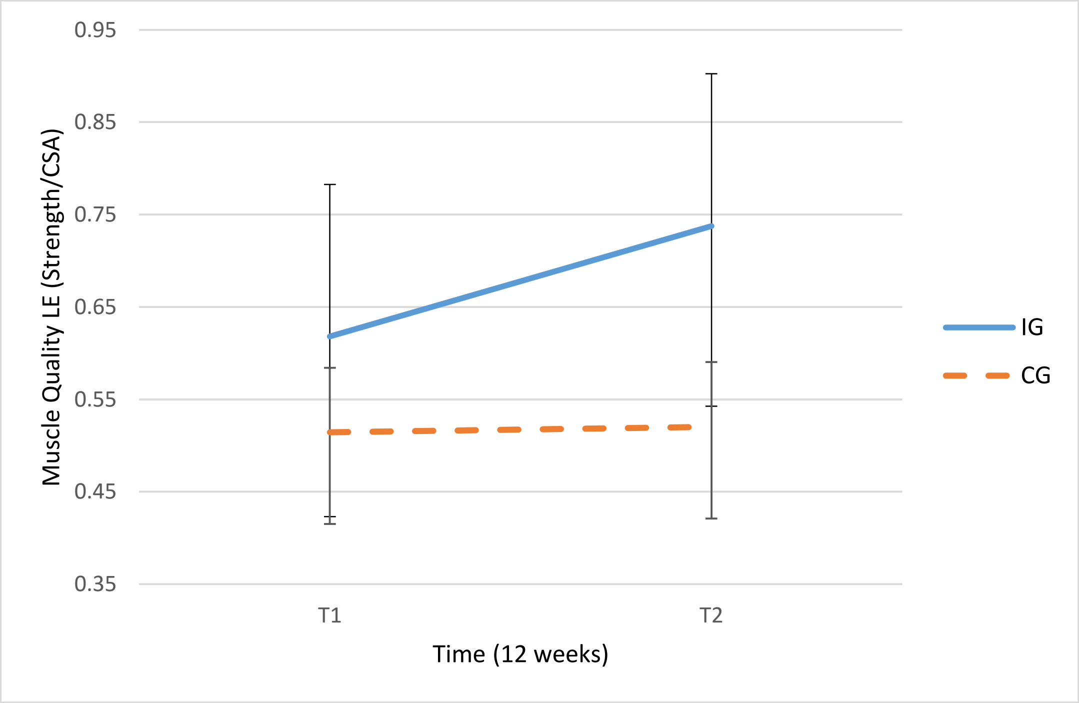

Figure 11. Interaction effect for MQLE. The effect of a 12-week resistance training intervention on leg press muscle quality (MQLE) for the intervention group compared to the control group. Group × Time interaction for MQLE ($p < 0.05$).

Physical Activity

The average wear-time by day and by group is shown in Table 6. Due to a family emergency out of state, one woman in the IG was unable to complete the T2 accelerometer data collection. Her data were used for all analyses except for physical activity analyses and, therefore, the *n* for the physical activity data was only 15 as opposed the higher *n* of 16 for all other analyses.

Wear-time was measured in hours per day. Although there were small variations in the wear-times for both the IG and CG group members, there was not a significant interaction or main time effect for wear-time ($p > 0.05$) (Table 6). At the beginning of the study (T1), the CG wore the accelerometers nearly 36 minutes more than the IG.

Table 6. Hours of Wear-Time by Day and by Group (*n* = 15)

Day	Group	TI (baseline)	T2 (week 12)
1	IG	12.7	14.0
	CG	13.6	13.3
2	IG	13.8	13.7
	CG	14.3	13.8
3	IG	12.9	13.9
	CG	13.9	14.4
4	IG	12.6	14.2
	CG	12.8	12.8
5	IG	13.9	15.1
	CG	14.3	13.7
Total	IG	13.2 (± 0.6)	14.2 (± 0.5)
(***SD***)	CG	13.8 (± 0.5)	13.6 (± 0.6)

However, at T2 the IG had worn the accelerometers nearly 36 minutes more each day (Table 6). Since these differences in wear-time were not significantly different, wear-time was not used as a co-variate for further analyses.

The specific physical activity variables analyzed were total steps/d, moderate to vigorous PA ≥1 minute (MVPA), time engaged in light physical activity (LPA), and sedentary time (ST). No significant time or interaction effects were seen for steps/d, ST or time in MVPA ($p > 0.05$) (Table 7). There was a statistically significant group × time interaction for time engaged in LPA ($F(1, 12) = 10.84$, $p = 0.006$) (Figure 12). Follow-up *t*-tests indicated that the intervention group had a greater increase in LPA from baseline to posttest compared to the control group (Mean difference = 25.08min/d, $p < 0.001$, Cohen's $d = 0.40$) amounting to a small-to-medium sized effect.

Table 7. Physical Activity Data Based on Tri-axial Accelerometry ($n = 15$)

	Group	T1	T2	Time (*p* value)	Group x Time Interaction (*p* value)
Wear-time (hrs/d)	IG CG	13.2 (±1.6) 13.8 (±1.3)	14.2 (±1.6) 13.6 (±1.0)	$p = 0.2$ $p = 0.7$	$p = 0.1$
Steps/d	IG CG	5285(±1653) 4788(±2884)	5687(±1685) 4509(±754)	$p = 0.7$ $p = 0.6$	$p = 0.9$
MVPA (min/d)	IG CG	44.1(±18.2) 26.8(±14.7)	40.2 (±13.4) 28.9 (±12.3)	$p = 0.3$ $p = 0.9$	$p = 0.1$
ST (min/d)	IG CG	486.3(±84.2) 524.8(±72.3)	506.1(±129.7) 515.1(±82.8)	$p = 0.1$ $p = .02$	$p = 0.4$
LPA (min/d)	IG CG	259.5(±43.8) 283.0(±58.7)	307.9(±74.6) 276.9(±51.1)	$p = .07$ $p = 0.2$	$p < 0.01$

Note. MVPA, bouts of ≥1 minute moderate to vigorous physical activity; ST, sedentary time. Significance set at $p < .05$

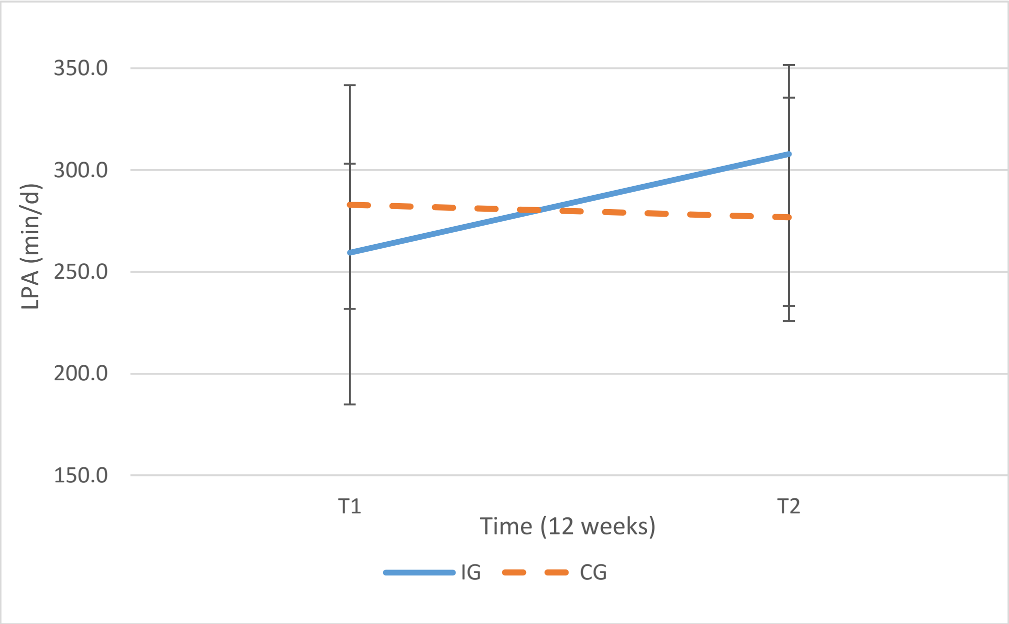

Figure 12. Interaction effect for LPA. The effect of a 12-week resistance training intervention on light physical activity (LPA). The IG increased time spent in LPA from T1 to T2 while CG spent less time engaged in LPA. Group × Time interaction for LPA ($p < 0.01$).

Discussion

We believe that this is the first study to use a high-intensity resistant training (RT) intervention following RYGB weight loss surgery. The only known study to date using a RT protocol with RYGB patients used moderate loads (Stegen et al., 2009). The current study employed loads at or near 100% of maximal loads (1-3RM).

Consequent to the high-intensity training, a significant interaction effect was observed for both leg press (LP) and leg extension (LE) strength resulting in the large effect size for both LP and LE (2.4 and 2.0, respectively). The IG improved their LP strength by 46% and LE strength by 18%. No other intervention studies with bariatric surgery patients have reported LP scores, so LP comparison data are unavailable. However, the 18% improvement in LE strength was much smaller than that reported by Stegen and colleagues (2009), who reported a 72% increase in LE strength with a combined exercise program of both aerobic and resistance training. The difference in the increases in strength between the two studies may reflect a number of factors. Stegen and colleagues allowed subjects to self-select membership into either the control or exercise group. It is possible that the Stegen participants who were most highly motivated to train selected the training group resulting in very large gains in LE strength. Conversely, the current study controlled for selection bias by randomly assigning subjects to either the IG or CG. A second factor that may explain the higher percent increases in LE strength for the Stegen subjects compared to subjects in the IG from the current study may be the result of the method of strength testing. Stegen used the Holten method to predict 1RM based on 6-12 repetition lifting while the current study used direct 1RM testing for the LE.

A third factor that may explain the difference in strength gains between the two studies is the timing of strength testing and exercise intervention. In the Stegen study, subjects were tested prior to surgery and again 4 months later and their exercise intervention started 1 month postsurgery. Subjects in the current study were tested and began their exercise intervention 8 weeks postsurgery. Baseline values for LE strength were similar in each study (35.5 ± 11.4kg for Stegen and 32.5 ± 6.0kg for Daniels). However, the postexercise values were dissimilar (58.0 ± 25.6kg for Stegen vs 38.3 ± 6.4kg for Daniels). It is possible that the 8-week delay in training in the current study may have allowed for greater loss in muscle CSA, which then resulted in lower strength gains. The exercise intervention in the Stegen study, starting 4 weeks earlier than the current study, may have had a sparing effect on muscle mass and muscle strength. It is possible that starting training sooner after surgery, as in the Stegen study, may have a positive effect on muscle sparing leading to greater gains in strength with RT.

In the current study, those in the CG lost 4% strength for LP and 3% for LE. The loss of strength observed in the CG is in agreement with other studies with the exception of the magnitude of the loss. Hue et al. (2008) showed a loss of isometric leg extension strength (33.5%) in 10 untrained male subjects 12 months after having undergone duodenal switch weight loss surgery and Stegen et al. (2009) showed a 16% loss 4 months after RYGB in controls.

Strength and FFM

The loss of strength observed in postbariatric surgery patients has been proposed to be due to a loss of FFM (Hue, 2008 & Stegen, 2009). Similarly, in their meta-analysis that examined losses in FFM after bariatric weight loss surgery, Chaston and colleagues

(2006) hypothesized that postsurgery decreases in strength were a reflection of losses of FFM. In spite of the hypothesized relationship between loss of strength and loss of FFM, no studies have been designed to use RT to increase strength postbariatric surgery and determine the impact on FFM or SM.

The current study was designed to provide insight into the possible relationships between postsurgery losses of FFM, decreases in skeletal muscle, and decreases in muscular strength and to determine if a RT intervention could increase FFM, skeletal muscle mass (CSA), and strength. Surprisingly, in the current study there was not a significant decrease in FFM for either the CG or IG. In fact, a nonsignificant mean gain of 0.2kg FFM was observed in the CG while the IG experienced a nonsignificant mean loss of 1.4kg FFM (Table 4).

In a 2006 study on bariatric surgery patients, Carey et al. showed a loss of 3.6kg of FFM 4 weeks after surgery and a loss of 9.4kg at 3 months. Similarly, Das et al. (2003), also using hydrostatic weighing, reported a loss of 11.2kg of FFM or 21% of the total weight lost 14 months after surgery. Levitt et al. (2010), using total body water and DEXA, showed significant postsurgery losses in muscle mass of 6.6kg or 26.9% of baseline muscle mass 6 months post-RYGB. The changes in the muscle mass over the course of the Levitt et al. (2010) study are important to note. The whole body muscle loss was most dramatic from baseline to 6 weeks postsurgery (-29.2%) with a slight rise from week 6 to 6 months (2.3%) (see Table 8).

The distinguishing variable between the work of Levitt et al. (2010), Carey et al. (2006), and the current study is the timing of the FFM or muscle mass assessment. Previous researchers assessed FFM and SM prior to surgery and then at varying intervals

Table 8. Summary of the Time Course of Measurements of Muscle Tissue

Author	Baseline	Surgery	Wk 2	Wk 6	Wk 8	Wk 20	Wk 24	Wk 52
Levitt et al. (Muscle mass in kg)	30 – 70 → days pre (24.6)	→	X → (NA)	X → (17.4)*	→	→	X → (18.0)	X (15.9)
Daniels et al. (FFM in kg)					X →	X		

Levitt et al. measured muscle mass (kgs) pre-RYGB surgery and again at various time points after. Methodological differences between the previous researchers and Daniels et al. may explain the differences in outcomes for muscle tissue variables (weight vs CSA and FFM).
*Notice the significant decrease (29%) between baseline and week 5.

postsurgery. The current study, however, did not measure FFM prior to surgery, but rather 8 weeks post-RYGB surgery and again at 20 weeks. Perhaps in not using a pre-surgery FFM assessment (see Table 8), the period of rapid FFM loss observed by Levitt et al. (2010) did occur, but was missed due to methodological differences in the current study, particularly for the CG participants.

Although FFM has been used to indirectly assess changes in muscle with exercise following RYGB surgery, very little research has been done using techniques to more directly quantify changes in muscle. Two studies using ultrasound to measure thigh muscle cross-sectional area (CSA) have reported significant losses in CSA following RYGB. Lyytinen et al. (2013) reported a loss of 21.3%, 15.2%, and 26.6% for the rectus femoric, vastus lateralis, and vastus medialis muscles, respectively, while Pereira et al. 2012) reported a 32% loss in thigh muscle CSA 90 days after RYGB weight loss surgery.

Strength and CSA

In an effort to provide further insight as to the impact of RYGB and RT on leg skeletal muscle, in the current study, MRI was used to assess QCSA and WTCSA. The anticipated decrease in QCSA and WTCSA following RYGB was not observed. Instead the QCSA and WTCSA data were similar to the FFM results. There was not a significant decrease in either QSCA or WTCSA for CG. Furthermore, even though the IG experienced a significant increase in strength, there was not an associated increase in either QCSA or WTCSA.

While the differences in CSA findings between this study and other studies may be due to the sensitivity of the ultrasound measurement of CSA compared to MRI to measure CSA as used in the current study, the delay in the timing of postsurgery CSA assessments presented in Table 8 could also be a contributing factor.

Data by Periera et al. (2012) using ultrasound show that the steepest losses in CSA occurred in the first 3 months (~12 weeks) following surgery (16% from baseline to 30 days and 18.5% from 30 to 90 days). The CSA measurements for the current study did not occur until 8 weeks following surgery, providing an explanation for a lack of decrease in CSA in the CG (Table 9).

Another factor contributing to the lack of a significant change in QCSA or WTCSA with RT is that the study did not have adequate power to determine a difference. The original power determinations were done on the strength variables and not QCSA or WTCSA because of the lack of previous studies for the calculation of effect size. Although there was not a significant group by time interaction for either QCSA or WTCSA, there was a significant correlation between gains in strength and changes in

Table 9. Summary of the Time Course of Measurements of CSA

Author	Pre Surgery 30-180 days	Surgery	Wk 4	Wk 8	Wk 12	Wk 20	Wk 24	Wk 36
Periera et al. CSA(cm)	→ (3.2)	→	→ X (2.7)*	→	→ X (2.2)*	→	→ X (2.1)**	
Lyytinen et al. Vastus Lateralis CSA(cm^2)	X → (9.7)	→	→	→	→	→	→	→ X (7.1)*
Daniels et al. WTCSA(cm^2)				X → (113.6)	→	→ X (109.5)		

Periera et al. and Lyytinen et al. measured CSA pre-RYGB surgery and again after. Lyytinen et al. measured at multiple postsurgery time points with a mean of 8.8 ± 3.7 months. Methodological differences between the previous researchers and Daniels et al. may explain the differences in outcomes for CSA.
Note: $^*p < 0.05$, $^{**}p < 0.01$ from baseline

FFM and CSA. Due to the low power for the FFM and CSA variables, the relationship between FFM and CSA was examined by Kendall's Tau to assess the relationships. Results of the analysis indicated a significant but moderate correlation between ΔQCSA and ΔLE ($\tau = .43$; $\tau^2 = .19$; $p < .05$) (Figure 13).

Diet

One factor that was not measured in the current study, but may have had a significant impact on the FFM as well as CSA responses of the IG to RT, was caloric intake. Many subjects in the IG reported daily caloric intakes at or well below 500 kcals. Some reported not being able to eat for several days because eating resulted in vomiting. The dramatic nature of the caloric restriction in the 12 weeks of the current study may

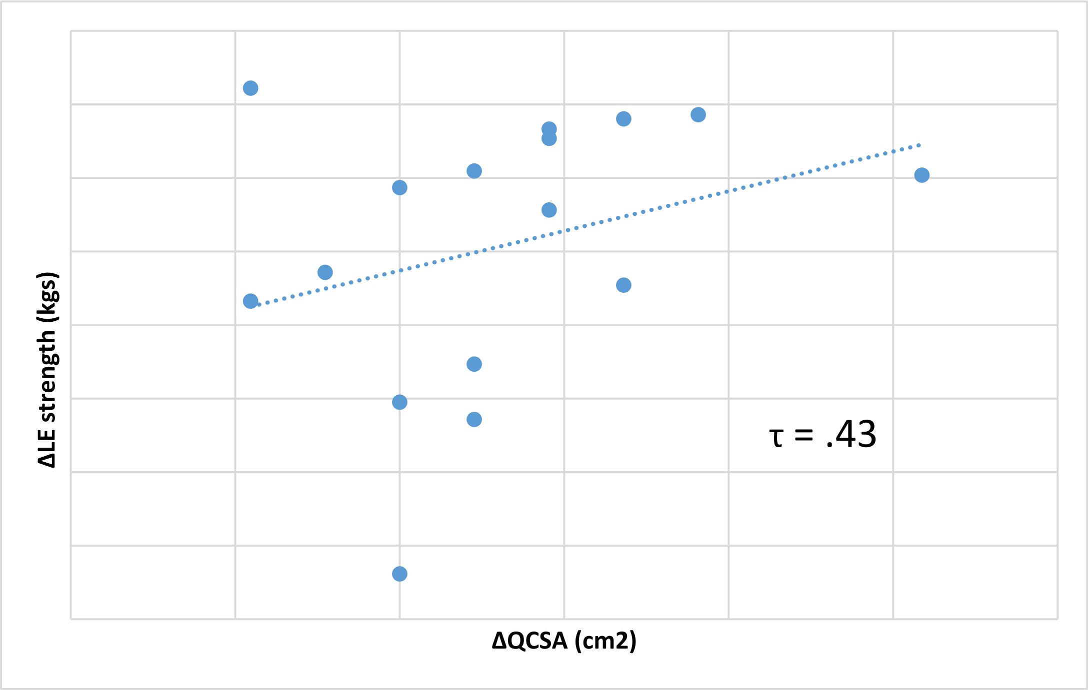

Figure 13. Correlation between ΔLE and ΔQCSA.

explain the lack of muscle hypertrophy in the IG. Lemon (1997) reported that for hypertrophy to occur protein intake needs to be adequate during RT, and that overall caloric intake needs to be adequate to fuel the anabolic process. Perhaps the restrictive and malabsorptive nature of the RYGB surgery prevented the consumption of adequate protein and calories to support muscle hypertrophy.

It is also possible that the RT intervention was of too great an intensity and volume for the severe caloric restricted experienced by the IG participants. If the combination of calorie restriction and the increased energy demand created by participating in RT created a state of metabolic catabolism, increases in muscle CSA would be impossible. The previous studies reporting increases in CSA with exercise training postbariatric surgery did not use RT of the same intensity employed in the current study.

Muscle Quality

Muscle quality (MQ) is the quotient of strength divided by muscle volume or CSA and is an indicator of muscle function. The present study showed significant interaction effects for MQ for both LP and LE. Upon further analysis, it was determined that the IG experienced a significant increase in MQ while the CG did not. These results combined with the lack of change in CSA points to changes in strength as the driving factor for the change in MQ (increase in strength of 59.4kg in IG and a loss of 4.8kg in the CG). The small decrease in strength in the CG may be attributed to the slight decrease in CSA observed (-2.9cm^2) (Table 4).

Strength changes are a combination of neurological, morphological, and anatomical (muscle CSA) adaptations, with no single adaptation being solely responsible for the strength increases. Jones, Bishop, Woods, and Green (2008) and Kreamer et al. (1997) point out the changes in strength that occur are due to positive changes in the muscle's anatomical, physiological, and biochemical makeup. Gains in strength, especially without gains in muscle hypertrophy, as seen in the early phases of a RT program, are thought to come from neurological adaptations (Moritani & De Vries, 1979) including increased rate-coding, motor unit recruitment and type II fiber activation, and reduced coactivation of antagonist muscles (Folland & Williams, 2007; Häkkinen et al., 1998). Strength changes seen in the IG in the current study are likely the result of these neurological adaptations. Moratani and De Vreis (1979) showed a higher percentage of early strength gains were accounted for by neurological adaptations, but as time went on (4-6 weeks after the start of RT), a higher percentage of strength was accounted for by increases in CSA. However, the increase in strength may be more complex.

It is possible that an increase in individual type II fiber size may be responsible for at least some of the increase in strength. Hypertrophy of individual muscle fibers results in greater numbers of cross-bridges in parallel. This is thought to account for the overall increase in muscle CSA and the concomitant increase in strength (Aagard et al., 2001; Cormie et al., 2011; Folland & Williams, 2007). However, it may be possible that while individual type II fibers increase in size the number of type II fibers may not be sufficient to impact whole muscle CSA.

Changes in strength and thus MQ have been shown to be moderately correlated with midthigh muscle volume (Roth et al., 2001), but Jones et al. (2008) points out that while strength is closely related to muscle CSA, other factors such as neurological adaptations account for the variability in strength. Muscle quality changes in the present study are in agreement with Jones' findings. We did not observe increases in CSA but strength increased significantly.

Another possible explanation for the increase in strength without a concomitant increase in total muscle CSA is the proliferation of individual muscle fibers. Martel and colleagues (2006) showed an increase in type IIx fibers in elderly women (65-75 y. o.) having undergone RT but no increase in type I or IIa fibers. Because IIx fibers are associated with high maximal strength and have a large capacity for myoplasticity, it is possible that the changes in LP and LE strength came from hypertrophy of individual muscle fibers lending to greater force per fiber, without an observable change in whole muscle CSA.

Physical Activity

The use of an objective measuring device to quantify physical activity (PA) was another unique aspect of the current study. We set out to determine if RT would impact PA after RYGB surgery. Since changes in strength have been shown to increase indices of physical activity (PA) such as ADLs, independence, quality of life (QOL), and physical performance, as well as decrease fall, morbidity, and mortality (Cawthon et al., 2009; Manty et al., 2012; Metter et al., 2002; Misic et al., 2007; Moncada, 2011; Ozcan et al., 2005; Schaap, Koster, & Visser, 2012), we felt it was reasonable to determine if RT following bariatric surgery influenced PA.

Based upon previous work, the impact that bariatric surgery on physical activity has not been clearly elucidated. While some researchers have shown that PA increases following bariatric weight loss (Bond et al., 2008; Hunter et al., 2000; Karason, Lindroos, Stenlöf, & Sjöstrom, 2004), others have not observed increases in PA with bariatric surgery (Jacobi et al., 2011; Lemmer et al., 2001). Most of the initial reports of increases in physical activity following bariatric surgery used self-report data or questionnaires to quantify physical activity (Bond et al., 2008; Karason, Lindroos, Stenlöf, & Sjöstrom, 2004; Wilms, Ernst, Thurnheer, Weisser, & Schultes, 2013). More recently, researchers who have used objective techniques (accelerometers and pedometers) to measure physical activity have reported that there is no change in physical activity and that the physical activity of bariatric patients remains below recommendation for a healthy life (Jacobi et al., 2011).

The acclerometry-derived steps/d values for both the CG and IG were observed to remain unchanged following surgery. Furthermore, the T2 values for both groups were below existing recommendations for a healthy adult's daily physical activity. Tudor-Locke et al. (2011) suggests 7,000-10,000 steps per day while Wilmot et al. (2012) suggests 30 minutes of moderate to vigorous physical activity (MVPA) per day for 5 days a week. The steps/d values in the current study were lower than Tudor-Locke's recommendation (5285 ± 1653 for the IG at baseline vs 4788 ± 2884 for controls and 5687 ± 1685 for the IG at study conclusion vs. 4509 ± 754 for controls) both at T1 and T2 (Table 7).

Furthermore, there was no significant change in steps per day for either group ($p > .05$) (Table 7). The number of steps/d was much lower than that reported by Hansen et al. (2012) in normal weight women aged 20-64 years (8440 ± 81 vs 5098 ± 1219) and by Langenberg et al. (2015) who reported steps/d of 7140 ± 3422 in a cohort of 71 male and female bariatric surgery candidates. It may be the highly sedentary nature of our study participants accounts for the large difference between the current study participants and the Hansen et al. (2012) and Langenberg et al. (2015) data. Some of the difference may also be accounted for by the wear-time in each study. The wear-time in the current study was 13.5 hrs compared to 14.6 and 21.4 for the Hansen and Langenberg studies, respectively. The lower step counts may also be due to the malaise and low energy reported by study participants during the 6 weeks postsurgery. The combined effects of healing from the surgery, low caloric input, and the body's metabolism changing to a predominantly ketogenic state may have contributed to lower activity when compared to nonsurgical populations. Months after the conclusion of the current study, two subjects in the IG stayed in contact with the author of this manuscript. They continued to wear a self-purchased commercial pedometer. On several occasions they reported steps/d similar to those found in this study (around 5000). While these data have not been scrutinized using the scientific method, they do offer some insight into the daily PA of this population.

Past research on the effects that RT has on PA has been mixed. Marcus at al. (2009) showed improved strength led to a trend in more steps per day ($p = .10$), but others have not (Hughes et al., 2001; Lemmer at al., 2001; Rangan et al., 2011) reported such a trend. Engaging in adequate PA each week has, however, been shown to be associated with better physical (Warburton, Nicol, & Bredin, 2006) and mental health (Paluska & Schwenk, 2000), as well as weight loss and weight maintenance (Fogelholm & Kukkonen-Harjula, 2000; Saris et al., 2003) and counting the number of steps during the day is an easy and effective way to monitor one's PA. It is clear from past research as well as the current study that more research is needed in this area to elucidate any relationship between improvements in strength and greater PA. Similarly, there was no significant change in time engaged in MVPA ($p > .05$), although the IG did surpass the minimum recommended 30 min/d as pointed out by Wilmont et al. (2012).

When analyzing the current MVPA data, we initially used bout times of ≥10 minute (Bond et al., 2010; Catenacci et al., 2011; Jeffries et al., 2014); however, it became immediately apparent that almost no MVPA time was spent in bouts ≥10 minutes. Therefore, we opted to use ≥1-minute bouts of MVPA to quantify this variable. Mean time spent in MVPA was higher in the IG (42.1 ± 15.8 min/d) compared to controls (27.9 ± 13.5 min/d), which is above or close to the recommendation of 30 minutes/day set by the ACSM. In the current study, time engaged in MVPA for the CG was similar to results reported by Bond et al. (2010) (~27.9 vs. 26. 4 ± 23.0 min/d), while the IG showed greater time spent engaged in MVPA compared to controls, but lower than normal weight controls from the Bond study (42.1 ± 15.8 vs. 52.4 ± 24. 7 min/d). Although we had hypothesized that increases in strength might result in increased time engaged in MVPA for the IG, no interaction effect was observed (Table 7). Subjects in this study freely admitted that they did not enjoy being physically active and acknowledged that their state of obesity was largely due to lack of PA. While most subjects looked forward to and enjoyed the RT portion of this study, at the conclusion of the study few subjects continued with a regular exercise routine.

The recommendations for times spent in MVPA set by the American College of Sports Medicine (ACSM) for weight loss is >250 minutes per week and >150 minutes per week for weight maintenance. Modest weight loss has been shown to be associated with higher step counts (Richardson et al., 2008) and greater time spent engaged in PA. Based on these findings, more time spent engaged in MVPA should be a goal for sustained weight loss.

Since subjects in the current study showed no significant change in MVPA or steps per day, we decided it may be more prudent to objectively assess changes in sedentary behavior as a marker for change in PA. In the current study, the average time spent engaged in sedentary behavior for both groups was 508.0 ± 92.3 minutes or 8.5 hours per day, somewhat higher than the average of 462 min/d in a cohort of > 6300 subjects reported by Mathews and colleagues (2008), but very similar to data by Hansen et al. (2012) who reported average ST of 530 minutes/d in women aged 20-64.

Sedentary behavior has been classified between 0-499 counts/minute (Freedson, Melanson, & Sirard, 1998; McClain, Sisson, & Tudor-Locke, 2007). Most adults in the U.S. spend at least half their waking hours engaged in sedentary behavior while older adults spend even more time sedentary (>9 hrs/d) (Matthews et al., 2012). Sedentary behavior is considered a positive risk factor for cardiovascular disease, diabetes, and all-cause mortality (Ehrman, 2009; Gardiner, Eakin, Healy, & Owen, 2011) with the greatest time spent being sedentary associated with the greatest increase in risk (Wilmot et al., 2012). Time of >7hrs/day of sedentary behavior has also been shown to mitigate the positive effects of time spent engaged in MVPA (Matthews et al., 2012). However, Vatier and colleagues (2012) reported a cohort of 86 RYGB patients reduced their sedentary behavior, defined as TV viewing, after surgery from 3.0 ± 1.6hrs/d to 2.4 ± 1.4hrs/d in a self-report physical activity questionnaire. The large variability between these two studies may be due to the criteria for sedentary behavior. Matthews and colleagues used accelerometers to objectively measure sedentary time and included sedentary time (below 100 counts/min) during other activities such as driving or sitting at a desk. The Vatier study used self-report questionnaires and used TV watching as the criterion for sedentary behavior.

Due to the lack of change for MVPA, steps/d, and ST, we felt a closer look at LPA might be warranted. Interestingly, an interaction effect was observed for LPA. The IG went from 260 min/d of LPA to 309 min/d of LPA, an increase of 47 minutes/d (~15%), while the CG stayed the same. These numbers are somewhat higher than those reported by Hansen et al. (2012) of 238 min/d in women 20-64 years old. In the current study, the IG engaged in 10% more LPA at the conclusion of the study compared to the CG. Light physical activity (LPA) has been defined as 500-1951 counts/minute (Freedson et al., 1998).

The guidelines for PA would suggest that below a certain threshold of intensity or duration, no beneficial affect arises for cardiorespiratory fitness (CRF). Typically 40%–50% of HR reserve or 64%–70% of maximal HR accumulated in bouts ≥10 minutes (Ehrman, 2014) is used as the intensity threshold. Ross and McGuire (2011) concluded that CRF was, in fact, associated with the intensity of PA and showed that more moderate PA, even done sporadically through the day, was associated with higher CRF while LPA was not. In the current study, LPA dramatically surpassed MVPA, and PA was below the threshold necessary for successful weight loss or weight maintenance (Ehrman, 2014). While more activity, even LPA, is a step in the right direction, especially for those who have a history of sedentary behavior, it may not be enough to improve CRF or maintain or promote weight loss.

Several studies that have looked at the effect PA has on weight loss after bariatric surgery have shown that PA is associated with greater percent excess weight loss and lower BMI (Bond et al., 2008; Chevallier et al., 2007; Vatier et al., 2012) and PA might be the most important single factor for maintaining weight loss after RYGB (Hatoum et al., 2009). Unfortunately, none of these studies measured LPA and all used subjective self-report data.

The amount of PA needed for weight loss and weight maintenance is not readily known. The ACSM recommends >250min/wk of MVPA. One study showed the difference between those who maintained weight and those who gained weight engaged in PA that burned far more calories than most research use during weight loss studies. A meta-analysis by Folgelholm & Kukkonen-Harjula (2000) reported weight loss studies measuring PA varied greatly between 80-300 minutes/wk, accounting for an estimated 560-2100kcal/wk based on moderate PA levels. It may be that the upper limits of these values are required to inhibit weight regain (Folgelholm & Kukkonen-Harjula, 2000; McGuire, Wing, Klem, & Hill, 1999).

There are no studies, to date, that address the relationship between CSA and PA. The current study wished to determine if RT would increase daily PA, an indicator of physical function. Since the only significant change observed was with LPA, we assessed the correlation between the changes in LPA (ΔLPA) and changes in WTCSA (ΔWTCSA). A moderately high correlation was observed between ΔWTCSA and ΔLPA ($\tau = .51$; $\tau^2 = .26$ $p < .05$) (Figure 14) indicating that 26% of the variability in LPA can be explained by the change in WTCSA. No correlation was observed between any other muscle-related variables. While the correlation between ΔWTCSA and ΔLPA are only moderately high, these data are encouraging with respect to using a resistive exercise intervention to promote PA.

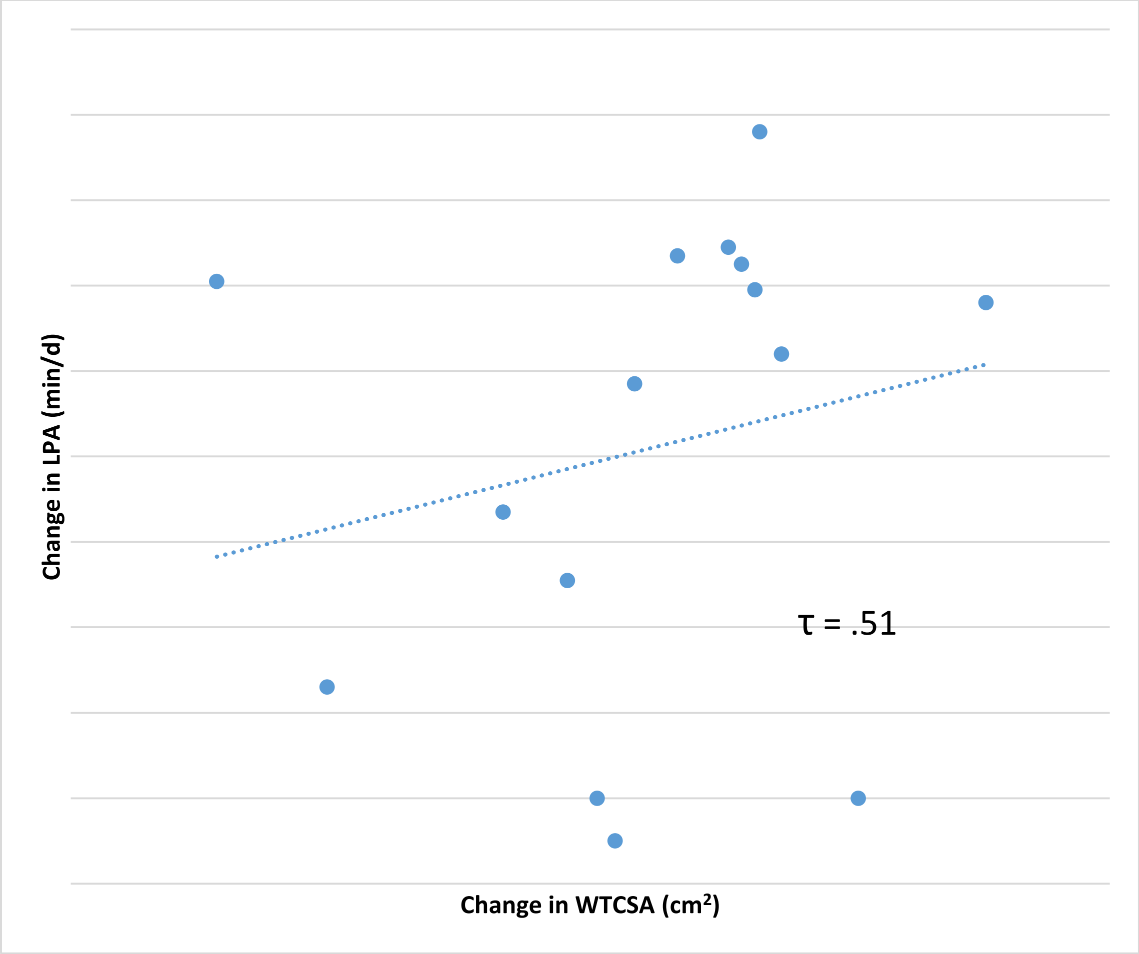

Figure 14. Correlation between ΔLPA and ΔWTCSA.

Body Composition

Body composition measurements using air displacement plethysmography showed no interaction effects for any of the variables. However, significant time effects were observed for all variables except FFM. One subject in the CG showed unusually large increases in FFM so all analyses were conducted with and without this subject. No significant differences were observed for any of the body composition variables under any of the analyses.

Dramatic losses in fat mass (FM) were observed in both groups with an average of 14.2kg of fat mass lost (-14.3 ±3.6kg for IG and 15.1 ± 5.4kg for CG). The absolute values for FM are slightly lower than results from Stegen et al. (2009) who showed a loss of 19.0kg of FM for nonexercising controls and 17.3kg for those engaged in both aerobic and resistance exercise. However, Stegen measured FM prior to surgery and again 4 months after surgery. In the present study, FM was measured 8 weeks postsurgery and again 12 weeks later. The slight difference may be attributed to the loss of FM in the weeks immediately after RYGB. Changes to percent body fat (%BF) were also significant.

Not surprisingly, there was no interaction effect observed for %BF in the current study but a significant time effect was observed for both groups (Table 3). A loss of 7.5 %BF was reported in the current study compared to a ~6% drop reported by Stegen et al. (2009) 4 months post-RYGB. These changes were larger than those reported by Trakhtenbroit et al. (2009) who showed a loss of 2.5 %BF 3 months following RYGB. The differences between studies may be due to timing of BF assessment. In the current study, the initial measurement was taken 8 weeks following surgery and again 12 weeks later, unlike the two previous studies that measured %BF prior to surgery and again after surgery.

Significant changes in BMI were observed over time in both groups. BMI fell by 5 points (kg/ht^2) (Tables 1 and 3) compared to Stegen et al. (2009) who reported a change of 8.2 points 4 months postsurgery. The observed decreases in BMI are lower than those reported by Tamboli et al. (2010) and Trakhtenbroit et al. (2009) who reported a decline of 12.8 points 6 months postsurgery and 11.2 points 3 months postsurgery, respectively.

Again, these differences are likely due to the fact that in the current study, the T1 BMI values were not determined until 8 weeks after surgery, missing the rapid weight loss that occurs in the 8 weeks following surgery.

Reasons for the anthropometric and body composition changes that occurred in the current study were multifactorial. Severe caloric deficits, nutrient malabsorption, reduced physical activity following surgery, as well as neuro-hormonal changes (Chaston et al., 2006) are all probable factors leading to dramatic weight loss, loss of FM and FFM, and changes in BMI. However, the dramatic restriction in caloric intake (-2062 +/- 271 kcal/day) and to a lesser extent from the malabsorptive aspect of the weight loss procedure (-124 +/- 57 kcal/day) (Odstracil et al., 2010) are the two primary reasons for the changes in body composition variable following RYGB.

Summary

While the present study showed that RT can significantly increase leg strength post-RYGB surgery, there was no evidence that the RT increased FFM or muscle CSA. It was also observed that RT increases LPA, but the clinical significance of increases in LPA remains to be seen.

It is clear that more research using MRI or CT scans to measure CSA and more subjects to increase the statistical power to determine if RT can stimulate muscle hypertrophy following RYGB (Heymsfield, Gallagher, Visser, Nunez, & Wang, 1995; Worsley, Kitsell, Samuel, & Stokes, 2014) is warranted. Presurgery assessments in addition to multiple postsurgery assessments would further our understanding of RT as a strategy to optimize bariatric surgery outcomes. Lastly, more research is needed to determine if behavioral strategies in concert with RT increased PA following RYGB.

CHAPTER 5

FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

Findings

The first major finding of the current study was that the IG experienced a statistically significant increase in both 1RM leg extension strength and 3RM leg press strength while the CG experienced no significant change in either variable. The observed increase in leg strength for the IG provides additional evidence in support of RT as an effective strategy for increasing the strength of bariatric surgery patients. In addition, it should be noted that the RT program involved high-intensity exercises, the first time high-intensity RT for bariatric patients has been reported in the literature.

A second finding was that neither FFM nor muscle CSA, observed from body composition analysis and MRI, increased for either the IG or CG. Apparently, the increases in leg strength reflect neurological adaptation as opposed to changes in muscle mass since there was a lack of increase in either marker of muscle hypertrophy. This is the first study to use MRI to assess changes in muscle CSA in bariatric surgery patients that have undergone a postsurgical RT program. While no changes in FFM or CSA were observed in the IG, it was rather surprising to observe no changes in the CG FFM or CSA since other authors report losses in FFM and CSA following bariatric surgery. The lack of change in FFM and CSA may be explained by differences in the time period over which FFM and CSA were measured in the current study compared to previous research.

In the current study, the baseline values for FFM and CSA were measured 8 weeks postsurgery and then again 20 weeks postsurgery. Other studies completed baseline measurements prior to surgery and then from 1, 3, and 6 months (Periera et al., 2012) and 8.8 months postsurgery (Lyytinen et al., 2013). It may be that the greatest losses of FFM and CSA occur within the first few weeks after surgery when bed rest, lack of activity, and severe caloric restriction combine to create high protein turnover resulting in muscle atrophy.

The third finding was the significant increase in MQ for the thigh musculature. Since MQ is calculated by dividing strength by CSA, the increase observed in MQ can be attributed to the significant increase in strength.

The fourth finding was that there was a significant interaction effect for LPA. While we would have liked to see an increase in MVPA as well as steps/d, the interaction effect seen with LPA is encouraging. Of interest was that 26% of the variability in the change in LPA was shown to be associated with changes in WTCSA. The data for ST are more troubling. We were hopeful that a RT protocol would change sedentary behavior; unfortunately, this was not the outcome and while not significant, the IG actually increased ST by 20 minutes.

Conclusions

Based upon the findings from the current study, the following conclusions have been made:

1. A high-intensity periodized RT program was shown to be a potent stimulus for promoting leg strength and MQ among Caucasian females living in Utah who have undergone Roux-en-Y gastric bypass weight loss surgery.

2. A periodized RT program may not result in an increase in either FFM or muscle CSA of postbariatric surgery patients. A possible explanation for the lack of an increase in FFM and muscle CSA may be a reflection of substrate availability. Following bariatric surgery, there is a substantial decrease in both caloric consumption and nutrient absorption, which may have resulted in inadequate energy or amino acids to support the growth of additional muscle tissue. RT, without specific programming for behavior change, has a modest impact on daily PA. Increases in LPA are promising, but should be viewed with cautious enthusiasm. Future research is needed to determine if exercise in combination with behavior modification will allow RYGB patients to adopt long-term participation in increased levels of daily physical activity and or exercise programming.

Recommendations

Future Research

The most important suggestion for future research is to use a presurgery baseline assessment of FFM and CSA. By using presurgery assessment of FFM and CSA, more insight into the response of muscle mass to bariatric surgery could be obtained. For example, including a presurgery data collection time point might provide insight as to why the current study found very different results than previous studies in regards to FFM and muscle CSA.

In addition, since this was the first study to use MRI to measure CSA, it is also recommended that future research use precise imaging techniques such as MRI, CT, and DEXA to accurately quantify changes in muscle size. While there is substantial research that indirectly measures changes in FFM following bariatric weight loss surgery, there is little research using more advanced techniques to precisely track changes. We would also recommend implementing whole body imaging techniques as opposed to regional body scans to elucidate changes in muscle CSA and FFM. While use of regional body imaging techniques are less expensive and less time consuming, whole body imaging literally gives a more precise picture of changes in lean tissues.

A third recommendation for future research involves comparing the effects of the use of RT protocols varying in duration, intensity, and frequency. The current study used a high-intensity, periodized program that may have been too intense under the severe caloric conditions associated with RYGB to elicit significant protein synthesis and muscle growth. Due to the lack of research and the multitude of possible RT programs, there is much that could be learned before suggestions for the most appropriate RT protocols for this population can be made.

Fourth, we recommend the continued use of objective techniques for measuring PA while implementing behavior change strategies with RT training. We also suggest that the focus be on assessing sedentary behavior and LPA rather than just MVPA. Obese individuals are obese in part due to a lack of activity. It may be unreasonable to measure indices such as MVPA in a population that is prone to engage in little to no PA. Setting goals of increasing LPA, decreasing ST, and increasing bouts of MVPA of less than 1 minute duration may be more attainable for bariatric surgery patients.

APPENDIX

MEDICAL HISTORY QUESTIONAIRRE

University of Utah
Department of Exercise and Sports Science

Name:______________________________ Age:________

Please circle Yes or No when answering the following questions

Do you currently have cancer?
Yes No

Do you have now or have you ever had a heart attack, coronary bypass surgery, angioplasty, stroke or heart disease
Yes No

Do you have diabetes?
Yes No

Do you experience claustrophobia or do you have a cardiac pacemakers, or other things that will prevent you from having an MRI?
Yes No

Do you have anemia related to surgery?
Yes No

Do you currently or have you smoked in the past 6 months?
Yes No

Do you currently have any muscle or skeletal issues such as arthritis, damaged ligaments or tendons, torn muscles, etc?
Yes No

If you answered Yes to any of the above questions please provide a short explanation

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