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Maintaining Skeletal Muscle Through Eccentric Exercise after Bariatric Surgery: A Randomized Controlled Trial

Joshua Jed Kelley
Brigham Young University

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Maintaining Skeletal Muscle Through Eccentric Exercise After Bariatric Surgery:

A Randomized Controlled Trial

Joshua Jed Kelley

A thesis submitted to the faculty of
Brigham Young University
in partial fulfillment of the requirements for the degree of

Master of Science

Lance E. Davidson, Chair
James D. LeCheminant
James D. George

Department of Exercise Sciences

Brigham Young University

ABSTRACT

Maintaining Skeletal Muscle Through Eccentric Exercise After Bariatric Surgery: A Randomized Controlled Trial

Joshua Jed Kelley
Department of Exercise Sciences, BYU
Master of Science

Purpose: To investigate the effects of eccentric exercise on lower body skeletal muscle mass during rapid body mass loss induced by bariatric surgery. Methods: All participants began 6 to 8 weeks after undergoing Roux-en-Y gastric bypass (RYGB) or sleeve gastrectomy (SG). Skeletal muscle mass (SMM) in the lower body was measured via magnetic resonance imaging (MRI); additional exercise measurements included muscular strength and functional capacity. Quality of life was measured using Short Form 36 (SF-36). Nineteen females (age = 37.6 ± 9.8 yr, height = 164.4 ± 7.2 cm, mass = 106.9 ± 15.6 kg) were randomly assigned to 1 of 3 groups: eccentric exercise (EEX; n = 6), concentric exercise (CEX; n = 7), or standard-of-care control (CON; n = 6). Exercise groups performed 30-minute lower-body exercise sessions 3 times per week for 16 weeks. Each month the exercise tests were evaluated. At the end of 16 weeks, all participants performed the final exercise tests, received a final MRI scan, and completed the SF-36 questionnaire. Results: Thirteen individuals completed the study. All groups lost mass: CON: 21.4 ± 3.7 kg ($p < 0.001$), CEX: 19.9 ± 4.0 kg ($p = 0.001$), and EEX: 21.8 ± 3.3 kg ($p < 0.001$). SMM decreased in all groups: CON: 0.77 ± 0.5 kg ($p = 0.18$), CEX: 1.19 ± 0.6 kg ($p = 0.06$), and EEX: 0.90 ± 0.5 kg ($p = 0.09$). The skeletal muscle loss in percent of total mass loss was 3.7 ± 4.1%. All measures of muscular strength showed no difference, except for a small decrease in dynamic ($60^\circ \cdot \text{sec}^{-1}$) strength in the eccentric group. Functional capacity and physical quality of life increased significantly in all groups ($p < 0.05$). Conclusion: SMM loss still occurred in the lower body regardless of resistance training, but the loss was less than what was previously documented. Improved postsurgical functional capacity and physical quality of life may be due to a reduction in fat mass and maintenance of muscular strength during the period of rapid mass loss.

Keywords: eccentric, bariatric surgery, skeletal muscle mass, magnetic resonance imaging

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INTRODUCTION

Over the past decade in the United States, rates of obesity (body mass index (BMI) > 30 $kg \cdot m^{-2}$) and severe obesity (BMI > 40 $kg \cdot m^{-2}$) have continued to trend upwards. From 2007 to 2015, overall rates of obesity have increased from 33.7% to 39.6%, while rates of severe obesity have increased even faster from 5.7% to 7.7%—a 35% increase [1]. Severe obesity has been linked with a low quality of life and a variety of comorbidities: hypertension, diabetes, osteoarthritis, sleep apnea, and depression [2,3]. Long-term treatments for severe obesity are a major concern due to the high economic cost to the United States healthcare system [4].

One of the most successful long-term treatments for severe obesity is bariatric surgery [5,6]. The number of weight-loss surgeries has dramatically increased with the rates of severe obesity. Weight loss surgery provides better long-term mass reduction and greater reductions in comorbidities than standard diet and exercise [5]. A majority of these health benefits are seen within the first 6 months [7]. Roux-en-Y gastric bypass (RYGB) and sleeve gastrectomy (SG) surgeries are 2 of the leading procedures performed. RYGB and SG surgeries significantly reduce mass and often restore metabolic health—including remission of type 2 diabetes mellitus, improved insulin response, and significant reductions in hypertension and dyslipidemia [6,8].

As a result of the reduction of body mass and improved health conditions, both functional capacity and quality of life are improved [9-11]. However, with a large reduction in body mass, approximately 24 to 41% of the total body mass loss can be attributed to fat-free mass (FFM) [7,12-14]. Along with this loss of FFM, muscular strength decreases from 4 to 40%, depending on the muscle groups, with a greater decrease in the upper extremities [15-17]. Although guidelines for the loss of FFM during body mass loss are not well established, a loss of less than 22% has been deemed acceptable [18]. However, a loss of FFM greater than 22% of the total mass loss could harm the resting metabolic rate, the maintenance of functional capacity as one ages, thermoregulation, and weight management [18]. Of the FFM loss after bariatric surgery, about 90% is considered skeletal muscle mass (SMM) [19]. Longer-term data suggest that the SMM continues to be lost up to 5 years after surgery, even when individuals start to regain body mass [19]. Therefore, the continued loss of SMM may negatively affect long-term muscular strength and functional capacity. This concern increases in aging populations where sarcopenia is a common problem.

In healthy populations, both resistance and aerobic exercise training result in increased SMM, muscular strength, and functional capacity [20-22]. During rapid body mass loss using caloric restriction, resistance training has been shown to attenuate the loss of SMM and FFM, improve strength, and improve functional capacity [23-27]. However, exercise interventions during the rapid body mass loss following RYGB and SG have failed to suggest that exercise attenuates the loss of FFM; most studies have suggested that the prevention of some of the FFM loss after surgery is not possible [15,16,28,29]. Although standard resistance training or aerobic training has been used, no study has examined the effects of eccentric exercise to attenuate the loss of SMM. Eccentric exercise has shown to induce muscular hypertrophy greater than standard concentric resistance training, assuming the eccentric overload threshold is exceeded [30,31]. This threshold is a specific intensity that the eccentric resistance must achieve to provide a large enough volume to adequately stimulate skeletal muscle cells for hypertrophy [30]. Since exercise-induced fatigue is a common side effect for postbariatric surgery patients [32], eccentric exercise may be a superior form of exercise due to its low energy cost. Eccentric contractions use only a fraction (1/7 to 1/6) of the energy cost to produce the same force as concentric contractions [33-35]. Furthermore, eccentric contractions can produce 2 to 3 times the amount of force compared to a standard concentric contraction [30,35]. Therefore, the combination of low energy cost and high force production may be factors that stimulate skeletal muscle hypertrophy greater than standard resistance training [36]. We hypothesis that all groups will have a significant reduction in SMM; however, the EEX will lose less SMM. Thus, the EEX will have greater improvement of muscular strength than the CEX, while CON will have a significant decrease in muscular strength [16]. We also anticipate that all groups will improve in functional capacity and physical quality of life. However, we expect that CEX will have a greater improvement than the CON, and EEX will have the greatest improvement.

METHODS

Subjects

Twenty-seven women (ages 21 to 65 years) were recruited through Utah Valley Surgical Center one month before having either RYGB or SG surgery. Participants were free of cardiovascular diseases and metabolic diseases and were able to participate in a 16-week supervised leg exercise training program at the start of the study. At the commencement of the study, all participants were 6 to 8 weeks postoperation. Eight participants dropped out before completing the initial testing and randomization (Figure 1). Following initial testing, 19 participants (age = 37.6 ± 9.8 yr, height = 164.4 ± 7.2 cm, mass = 106.9 ± 15.6 kg) were randomly assigned into 1 of 3 groups: standard-of-care control (CON; n = 6), concentric (CEX; n = 7), and eccentric (EEX; n = 6). Randomization was done by using a stratified randomization approach on Microsoft Excel. The group assignments were then revealed to both researchs and participants of the group assignment after completion of the initial testing. At baseline there was no statistically significant difference between groups in BMI, SMM, age, height, and mass.

Procedures

A week prior to starting the intervention, participants attended an individual orientation meeting to go over the study and sign the consent form. Within that first week following the orientation, all participants received a magnetic resonance imaging (MRI) scan to measure cross-sectional muscle mass. Each MRI scan was performed at the university's MRI facility. Following the MRI scan, participants performed a series of exercise tests: (1) a single-leg 1-repetition maximum (1-RM) leg press, performed bilaterally; (2) a series of 1 maximal strength single-leg contractions, performed bilaterally: 1 isometric knee extension set at 70°, and 2 isokinetic knee extensions at $60°\cdot s^{-1}$ and $120°\cdot s^{-1}$ (BIODEX); (3) a 6-minute walk test (6MWT); (4) a 30-second stand-sit test (30STS). Participants also filled out a quality of life questionnaire, SF-36. Following randomization, each group repeated the series of exercise tests each month until the end of the study. Prior to the final exercise assessment, at the completion of week 16, all participants underwent a final MRI scan and completed the SF-36 questionnaire.

Exercise Intervention

Both EEX and CEX intervention groups participated in time-matched supervised exercise sessions, 3 times per week for 16 weeks. Subjects were required to meet a compliance threshold of 75% of all exercise sessions. The eccentric group performed eccentric exercise on the Eccentron (BTE, Hanover, MD), an isokinetic machine that facilitates alternating, single-leg muscle-lengthening (eccentric) contractions. The eccentric resistance was set greater than 138% of the measured single-leg press 1-repetition maximum [30], The duration of the first exercise session started at 5 minutes and gradually increased to 30 minutes over the first 4 weeks, with the isokinetic speed set at 23 repetitions per minute. The duration of 30 minutes was maintained throughout the remainder of the study; however, the exercise load increased each month based upon their new measured 1-RM. The concentric group followed a similar progression pattern for time increments and increased resistance each month. However, the concentric group performed single-leg presses as their mode of exercise. The resistance was set at 70 to 80% of their 1-RM, as measured during each exercise test. The concentric group performed a series of single-leg presses of 10 repetitions with the right leg, then 10 repetitions with the left. Upon completion of this set, participants were given a 1-minute rest. This was repeated until the end of the exercise session. Following each exercise session, the intensity and exercise volumes were recorded. Each subject reported their perceived level of exertion based upon a self-reported rating of perceived exertion (RPE) scale from 0 to 10. These reported values were used to assess that each participant's exercise session was an adequate intensity (at least an RPE of 7). The total exercise volume was not matched between groups due to the eccentric force being greater than the 1-RM concentric force and the greater number of repetitions as a result of the low energy cost, which allows more repetitions to be performed without requiring a rest period. All groups were instructed to follow the same standard-of-care physical activity recommendation from their operating physician of 150 minutes of moderate physical activity and 2 days of resistance training per week, regardless of group assignment.

Muscular Strength

Single-leg 1-repetition maximums (1-RM) were performed on a leg press machine. Each leg started at a 90° knee angle, which was measured using a goniometer. After a light-weight bilateral leg-press as a warm-up, the starting 1-RM load was estimated. Participants then attempted to complete the predicted 1-RM with one leg, and then the other; participants were given at least a 1-minute rest before attempting a higher weight. The procedure continued until a 1-RM was completed with proper form. During this procedure, participants performed no more than 5 attempts to reach their single-leg 1-RM. The 1-RM was measured to the nearest 5-pound increment. The BIODEX system 4 Pro was then used to assess peak knee extension torque through 3 series of single-leg contractions on each leg: 1 isometric contraction at a 70° of flexion, and 2 isokinetic contractions set at $60^{\circ}\cdot\mathrm{s}^{-1}$ and $120^{\circ}\cdot\mathrm{s}^{-1}$ isokinetic knee extension. All 3 BIODEX measurements were performed in 1 leg starting with the isokinetic $120^{\circ}\cdot\mathrm{s}^{-1}$, then $60^{\circ}\cdot\mathrm{s}^{-1}$, and ending with the 70° isometric contraction. Then researchers adjusted the machine to measure peak torque values for the second leg, in that same order. Each test required a series of 3 repetitions; the average difference between repetitions was required to be less than 15% to be considered maximal effort. If the series did not meet these requirements, participants were given a 1-minute rest prior to repeating that series.

Magnetic Resonance Imaging

Lower body SMM was measured using a multislice magnetic resonance imaging (MRI) protocol. All MRI scans were performed by trained magnetic resonance (MR) staff at the BYU MRI research facility using a Siemens TIM-Trio 3.0T MRI scanner. Participants were positioned supine on the MRI table and entered the magnet feet first. The scans assessed the cross-sectional area of the trunk and lower limbs using axial images every 5 centimeters. The first set of 7 images was centered at the L4 to L5 intervertebral space and required a 20-second breath-hold to minimize abdominal movement during acquisition. All images acquired were a 10 mm thickness with an interslice gap of 40 mm. The next sets of 7 images began at the femoral head and continued inferiorly, usually requiring 3 sets of 7 images (hip, knees, and feet) to complete the scan. The total time required to obtain all MR data (27 images) for each subject was less than 30 minutes. Prior to performing each scan, participants completed a screening form as required by the university's MRI facility. This screening form was to ensure that the participant had low risk of possible complications associated with MR.

Following MRI collection, each image was analyzed by trained image analysts using specialized software (sliceOmatic, TomoVision, QC, Canada). Randomized group assignments were blinded to the image analyst. Lean tissue, intramuscular adipose tissue, visceral adipose tissue, subcutaneous adipose tissue, and skeletal muscle volumes were quantified by visually tagging these tissues on each image. Lower body muscle volume was calculated by using the tagged tissue areas within each image and a truncated cone approach to calculate estimates of tissue volumes for the 40 mm gaps between images. Skeletal muscle volumes were converted to masses using assumed tissue density constants of 1.04 g/mL [37].

Functional Capacity

The 6MWT was performed in a rectangular corridor within the Human Performance Research Center in the Richards Building. The corridor length was measured 1 foot from the inside wall along the participants' route, creating a 1-lap distance of 330 feet. The lap distance was measured with the Trumeter 5505 measuring wheel. Each lap was recorded by a trained research assistant, and, upon completion of the sixth minute, the remaining distance was measured from the initial starting point to the front of the participant's foot. The total distance was recorded to the nearest foot. After the measurement, all distances were converted to meters. The 6MWT not only represents functional capacity, but is also correlated with cardiorespiratory fitness and quadriceps muscle strength [38] and can be used to predict the peak VO_2 and maximal oxygen uptake (VO_2max) [39-41]. The 30-second stand-sit test (30STS) was performed using a 20-inch wide bariatric chair, without armrests, rated for 1000 pounds. Participants were instructed to start seated, stand up, then return to a seated position while keeping their arms folded in front of them. One full repetition included going from a seated to a standing position, and then returning to a seated position. Participants were instructed to perform as many repetitions as possible within a 30-second period. The number of repetitions was recorded to the last half repetition.

Quality of Life

The SF-36 is a generic assessment of quality of life. The questionnaire contains 36 questions divided into 8 sections to assess different aspects of life: vitality, physical function, bodily pain, general health perceptions, physical role, emotional role, social role, and mental health. These 8 sections were clustered into 2 categories—the physical component and the mental component. The physical component includes scales to measure physical function, bodily pain, physical role, and general health. While the mental component scales the vitality, emotional role, social role, and mental health. The scales are converted to a numerical score ranging from 0 to 100 [42]. The general purpose of the SF-36 is to assess an individual's health status cost effectively [43], and is a commonly used assessment of quality of life in obese and postbariatric individuals [44].

Statistical Analysis

Descriptive statistics were calculated for all collected variables on the whole sample and by randomly assigned groups. For continuous variables, mean and standard deviation were calculated. The dependent variables, muscle mass, muscle strength (1-RM leg press and BIODEX slow, fast, and isometric forces), functional capacity (30-second stand-sit and 6-minute walk), and quality of life (mental and physical component scores) were analyzed using an ANCOVA model. The ANCOVA was then verified with a mixed-model analysis of variance which utilized all available data in the analysis and allowed for subjects with missing data to be included in the analysis. The SAS procedure ANCOVA was used to measures changes between premeasurements and postmeasurements of all dependent variables based upon group assignment. Covariance factors included surgery type and baseline 6MWT—the 6MWT not only represents functional capacity, but it is also correlated with cardiorespiratory fitness, BMI, and quadriceps muscle strength [38]. The baseline 6MWT was controlled for in the ANCOVA because it was lower at baseline in EEX than in both the CEX and CON.

A second model, PROC MIXED, was used to verify the ANCOVA results and to include all participants regardless of missing data. Subjects were indicated as a random effect with an autoregressive covariance matrix. The mixed-model included adjustment for surgery type, observation (time), and the interaction between surgery type and time as fixed effects. The LSMEANS option was used to estimate the mean and standard error of the mean at each observation for each randomized group and were reported as adjusted means and standard errors of the mean. The ESTIMATE statement was used to estimate the change between observations in the dependent variable for each randomized group, and to compare the changes between the randomized group and surgery type. To assess the effect of age or time-since-surgery on these relationships, all models were repeated with either baseline age or time-since-surgery included as a covariate. All statistical calculations were performed using the SAS statistical software procedure (version 9.4). The level of significance for all statistical tests was taken as 0.05.

RESULTS

Nineteen participants (RYGB n = 8, and SG n = 11; age = 37.6 ± 9.8 yr, height = 164.4 ± 7.2 cm, mass = 107.1 ± 15.6 kg, BMI = 39.6 ± 5.3 $kg \cdot m^{-2}$) finished baseline testing. Six participants dropped out during the intervention, and 13 participants completed the study (Figure 1). When factoring out the noncompleters, the completers baseline means were higher for age, 37.9 ± 8 yr; height, 165.9 ± 7.3 cm; and mass, 108.4 ± 16.0 kg; while BMI was less, 39.3 ± 4.3 kg·m^{-2}. Additionally, muscle mass, skeletal muscle percent, and all strength measurements were higher, but functional measurements and quality of life were lower. However, none of these differences was statistically significant (Table 1). The total dropout rate was 31.6%; between surgery types, there was a 50.0% dropout rate of RYGB and an 18.2% dropout rate of SG. All dropouts were due to either injury and health, time constraints, or changes in personal lives. The concentric exercise group had the highest dropout rate of all the groups at 50.0%, compared to 16.6% in both EEX and CON. The CEX and EEX groups had a compliance of 84.1% and 93.6%, respectively, and an average RPE of 7.6 and 7.2, respectively.

Anthropometrics

All groups significantly decreased in body mass and BMI (Table 2). The CON had an overall decrease in BMI of 7.8 ± 1.3 kg·m^{-2} ($p < 0.01$), the CEX of 7.6 ± 1.4 kg·m^{-2} ($p < 0.01$), and the EEX of 8.0 ± 1.1 kg·m^{-2} ($p < 0.01$). The amount of mass loss was not different between groups. The CON decreased by 21.4 ± 3.7 kg ($p < 0.01$), the CEX by 19.9 ± 4.0 kg ($p < 0.01$), and the EEX by 21.8 ± 3.3 kg ($p < 0.01$). The mixed-model adjusted values showed no significant difference between groups at any given period, and that all groups continued to lose significant body mass each month. Surgery type was a significant covariate for BMI change; those who had RYGB decreased by 9.3 ± 2.6 compared to SG, who decreased by 6.2 ± 2.1.

Skeletal Muscle Mass

Lower-limb SMM decreased in all groups: the CON by 0.77 ± 0.5 kg ($p = 0.18$); the CEX by 1.19 ± 0.6 kg ($p = 0.06$); and the EEX by 0.90 ± 0.5 kg ($p = 0.09$) (Table 2). While the percent SMM loss of the total mass loss, Δ SMM (kg)/Δ mass (kg), was 5.7 ± 4.5%, 3.8 ± 2.7%, and 2.8 ± 5.5% for the CEX, EEX and CON (Figure 2). The overall percent of SMM of the lower body relative to total body mass increased in all groups: the CON by 2.7 ± 0.4% ($p < 0.01$); the CEX by 2.2 ± 0.4% ($p < 0.01$); and the EEX by 2.6 ± 0.4% ($p < 0.01$).

Muscular Strength

Muscular strength did not significantly change in any group in any of the strength measurements except a decrease in dynamic strength of $60°\cdot s^{-1}$ in the EEX. Dynamic strength of $60°\cdot s^{-1}$ increased in the CEX by 38.6 ± 22.4 Nm ($p = 0.12$), while EEX and CON both decreased by 50.8 ± 19.0 Nm ($p = 0.03$) and 18.6 ± 20.9 ($p = 0.40$), respectively. No significant changes were elicited in dynamic strength of $120°\cdot s^{-1}$, or static strength (Table 2). Mixed-model adjusted values of strength results are presented at each time point in Figure 3.

Functional Capacity

Functional capacity significantly increased in all groups from preintervention to postintervention for both the 6MWT and 30STS (Table 2). At baseline, differences between groups in the 6MWT approached significance; the CEX walked farther than the EEX by 66.2 ± 35.8 m ($p = 0.07$), and the CON farther than EEX by 55.3 ± 37.2 m ($p = 0.14$). However, across each specific month no significant differences were observed between groups. According to the mixed-model adjusted values, the significant change in the 30STS occurred between baseline and month 1 in the EEX and CEX, while CON approached significance ($p = 0.06$). The CON did significantly increase from baseline to the second month and then experienced a nonsignificant upward trend. The EEX also improved significantly from the first to the second month and continued a nonsignificant trend upwards. The CEX increased gradually from month 2, but it was not significantly higher until the fourth month (Table 3). In the 6MWT, both EEX and CON increased significantly within the first month, while the CEX didn't reach significance until the fourth month. However, all 3 groups exhibited an upward trend each month in functional capacity.

Quality of Life

At baseline, the CEX group scored significantly higher than the EEX in the physical component of the quality of life questionnaire (SF-36, score 0–100) by a score of 9.8 ± 3.9 (p = 0.02). However, there were no other significant differences between groups in both the mental and physical components of the SF-36. The physical component increased significantly in all groups: EEX 11.2 ± 3.5 (p = 0.02); CON 18.1 ± 3.5 (p < 0.01); and CEX 9.7 ± 3.7 (p = 0.04). The mental component of quality of life did not change significantly. At the end of the study, there were no statistical differences between groups for either the mental or physical components of the SF-36.

DISCUSSION

Our primary hypothesis was to determine if eccentric exercise would attenuate low body SMM loss during the rapid body mass loss following bariatric surgery. Although previous studies have examined FFM changes, this is the first randomized controlled study to use MRI to measure lower body SMM following bariatric surgery. Only 2 previous studies have used MRI to measure skeletal muscle. One of these studies was a longitudinal study that examined the long-term loss of SMM following RYGB surgery [19], and the other examined the skeletal muscle cross-sectional area in the thigh following resistance training [15]. From the present study, there was no significant difference in SMM between groups. During the duration of the intervention, all 3 groups lost significant body mass. All groups lost some lower body SMM, averaging 3.7 ± 4.1% of the total body mass loss. Along with the loss of SMM, there was no significant change in muscular strength or the mental component of quality of life. However, all groups increased in the physical component of quality of life and both measures of function capacity—6MWT and 30STS.

Skeletal Muscle

Previous studies have estimated that full-body FFM loss ranged from 24 to 41% of the total body mass loss, with no difference between exercise and standard-of-care control groups [7,12-16,28,45,46]. Although the findings from the present study support these previous findings, the differences in values may be a result of differences in research design, measurement instrumentation, and the loss of mass from other fat-free tissue. The present study reported an average lower-limb SMM loss of 3.7% of total weight loss—with 3 participants reporting no change or an increase in lower limb SMM. Only 1 study to date has reported full-body SMM following bariatric surgery, which documented a percent SMM loss of 15% in women and 19% in males during the first year [19]. Since limited research has examined the changes in SMM via MRI, a discrepancy between FFM loss measured in previous studies and SMM loss via MRI may exist. The relatively higher loss of FFM compared to SMM may partially explain the overestimation of percent FFM loss from measurement instruments. Dual-energy X-ray absorptiometry (DXA) may initially overestimate FFM in an obese population [47], thus overestimating FFM loss with total body mass loss. Additionally, the reduction in organs such as the spleen, kidney, and liver, along with blood plasma reduction during body mass loss [48,49], can be contributing factors to greater levels of FFM loss. Since the present study only examined SMM in the lower body from 2 to 6 months after surgery, regional variations and the time of the intervention may have been factors. The upper body and lower body SMM respond differently to exercise as well as atrophy. During bed rest, lower body SMM is lost more rapidly than upper body SMM [50]; however, no research has examined regional SMM loss after bariatric surgery.

Stegen et al reported greater decreases in upper body strength after bariatric surgery than in the lower body, which may allude to a difference in regional SMM loss [16]. Additionally, the present study examined SMM starting 2 months postoperation. During the first 2 months, body mass loss is more rapid and may consist of a higher percent of FFM and SMM loss.

The load placed on the muscle from exercise is 1 pathway that stimulates skeletal muscle protein synthesis [51]. However, the role that exercise plays in SMM preservation after bariatric surgery remains unclear since most studies, including the present study, may have been underpowered to detect hypertrophic changes in SMM due to the complex nature of changing catabolic and anabolic stimuli following bariatric surgery. Mechanical forces caused by exercise stimulate the various anabolic pathways, resulting in transcription of structural genes, changes in protein synthesis, and metabolism [52]. The dynamic rates of synthesis and degradation response to exercise vary depending on age, nutrition and sex [53]. In a fasted state, protein degradation is greater than synthesis; in a fed state, protein synthesis is greater than degradation. The positive energy state increases amino acid and glucose availability, both inhibiting protein degradation via insulin [53,54], and stimulating protein synthesis via the amino acid leucine [54]. Therefore, low caloric intake mixed with malabsorptive properties of bariatric surgery may dramatically influence protein synthesis. Despite the emphasis on high protein consumption following RYGB and SG, recommended protein intake is not typically met by patients for up to 1 year after surgery [55-57]. Additionally, resting hormonal concentrations of insulin-like growth factors (ie, IGF-1), cortisol, and testosterone change after bariatric surgery and may impact SMM loss. Obesity is shown to be associated with low levels of IGF-1 and high levels of cortisol and testosterone in females [58-60]. Following bariatric surgery, the already low levels of IGF-1 remain low for up to 6 months postoperation [61], elevated testosterone concentrations decrease to normal ranges within 3 months after bariatric surgery [59,62], and cortisol levels remain elevated [63]. Therefore, the combination of high cortisol, decreasing testosterone, and low IGF-1 levels, in combination with severe dietary restriction may inhibit protein synthesis and stimulate protein degradations during the rapid body mass loss after bariatric surgery.

The current study supports the general loss of FFM and SMM following bariatric surgery; however, the magnitude of SMM loss was less than anticipated. However, this may be explained by variations in instrumentation, methods, and time after surgery. The balance between protein synthesis and degradation is a complex dynamic event that is multifactorial. Mechanical force production by skeletal muscle is considered a major stimulator of SMM hypertrophy; however, the hypertrophic effect of exercise may not be enough to overcome the catabolic effects of an extreme energy deficit or hormonal changes observed after bariatric surgery. Due to the combination of stimuli present following bariatric surgery, higher-powered studies are needed to adequately determine the effect of exercise on SMM following bariatric surgery.

Muscular Strength

The CON in the present study may be congruent with that of previous studies, which showed no change in muscular strength from 2 to 6 months postoperation. While some previous studies have shown a reduction in muscular strength, these measurements have used preoperative values as their baseline measurement. Stegen et al showed a decrease in quadriceps muscular strength by 16% from preoperation to 5 months postsurgery, with a greater decrease in upper body mass [16], while Miller et al showed a 12% reduction in isometric knee extension strength from presurgery to 6 months postsurgery [64]. The results illustrated an incremental decrease over time, but no significant difference was seen between 3 weeks and 6 months postoperation

[64]. Additionally, Daniels et al showed no change in muscular strength from 2 to 5 months postoperation [15], and Campanha et al showed an increase in muscular strength from 3 to 9 months postoperation [65]. Thus, the muscular strength loss seen in previous studies may be seen within the first few weeks after operation and may remain constant during the first 6 months.

Two major components of strength change are neurological adaptations and skeletal muscle hypertrophy. Although variation between the 2 types of exercise may be partially due to training specificity, those who train regularly in eccentric, concentric, or isometric muscle contractions will naturally perform better on strength tests that feature those types of contractions [66]. Since all groups lost SMM, neurological adaptations may be a key player in strength gains and strength preservation. In previous postbariatric surgery resistance training studies, exercise has led to significant improvements in muscular strength. Stegen's study demonstrated a 72% increase in quadriceps strength, and Daniels et al showed a 36% increase in knee extension, even though FFM and SMM were lost [15,16]. In a normal population, initial strength changes are due to increased neurological adaptations and motor unit synchronizations [67], and Abe et al suggested that strength increases are seen in as little as 2 weeks [68].

Functional Capacity

All groups exhibited a significant increase in both measurements of functional capacity pretraining to posttraining; however, no significant difference was found between the groups.

Six-Minute Walk Test

Previous studies have shown that functional capacity measured via 6MWT has increased as a result of body mass loss following bariatric surgery [16,69,70]. Compared to an age-matched healthy populations' normative values, as measured by Casanova et al, the average initial walking distances for all groups in the present study was less than the 10th percentile [71].

By the completion of the present study, the average distance walked for all groups had increased comparative to the distances reported of the 25 to 50th percentiles of Casanova's normative values. Since body mass is one factor that affects the 6MWT, the increase in distance walked is likely attributed to the body mass loss following bariatric surgery [72]. However, exercise interventions following RYGB or SG have shown to increase distance walked and walking speed more than the controls [16,73,74]. Since muscular strength is an additional factor that affects the 6MWT [75], exercise may cause weight-bearing and functional exercises to become easier by possibly maintaining SMM, increasing strength, and increasing fat loss [20]. The findings in the current study showed a significant increase in distance walked within the first month for both EEX and CON, but not until the final month for the CEX. However, a nonsignificant trend did continue to increase throughout the study, which suggests improvements in walking distance happen in as little as 1 month and may continue to improve each month.

Stand–Sit Test

In the current study, no statistical difference was measured between groups for the 30STS. All groups increased significantly throughout the study; however, most of the change was seen within the first month. The increase of the exercise groups from the present study is consistent with previous research [16,76]. However, Stegen et al reported different findings, showing that only the exercise group had significant increase in the 30STS, with no change in the control group [16]. However, Bohannon et al showed that the 30STS is positively correlated with knee extension strength and negatively correlated with body mass [77,78]. Since all groups exhibited a similar change in mass with no statistically significant change in muscular strength, the increase in 30STS is mostly likely attributed to the loss of body mass. The findings in the present study are consistent with Bohannon's theory that the 30STS is correlated with muscular strength and inversely correlated with body mass. The body mass loss in conjunction with preservation of strength shown within the first month may be contributing factors of the significant improvements in the 30STS during the first month. Although 30STS did not statistically increase each month to the next, the 30STS continued to trend upwards. This trend may be a result of the continued body mass loss from month to month and the preservation of muscular strength.

Quality of Life

All groups increased in the physical component of quality of life as measured with the SF-36 questionnaire, with no differences between groups. Tompkins et al and Josbeno et al showed that both the mental and physical components improved from before surgery to 6 months after surgery [70,79]. Tompkins also concluded that the 6MWT was correlated with the physical component of the SF-36. Accordingly, 6MWT distance increased with body mass loss, and the physical component of SF-36 also improved. Kolotkin et al reported that the improved functional component was correlated with total body mass loss [80]. Additionally, the present study did not show a significant change in the mental component within 4 months. Although the mental component may increase after surgery [70,79], Kolotkin’s findings showed that the mental component is not as responsive as the physical component [81].

Limitations

The primary weaknesses of this study were the small number of participants, high dropout rate, additional physical activity, and dietary intake. Although a mixed-model helped strengthen the power of the study, the model was not adequately powered to determine if a difference existed between groups in all dependent variables. Also, those who completed the study may have been more motivated to exercise and thus skewed the results. Additionally, both participants who gained SMM were in the CON. The reasoning why remains unknown; however, since both participants responded differently to average postoperative patients, their results may be a major contributor to why no difference was seen between groups. Additional factors that could have influenced SMM, as measured in the present study, include physical activity levels outside of the supervised exercise program and dietary intake. During body mass loss, dietary protein and total caloric intake are inversely correlated with FFM loss [23,56], thus both may contribute to some variation in SMM loss. Additionally, total physical activity levels are inversely correlated with FFM loss [23]. Since no additional physical activity requirements were given, beyond the recommendations given by the surgical center, and since physical activity was not measured outside of the supervised sessions, there may have been a large variation in daily physical activity patterns between participants. Although some studies support the fact that resistance exercise increases leisure-time physical activity [82]; the effect that resistance training plays on leisure-time physical activity is unknown for this specific population. Additionally, muscle soreness from resistance training and increased fatigue following surgery may be factors that cause a decrease in physical activity levels. Furthermore, muscular strength was measured through isometric and isokinetic knee extension forces; since neither exercise group performed knee extension exercises, the strength increases may not have been represented with the current exercise tests. To detect a difference between different strength training programs, strength assessments should match the specific exercise routines performed by the exercise groups.

CONCLUSION

In conclusion, the present study supported a loss in SMM; however, the loss was less than what was expected based on previously reported levels of FFM loss. Although no statistical difference was detected from the present study between eccentric exercise, concentric exercise and nonexercise groups, the role that exercise plays following bariatric surgery as an anabolic stimulus remains unknown. Currently, prolonged nutrient deficiency, as seen after bariatric surgery, inhibits protein synthesis resulting in a sustained imbalance between protein synthesis and degradation. Although exercise is a stimulus for protein synthesis in healthy populations, the anabolic properties of exercise as a stimulus has not fully been explored during the rapid body-mass-loss phase after bariatric surgery. Although SMM continues to decrease between 2 to 6 months postbariatric surgery, functional capacity and physical components of quality of life increase, while muscular strength does not appear to change, regardless of resistance training.

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Table 1 Descriptive Characteristics of Subjects at Baseline

	CEX **n = 7**	**EEX** **n = 6**	**CON** **n = 6**	**All** **n = 19**	**Completers** **n = 13**
Anthropometry					
Age (yrs)	38.3 ± 12.4	37.7 ± 8.7	36.8 ± 9.2	37.6 ± 9.8	37.9 ± 8.1
Height (cm)	164.0 ± 7.6	163.8 ± 8.9	165.5 ± 6.1	164.4 ± 7.2	165.9 ± 7.3
Body Mass (kg)	103.0 ± 14.1	110.2 ± 20.0	108.9 ± 14.1	107.1 ± 15.6	108.4 ± 16.0
BMI (kg·m^{-2})	38.4 ± 5.9	40.8 ± 5.1	39.8 ± 5.6	39.6 ± 5.3	39.3 ± 4.3
MRI					
Lower Body SMM (kg)	15.3 ± 1.7	15.2 ± 1.4	15.1 ± 1.0	15.2 ± 1.3	15.6 ± 1.3
SMM percent	15.0 ± 1.7	14.0 ± 3.5	14.1 ± 2.4	14.4 ± 1.8	14.6 ± 1.8
Strength					
Static 70° (N·m)	313.6 ± 70.5	297.3 ± 71.2	247.5 ± 75.6	287.6 ± 74.0	296.5 ± 68.6
Dynamic 60°·s^{-1} (N·m)	242.4 ± 54.5	269.5 ± 56.2	239.7 ± 47.6	250.1 ± 51.8	256.7 ± 47.8
Dynamic 120°·s^{-1} (N·m)	167.0 ± 35.3	174.3 ± 45.5	149.7 ± 29.9	163.8 ± 36.7	167.8 ± 36.3
1 Repetition Max (kg)	105.8 ± 58.1	94.7 ± 37.0	107.6 ± 39.3	102.9 ± 44.4	107.5 ± 47.2
Functional Capacity					
Six-minute Walk (m)	480.7 ± 48.0	414.5 ± 72.5	469.8 ± 46.1	456.3 ± 60.8	445.5 ± 65.7
Sit-stand (rep·30 s^{-1})	12.1 ± 1.7	13.9 ± 3.5	13.1 ± 3.0	13.1 ± 2.7	12.7 ± 2.6
Quality of Life					
Mental	57.7 ± 3.4	52.6 ± 11.1	47.8 ± 11.7	53.0 ± 9.7	51.8 ± 10.9
Physical	47.2 ± 8.15	37.3 ± 7.2	45.3 ± 8.1	43.5 ± 8.6	41.7 ± 9.0

CEX = concentric exercise; EEX = eccentric exercise; CON = control; BMI = body mass index; SMM = skeletal muscle mass.

Table 2 Changes in Anthropometric, MRI, Strength, Functional Capacity, and Quality of Life

	CEX		**EEX**		**CON**			
Variable	**Mean Change ± SE**	**p-value**	**Mean Change ± SE**	**p-value**	**Mean Change ± SE**	**p-value**	**F-value**	**p-value**
Anthropometry								
BMI (kg·m^{-2})	−7.56 ± 1.4	0.0005	−8.03 ± 1.1	0.0001	−7.82 ± 1.3	0.0005	0.03	0.9683
Body Mass (kg)	−19.9 ± 3.7	0.0010	−21.8 ± 3.3	0.0002	−21.4 ± 3.7	0.0004	0.07	0.9320
MRI								
Lower Body SMM (kg)	−1.19 ± 0.6	0.0635	−0.90 ± 0.5	0.0917	−0.77 ± 0.5	0.1758	0.21	0.8111
SMM percent	2.2 ± 0.4	0.0008	2.6 ± 0.4	< 0.0001	2.7 ± 0.4	0.0001	0.75	0.5009
Strength								
Static 70° (N·m)	37.9 ± 29.4	0.2327	−35.6 ± 24.9	0.1904	40.0 ± 27.3	0.1812	1.99	0.1987
Dynamic 60°·s^{-1} (N·m)	38.6 ± 22.4	0.1248	−50.8 ± 19.0	0.0283	−18.6 ± 20.9	0.4005	4.12	0.0588
Dynamic 120°·s^{-1} (N·m)	9.3 ± 21.3	0.6718	−20.1 ± 18.0	0.2954	19.1 ± 19.8	0.3621	0.88	0.4504
Functional Capacity								
Six-minute Walk (m)	160.9 ± 50.7	0.0131	121.2 ± 42.9	0.0223	130.5 ± 47.2	0.0244	0.20	0.8242
Stand-sit (rep·30 s^{-1})	7.7 ± 2.3	0.0100	6.6 ± 1.9	0.0092	5.2 ± 2.1	0.0412	0.42	0.6700
Quality of Life								
Physical	8.4 ± 4.4	0.0400	11.2 ± 3.5	0.0179	18.1 ± 3.5	0.0021	1.94	0.2240
Mental	1.7 ± 4.8	0.7361	−0.7 ± 4.5	0.8870	3.3 ± 4.5	0.4994	0.15	0.8629

CEX = concentric exercise; EEX = eccentric exercise; CON = control; BMI = body mass index; SMM = skeletal muscle mass.
Mean changes were based on ANCOVA analysis and were controlled for surgery type and fitness (starting Six-minute Walk).

Table 3 Functional Capacity

		CEX		EEX		CON	
Variable	**Time**	**Adjusted Mean ± SE**	**Adjusted diff ± SE**	**Adjusted Mean ± SE**	**Adjusted diff ± SE**	**Adjusted Mean ± SE**	**Adjusted diff ± SE**
Stand-Sit (reps·30^{-1})	BL	12.1 ± 1.4		13.6 ± 1.5		13.3 ± 1.5	
	M1	14.2 ± 1.4	2.0 ± 0.9[*]	16.0 ± 1.5	2.1 ± 0.9[*]	15.0 ± 1.5	1.7 ± 0.9
	M2	15.9 ± 1.6	1.7 ± 1.1[*]	18.4 ± 1.5	2.4 ± 0.9[*†]	16.4 ±1.5	1.4 ± 1.0[*]
	M3	17.0 ± 1.8	1.1 ± 1.2[*]	19.3 ± 1.5	0.9 ± 1.0[*†]	17.1 ± 1.6	0.7 ± 1.0[*]
	M4	18.3 ± 1.9	1.2 ± 1.2[*†]	19.6 ± 1.6	0.3 ± 1.0[*†]	17.6 ± 1.6	0.5 ± 1.0[*]
Six-Minute Walk (m)	BL	480.7 ± 24.3		414.5 ± 26.3		469.8 ± 26.3	
	M1	486.3 ± 25.8	5.6 ± 24.6	503.6 ± 26.3	89.2 ± 24.9[*]	543.2 ± 26.3	73.4 ± 25.0[*]
	M2	534.9 ± 30.6	48.6 ± 29.4	528.9 ± 26.3	25.2 ± 24.9[*]	524.7 ± 28.1	−18.5 ± 26.9
	M3	519.2 ± 35.6	−15.7 ± 34.0	545.9 ± 28.1	17.1 ± 26.9[*]	558.1 ± 28.7	33.4 ± 27.2[*]
	M4	595.1 ± 37.0	75.8 ± 34.8[*†§]	553.6 ± 28.7	7.7 ± 27.2[*]	578.4 ± 28.8	20.3 ± 89.5[*]

Adjusted values were based of the mixed model and predicted mean ± SE for each period. BL = baseline; M1 = month 1; M2 = month 2; M3 = month 3; M4 = month 4.

[*] Group mean is significantly different than baseline (BL) measurement ($p < 0.05$)

[†] Group mean is significantly different than month 1 (M1) measurement ($p < 0.05$)

[§] Group mean is significantly different than month 3 (M3) measurement ($p < 0.05$)

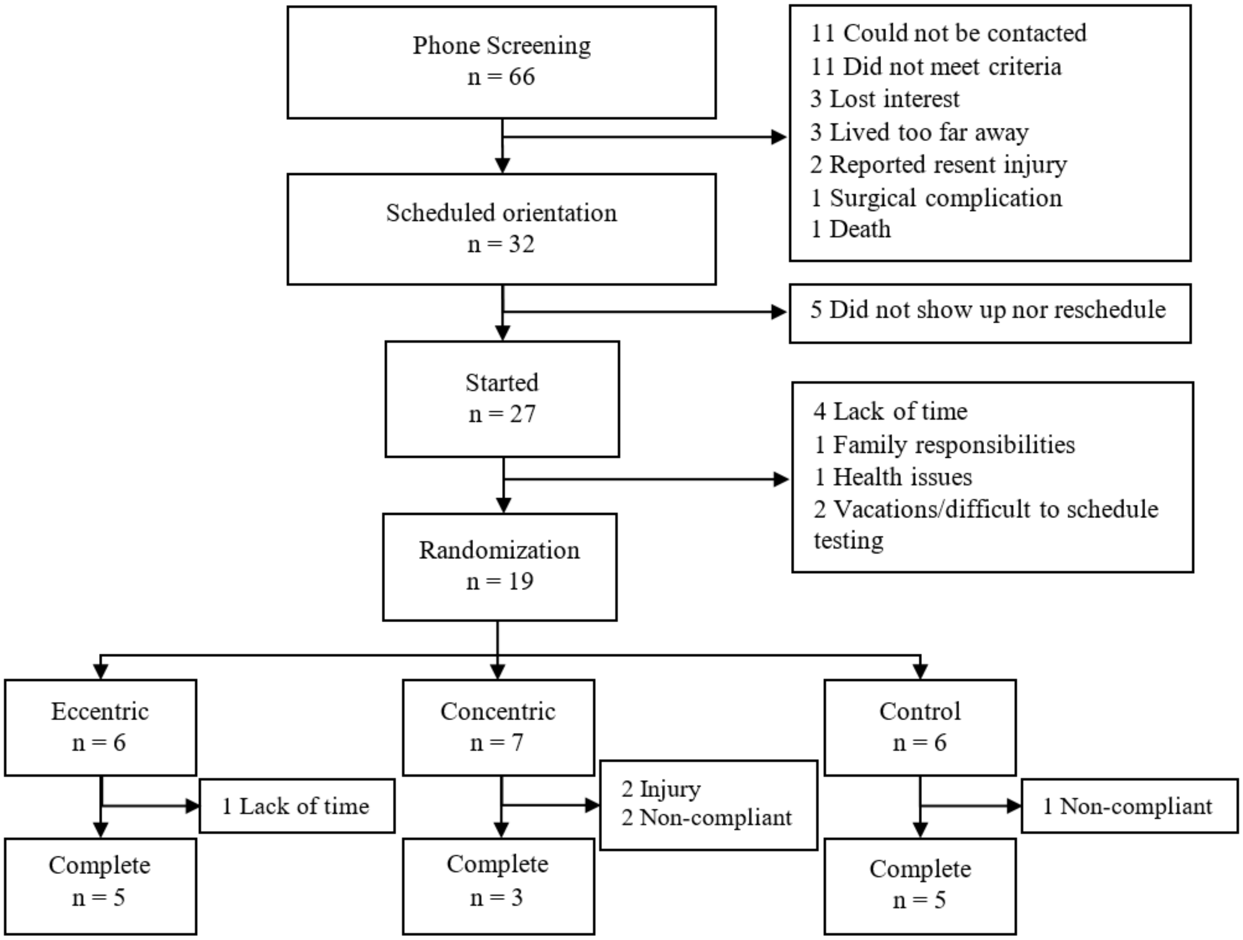

Figure 1 Flow Chart of Participant Selection.

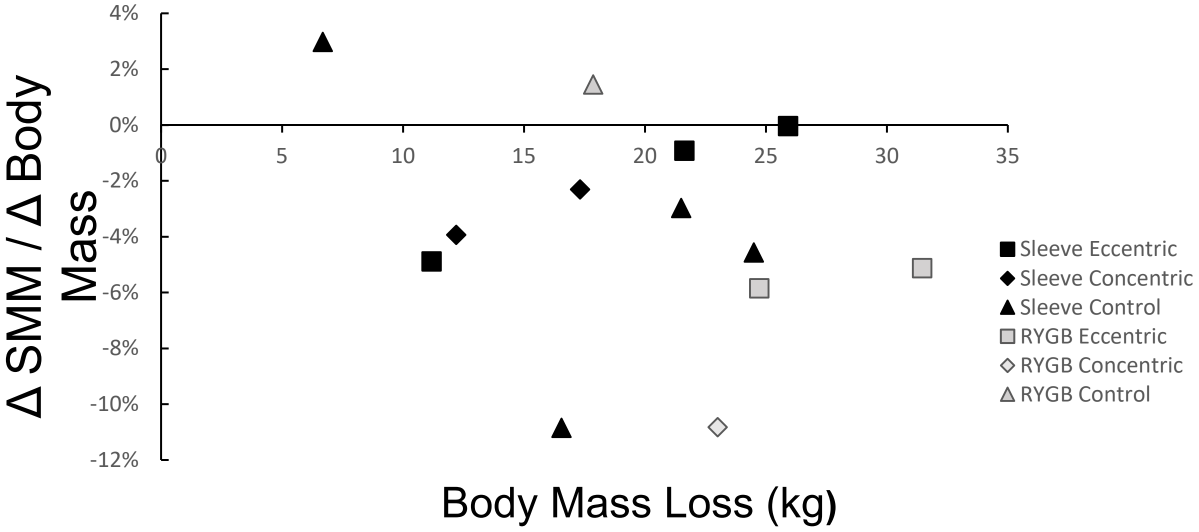

Figure 2 Percent Skeletal Muscle Change of Total Body Mass to Body Mass Loss, Unfiltered Data. Based on group assignment and surgery type.

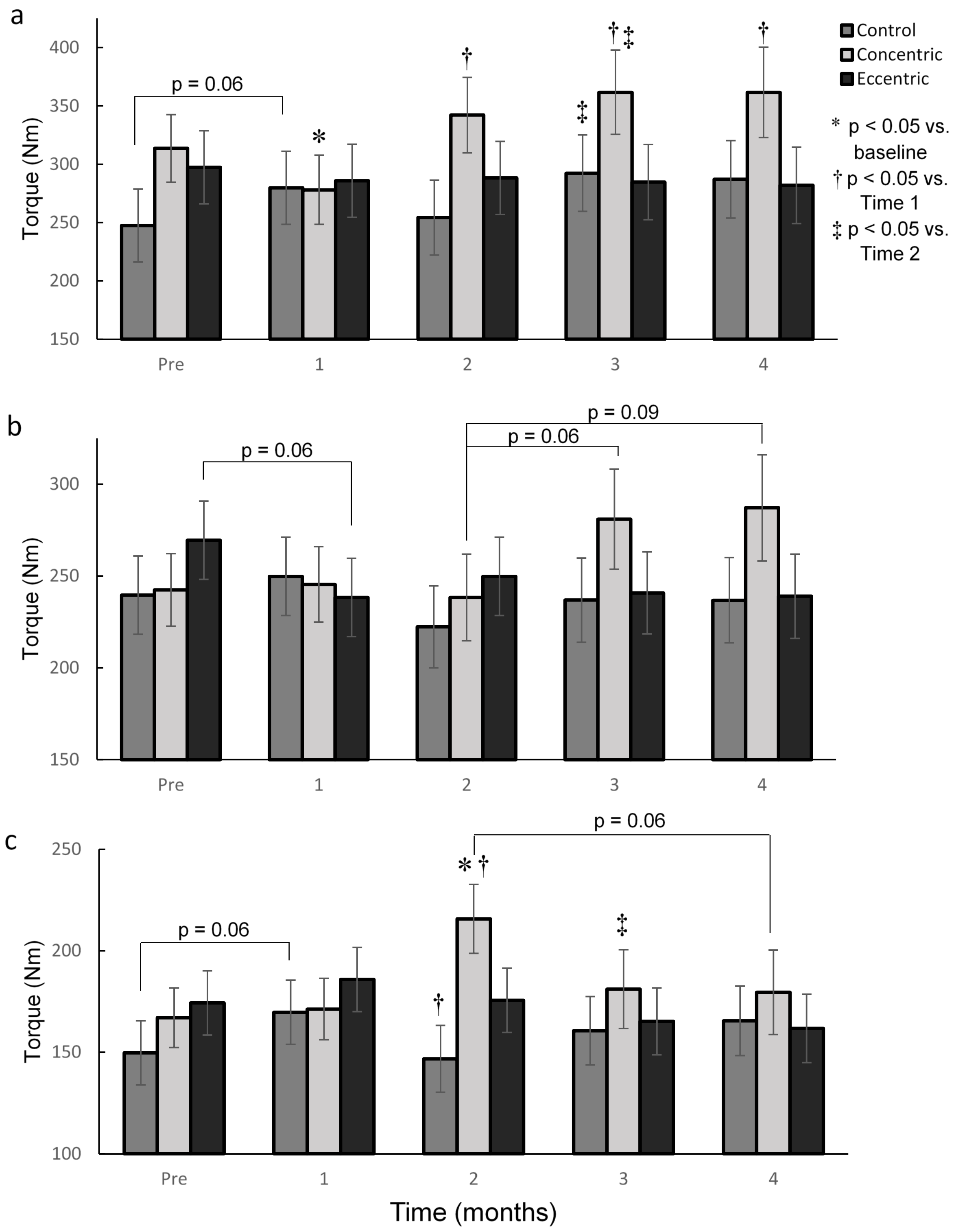

Figure 3 Muscular strength based on an autoregressive mix model, means ± SE
a Static strength 70°
b Isokinetic strength $60°\cdot s^{-1}$
c Isokinetic strength $120°\cdot s^{-1}$