Obesity Surgery
https://doi.org/10.1007/s11695-025-07685-z

RESEARCH

Adherence to an Early Exercise Plan Promotes Visceral Fat Loss in the First Month Following Bariatric Surgery

Johanna Pino-Zuñiga[1] · Paloma Lillo-Urzua[2] · Mariela Olivares-Galvez[1] · Ana Palacio-Aguero[1,3] · Juan Camilo Duque[1] · Rafael Luengas[1] · Jorge Cancino-Lopez[4,5]

Received: 9 September 2024 / Revised: 6 January 2025 / Accepted: 11 January 2025

Abstract

Background The evidence supporting the benefits of early exercise in post-bariatric patients is growing. This study analyzed the effects of early exercise (1-week post-bariatric surgery) on body composition in patients with overweight and obesity 1 month after surgery.

Methods Thirty patients (age 36.5 ± 12.3 [range, 18–65] years; body mass index [BMI], 36.2 ± 12.3 kg/m^2, range, 29–48) who underwent laparoscopic sleeve gastrectomy for bariatric surgery were instructed to participate in an exercise training program initiated on day 3 post-surgery and to follow a recommended protein intake of 60 g/day. After 1-month post-surgery, patients were stratified into those who adhered to exercise recommendations and those who did not. Pre- and post-differences in total weight loss (TWL), skeletal muscle mass (SMM), fat mass (FM), and visceral fat mass (VFM) were compared.

Results TWL, SMM, and FM loss were similar between non-adherent and adherent subjects (10.2 ± 3.5 kg and 11.9 ± 3.6 kg; $p = 0.2$; 2.9 ± 1.0 kg and 3.2 ± 1.2; $p = 0.2$; 6.2 ± 2.1 kg and 7.5 ± 3.6 kg; $p = 0.2$, respectively), whereas VFM was markedly reduced in the adherent group (29.9 ± 18.2 cm^2 vs 14.6 ± 9.4 cm^2; $p = 0.01$) compared to the non-adherent group. When the group was divided according to adherence to exercise and protein intake or non-adherence to both conditions, there was a significant difference in TWL, FM, and VFM losses ($p < 0.05$). In contrast, no differences in SMM were found.

Conclusions Early exercise training accelerated visceral fat mass loss during the initial recovery period in patients after bariatric surgery. Additionally, adherence to daily protein intake recommendations can increase total body weight and fat mass loss.

Keywords Abdominal visceral fat · Bariatric surgery · Exercise · Patients' adherence · Weight loss

Introduction

Bariatric surgery is an effective therapeutic strategy to induce body mass loss and to improve metabolic profile in obese patients [1]. Approximately ten percent of the initial body mass is lost during the first month after surgery as a result of the severe caloric restriction induced by procedure [2]. Unfortunately, there is also a rapid fat-free mass (FFM) loss during this period, which may go up to a third of the excess weight loss (EWL) [3, 4].

Obesity also is associated with an excess of visceral, subcutaneous, and ectopic fat and the evidence shows that abdominal fat depots are strongly correlated with cardiometabolic effects. Increased ectopic fat in and around the kidney is associated with hypertension, albuminuria, and progression of chronic kidney disease (CKD) [5]. The relationship between visceral fat and ectopic fat has been recently studied, showing a positive association between the accumulation of visceral fat deposits and periorgan and intraorgan fat (including skeletal muscle, liver, and renal sinus) [6].

The reduction of retroperitoneal adipose tissue volume and the improvement of intraperitoneal adipose tissue quality were associated with an improved metabolic health status in individuals with morbid obesity after bariatric surgery [7].

Key Points

- Those who adhered to exercise recommendations early after bariatric surgery lost significantly more visceral fat than those who did not.
- Combined adherence to exercise and protein intake increases overall fat and weight loss.
- Sixty-six percent of patients adhered to the exercise recommendations during the first month after bariatric surgery.

Extended author information available on the last page of the article

Published online: 14 February 2025

When comparing all available strategies for reducing visceral and subcutaneous fat, such as diet combined with exercise, pharmacologic treatments, and bariatric surgery, it has been reported that while the absolute reduction is greater for subcutaneous fat, the percentage reduction is higher for visceral fat, with no significant differences among the strategies studied [8]. On the other hand, regular physical activity has been shown to effectively reduce visceral fat, independent of changes in body weight, in individuals who are overweight or have obesity. Exercise has a superior effect on visceral fat reduction compared to dietary and caloric restriction interventions alone [9]. Also, a dose–response effect of exercise and visceral fat reduction has been reported recently in individuals with excess body weight and obesity [10]. Meanwhile, the evidence related to exercise programs after bariatric surgery and their effect on reducing visceral fat is scarce.

Bariatric surgery candidates are strongly encouraged to start with physical activity before the surgery and to continue afterwards [11]. The recommended physical activity for post-bariatric patients is similar to the recommendations for the general population, as there are no specified physical activity guidelines for bariatric patients taking specific characteristics of those patients into account such as rapid muscle mass loss during weight loss, history of inactivity, or reduced muscle mass percentage [12]. According to the current American Bariatric Surgery Guidelines, physical activity interventions are recommended to start one month after bariatric surgery [11]. However, recent literature supports the benefits of beginning exercise earlier, within the first month post-surgery [13].

Physical activity benefits in post-bariatric patients are related to preventing weight regain while preserving lean body mass [14]. It is widely accepted that exercise increases the synthesis rate of myofibrillar proteins, therefore contributes to the maintenance of muscle mass throughout lifespan [15, 16]. To favor WL and prevent weight regain, current guidelines recommend that post-bariatric surgery patients increase physical activity levels and engage in regular exercise [17]. Furthermore, it improves mental health by enhancing body awareness, cognitive function, and well-being [18].

Despite exercise being an indispensable part of the treatment of obesity, there is very low adherence to exercise programs and multiple barriers to carrying it out in this type of patient. Most studies show close to 50% adherence to an exercise program in people with obesity [19].

A scarcity of knowledge exists in patients during the first month after bariatric surgery and who begin a physical activity program early. Likewise, whether compliance to recommended exercise could prevent muscle mass loss or improve body composition, particularly through the reduction in visceral fat, in these patients is unknown. The aim of the present study was to evaluate the effects of patients' adherence to physical exercise recommendations during the first month after undergoing bariatric surgery and their impact on weight loss and body composition.

Materials and Methods

Participants

Thirty individuals [13 M: 17 F] with excess body mass, i.e., overweight and obesity (age, 36.5 ± 12.3 [range 18–65] years); body mass index [BMI] 36.2 ± 12.3 kg m^{-2}, range 29–48), underwent bariatric surgery sleeve laparoscopic gastrectomy. The patients were previously evaluated by the physical therapist to provide indications for physical activity during the first postoperative month, with the aim that the patient will begin with adapted strength exercises at the time of discharge from the hospital. These indications were reinforced within the hospitalization period through a visit from the physical therapist, the delivery of audiovisual material that consisted of a video on how to execute the exercises and precautions for carrying them out. In addition, the patient was given the green (4.6–6.7 pounds at 100–200% elongation) elastic bands (TheraBand®) to facilitate the early start of exercise at home.

After surgery, patients initiated exercise at day 3 post-intervention. Oral food intake resumed 24 h after surgery in a progressive manner based on nutrient consistency and volume in three phases: phase 1, from day 1 to day 3: clear liquid diet, phase 2: from day 3 to day 7: full liquid-dairy-based diet, and phase 3: from day seven onwards: puréed diet, mainly based in white meats and dairy products. Daily protein intake was recommended to be of 60 gr day^{-1} as white meats and dairy products as recommended by Mechanick J. I. et al. [11]. The indication for liquid intake per day was 1.5 L accumulated during the day (such as broths, dairy products, water, tea, infusions).

Exercise Training

All patients were instructed to resume their daily routine of both aerobic and resistance exercises as taught before surgery. Aerobic exercises consisted of a light walk with the goal of reaching 30 min per day, which could be divided into three 10-min periods. To evaluate the intensity of perceived effort during walking, the modified Borg's scale [20] was used, asking the patient to have a perceived effort of 3–4.

Resistance training was based on a circuit of 3 sets of 15 repetitions targeting 5 main muscle groups: calf raise, sit-ups from a chair, biceps curls, front row, and chess press. The first two exercises were executed with the body weight; the last three exercises were performed with an green elastic band (TheraBand®). Patients were instructed regarding the execution of strength exercises and coordination with breathing to avoid valsalva maneuver.

Body Composition

The patient's whole body and regional fat and lean body masses were measured before and after surgery by bioelectrical impedance analysis (BIA) with direct segmental multi-frequency in an octopolar InBody 770 body composition analyzer (InBody, Korea). BIA has shown a valid method with a good confidence level to determine body composition and visceral fat mass patients with obesity [21–24]. Prior to evaluation, patients had all metal items removed and were asked to empty their bladder. The patients stood barefoot onto the equipment's platform, matching the feet with the surface electrodes while holding up to the equipment's handles with their thumb and fingers contacting the electrodes. This position was held for 1 min with elbows extended and shoulders abducted at a 20–30° angle according to the specifications from the manufacturer. Records of body weight, fat mass, skeletal muscle mass, and skeletal muscle mass relative to excess of body weight and visceral fat mass were performed.

Patient Stratification

At the 1-month follow-up, subjects were divided into two groups according to their adherence to exercise recommendations (AD) and non-adherence to exercise recommendations (NAD). Additionally, a second stratification of patients was performed based on whether they adhered to both exercise and daily protein intake recommendations (ADEP) or neither exercise nor daily protein intake recommendations (NADEP). The study was conducted in accordance with the Declaration of Helsinki for human research and was approved by the ethics committee of Chilean Society of Bariatric and Metabolic Surgery (N°0010/2024).

Statistical Analysis

Data were tested for normality using the Shapiro–Wilk test. For within-group pre- and post-surgery differences, a paired *t*-test (parametric) or Wilcoxon test (non-parametric) was used. For delta differences between compliant and non-compliant groups in total body weight, fat mass, skeletal muscle mass, and visceral fat mass loss 1 month post-surgery, an unpaired Student's *t*-test or Mann–Whitney *U* test was used for parametric or non-parametric data, respectively. Effect sizes (ES) for pre- and post-deltas were calculated using Cohen's *d* values, with thresholds for small, moderate, and large effects set at 0.2, 0.5, and 0.8, respectively. Statistical significance was established at $p < 0.05$. Data were analyzed using GraphPad Prism 7.0 software for Mac.

Results

At the 1-month follow-up after bariatric surgery, patients were divided into those who adhered (AD) and those who did not adhere (NAD) to the exercise recommendation. Twenty patients (66%) reported adhering to the exercise, while ten reported not adhering. The baseline and 1-month post-bariatric surgery participants' characteristics are shown in Table 1.

Body Weight Loss

Body weight (Fig. 1A) was reduced by 10.2 ± 3.5 kg and 11.9 ± 3.6 kg in the NAD and AD group respectively ($p = 0.23$, ES = 0.47). The differences expressed as percentage of change was 10.2 ± 2.6% and 11.6 ± 2.3% in the NAD and AD group respectively ($p = 0.15$, ES = 0.57).

Skeletal Muscle Mass Loss

Skeletal muscle mass loss (Fig. 1B) was 2.9 ± 1.0 kg and 3.2 ± 1.2 kg in the NAD and AD group respectively ($p = 0.48$, ES = 0.27). The differences expressed as percentage of change was 9.9 ± 2.5% and 9.4 ± 3.0% in the NAD and AD group respectively ($p = 0.64$, ES = 0.18). Skeletal muscle mass loss percentage related to total weight loss was 30.4 ± 12.1% vs 27.6 ± 9.3% in NAD and AD respectively ($p = 0.49$, ES = 0.25).

Fat Mass Loss

Fat mass loss (Fig. 1C) was 6.2 ± 2.1 kg and 7.5 ± 3.6 kg in the NAD and AD group respectively ($p = 0.29$, ES = 0.44). The differences expressed as percentage of change was 12.8 ± 3.4% and 18.9 ± 9.6% in the NAD and AD group respectively ($p = 0.06$, ES = 0.84).

Visceral Fat Mass Loss

Visceral fat mass loss (Fig. 1D) was 14.6 ± 9.4 cm^2 and 29.9 ± 18.2 cm^2 in the NAD and AD group respectively ($p = 0.01$, ES = 1.05). The differences expressed as percentage of change was 6.7 ± 4.2% and 16.0 ± 10% in the NAD and AD group respectively ($p = 0.01$, ES = 1.21).

Compliance with Exercise Training and Daily Protein Recommendation

Those patients who adhered to both exercise and protein recommendations ($n = 11$) lost 12.8 ± 4.4 kg of body weight (Fig. 2A) compared to 8.1 ± 2.2 kg in those ($n = 6$) who adhered to neither exercise nor protein recommendations

Table 1 Baseline and 1-month post-bariatric surgery participants' characteristics

	Baseline	1 month	Delta	*p* vs baseline	*p* AD vs NAD or *p* ADEP vs NADEP
NAD BMI	36.9 ± 5.5	33.1 ± 4.7	3.8	0.05	0.68
AD BMI	34.3 ± 3.5	30.3 ± 2.9	4.0	< 0.0001	
NAD BW	99.7 ± 19.9	89.4 ± 17.7	10.2	< 0.0001	0.23
AD BW	102.1 ± 16.5	90.1 ± 13.8	11.9	< 0.0001	
NAD SMM	29.1 ± 6.5	26.1 ± 5.8	2.9	< 0.0001	0.48
AD SMM	34.7 ± 9.0	31.1 ± 8.4	3.2	< 0.0001	
NAD FM	47.8 ± 11.4	41.6 ± 10.0	6.2	< 0.0001	0.29
AD FM	40.4 ± 7.6	32.9 ± 7.5	7.5	< 0.0001	
NAD VFM	224.1 ± 30.7	209.5 ± 33.7	14.6	0.0009	0.01
AD VFM	195.5 ± 42.6	165.6 ± 44.0	29.9	< 0.0001	
NADEP BMI	33.8 ± 2.8	30.8 ± 2.9	3.0	< 0.0001	0.05
ADEP BMI	35.4 ± 3.7	31.3 ± 2.9	4.1	< 0.0001	
NADEP BW	89.4 ± 9.0*	81.3 ± 9.3	8.1	0.0003	0.02
ADEP BW	108.0 ± 16.9	95.2 ± 13.6	12.8	< 0.0001	
NADEP SMM	26.6 ± 3.8*	24 ± 3.3	2.6	0.0007	0.41
ADEP SMM	37.2 ± 8.1	34.0 ± 7.2	3.2	< 0.0001	
NADEP FM	41.9 ± 4.4	37.2 ± 4.4	4.7	0.0001	0.04
ADEP FM	42.2 ± 7.1	33.9 ± 5.8	8.3	< 0.0001	
NADEP VFM	207.3 ± 17.4	195.0 ± 17.3	12.3	0.005	0.02
ADEP VFM	202.5 ± 35.9	167.7 ± 32.2	34.8	0.0002	

BMI, body mass index (kg/m^2); *BW*, body weight (kg); *SMM*, skeletal muscle mass (kg); *FM*, fat mass (kg); *VFM*, visceral fat mass (cm^2); *NAD*, non-adhered; *AD*, adhered; *NADEP*, non-adhered to exercise and protein intake; *ADEP*, adhered to exercise and protein intake. NAD (n = 10); AD (n = 20); ADEP (n = 11); NADEP (n = 6). *Significant differences at baseline between groups

(p = 0.02, ES = 1.35). The differences expressed as percentage of change was 11.7 ± 2.7% and 9.2 ± 2.6% in the ADEP and NADEP group respectively (p = 0.09, ES = 0.94).

Regarding fat mass loss (Fig. 2B), patients who adhered to both exercise and protein recommendations lost 8.3 ± 3.9 kg compared to 4.7 ± 1.2 kg in those who adhered to neither exercise nor protein recommendations (p = 0.04, ES = 1.24). The differences expressed as percentage of change was 19.4 ± 7.8% and 11.3 ± 2.8% in the ADEP and NADEP group respectively (p = 0.02, ES = 1.38).

Skeletal muscle mass loss (Fig. 2C) was 3.2 ± 1.4 kg and 2.6 ± 0.8 kg in patients who adhered to both exercise and protein recommendations and those who adhered to neither exercise nor protein recommendations, respectively (p = 0.41, ES = 0.43). The differences expressed as percentage of change was 8.5 ± 3.1% and 9.7 ± 2.6% in the ADEP and NADEP group respectively (p = 0.45, ES = 0.42).

Visceral fat mass loss (Fig. 2D) was 34.8 ± 20.5 cm^2 and 12.3 ± 6.4 cm^2 in patients who adhered to both exercise and protein recommendations and those who adhered to neither exercise nor protein recommendations, respectively (p = 0.02, ES = 1.48). The differences expressed as percentage of change was 16.9 ± 8.7% and 5.9 ± 3.0% in the ADEP and NADEP group respectively (p = 0.009, ES = 1.70).

Discussion

Bariatric surgery has been shown to be an effective therapeutic tool for body weight control [25]. Our study confirms that during the first month after bariatric surgery, there is almost a ten percent reduction in body weight. This is similar to what is found in other studies with this kind of patient [26]. However, body composition has been gaining growing importance since the beneficial aspects related to muscle mass and the health risks and quality of life associated with muscle loss are now better understood [27, 28].

Moreover, the importance of visceral fat in cardiometabolic risk is recognized, as well as the beneficial aspects of bariatric surgery in reducing the risk of cardiovascular events associated with this type of fat accumulation [29, 30].

In regard to exercise therapy after bariatric surgery, most studies have reported that it does not begin before the first month. [31]. However, recent evidence suggests that early exercise therapy is well tolerated and safe in these patients [13]. In this study, we show results about body composition changes with special regard to visceral fat associated with adherence or non-adherence to early exercise recommendations. Sixty-six percent of patients adhered to the exercise recommendations during the first month after bariatric surgery.

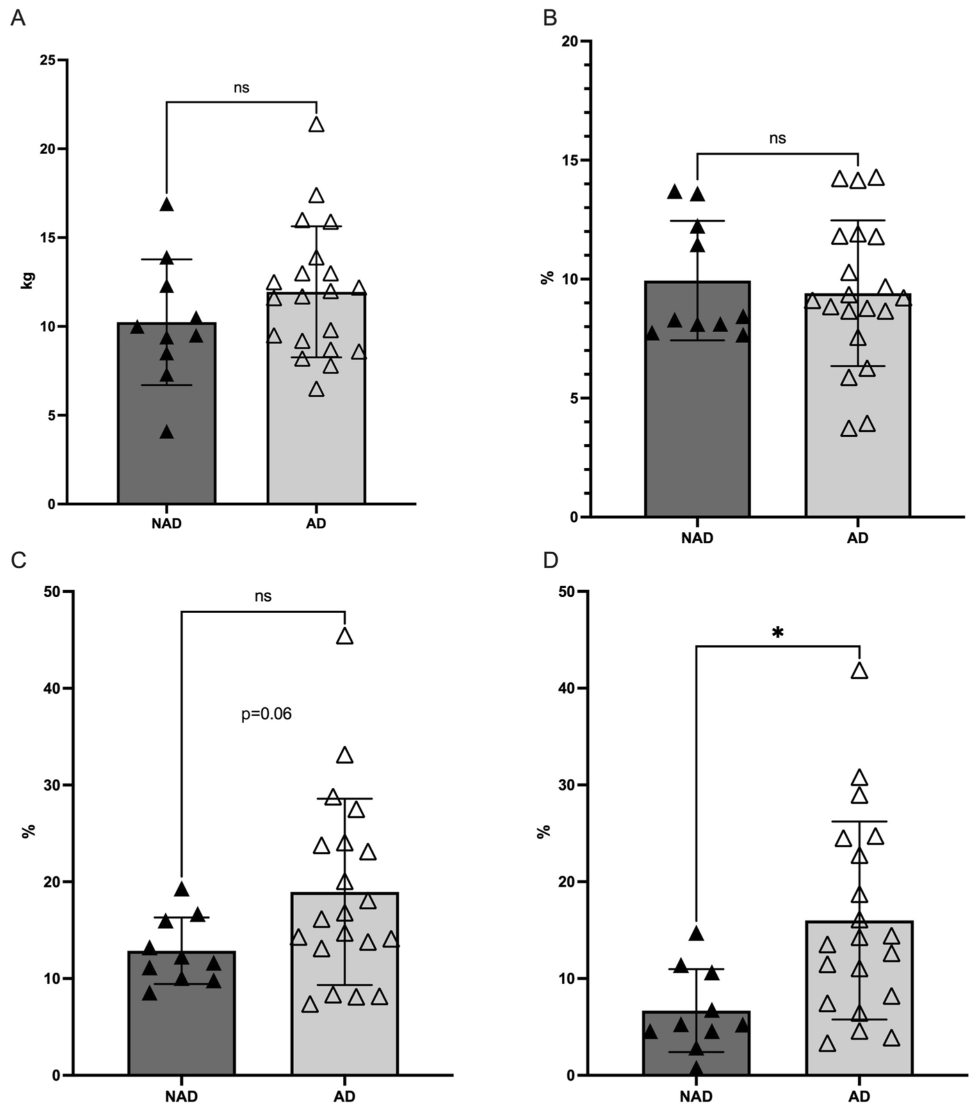


Fig. 1 Comparison between non-adhered (NAD) and adhered (AD) patients to exercise recommendations. Body weight loss (**A**). Percentage of skeletal muscle mass loss (**B**). Percent of fat mass loss (**C**). Percentage of visceral fat loss (**D**). *$p<0.05$

This was higher than the 33% adherence reported by Carpenter & Gilleland (2016) for individuals with excess body weight who were encouraged to continue a non-supervised exercise program [32]. The overall weight loss did not differ between groups; however, analysis of the percentage of fat mass loss revealed a 6.1% greater reduction, although non-significant, in the group adherent to the exercise recommendations ($p=0.06$).

On the other hand, the percentage of visceral fat loss was 9.3% higher in the AD group compared to the NAD group ($p=0.01$). Notably, this is the first study to report that adherence to exercise recommendations in early exercise therapy following bariatric surgery leads to a greater reduction in visceral fat mass.

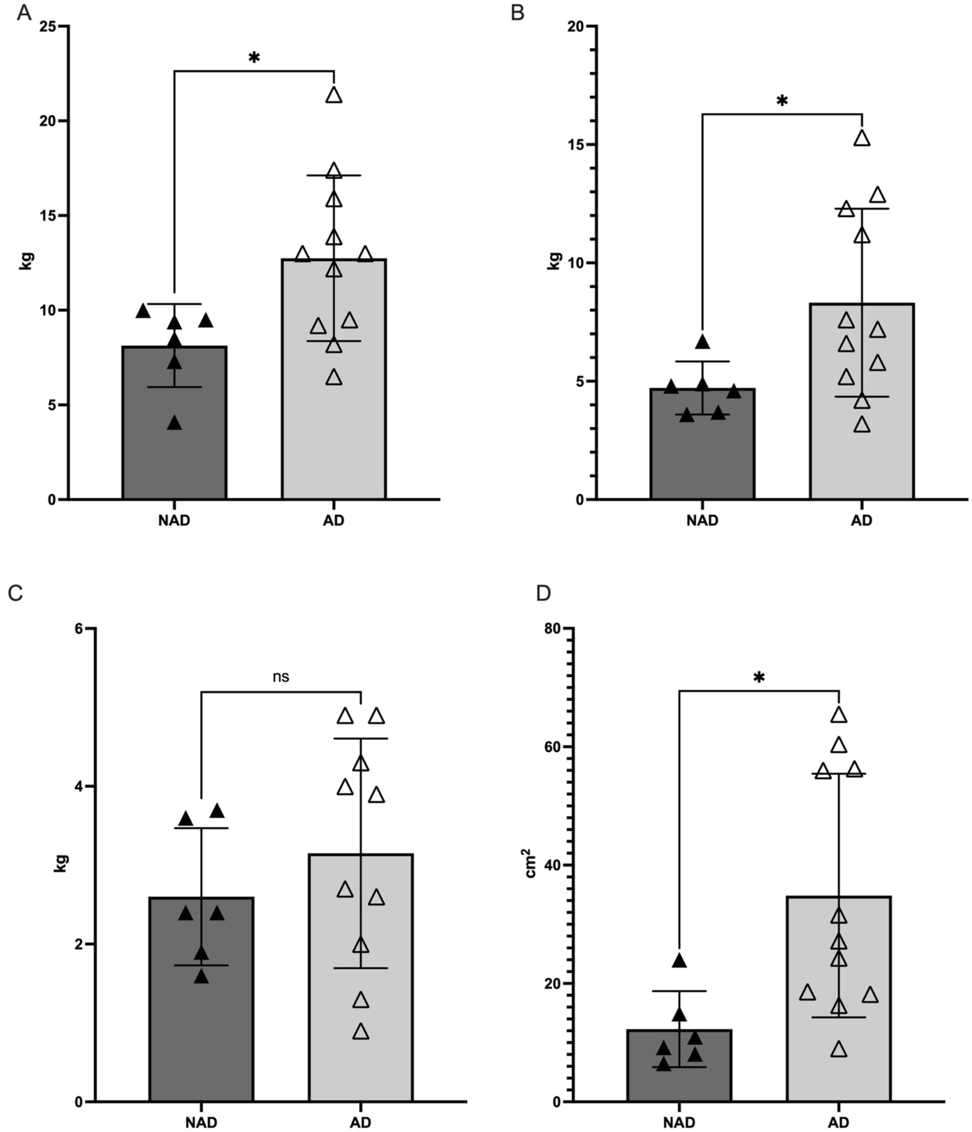
Exercise intensity could be a major factor in achieving the beneficial health outcomes related to visceral fat reductions, as recent studies have shown that high-intensity aerobic exercise is associated with visceral fat mass reduction [33, 34]. In the same way, it has been reported that high-intensity resistance training develops faster visceral fat loss than moderate intensity endurance and resistance training [35].

Hunter et al. showed that maintaining aerobic or resistance exercise training in 40-min sessions, twice a week for a year, prevents visceral fat regain [36]. Previous studies also have shown the effects of bariatric surgery and exercise programs on body weight and visceral fat mass reductions [37].

Losing a higher amount of visceral fat is positively associated with increased insulin sensitivity, which leads to better metabolic health [38]. In our study, eleven patients adhered to exercise recommendations and also reported adhering to protein intake recommendations. This group lost significantly more body weight, body fat mass, and visceral fat mass than patients who did not adhere to the exercise or protein intake recommendations, with statistically significant differences in all cases.

The effects of protein intake on visceral fat mass have been recently studied by Bel Lassen et al. [39]. They studied

Fig. 2 Comparison between non-adhered (NAD) and adhered (AD) patients to exercise and daily protein intake recommendations. Body weight loss (**A**). Fat mass loss (**B**). Skeletal muscle mass loss (**C**). Visceral fat loss (**D**). *$p < 0.05$



the changes in visceral fat mass after a 12-week moderate caloric restriction (600 cal less than the daily recommendation) plus a 68 g protein supplement added to the daily habitual intake. Visceral fat was reduced by 20.8 cm^2 after protein supplementation, which was a 6.6 cm^2 higher loss compared to the group that did not receive the supplementation ($p < 0.05$). This study concluded that protein supplementation, when added to a moderate caloric restriction, induces visceral fat loss.

These study results are in concordance with our findings, showing that the group adhering to exercise and protein intake recommendations lost a higher amount of visceral fat compared to those who did not adhere to these recommendations (ES = 1.48).

While this study provides valuable insights into the effects of adherence to early exercise recommendations on visceral fat loss after bariatric surgery, some limitations must be acknowledged. The small sample size limits the generalizability of the results, as it may not fully represent the broader population of post-bariatric patients. Additionally, the observational nature of the study, with groups assigned based on compliance rather than randomization, introduces potential selection bias, which further limits the generalizability of the findings.

Furthermore, unsupervised exercise training may lead to incomplete or inaccurate information from study participants regarding their adherence to exercise and protein intake. Although a stricter follow-up could have been implemented, this study intentionally relied on exercise and protein intake recommendations to evaluate their effects without additional follow-up strategies. Based on our findings, we suggest encouraging adherence to these recommendations for individuals undergoing bariatric surgery, as they may significantly enhance post-surgical outcomes.

An early exercise training program for post-bariatric surgery patients must be adapted to individual requirements and capabilities, as people with obesity may face different psychological and physical challenges during intense physical activity [40].

Developing new strategies where early exercise programs, with or without supervision, combining aerobic and resistance exercises, support patient adherence and lead to a significant reduction in visceral fat mass will contribute to optimizing long-term health outcomes, reducing complications associated with obesity.

Conclusion

In summary, our results highlight the importance of adhering to early exercise recommendations due to their positive effects on visceral fat mass reduction. Additionally, those who adhered to both exercise and daily protein intake recommendations early after bariatric surgery lost significantly more visceral and total fat mass than those who did not.

Author Contributions J.C.L.; J.P.Z. and M.O.G. contributed to the study conception and design. Recruitment and data collection were performed by J.P.Z.; JC.D.; R.L. and A.P.A. Statistical analyses and interpretation of the data were performed by J.C.L.; J.P.Z. and P.L.U. The first draft of the manuscript was written by J.C.L; J.P.Z. and P.L.U. and all authors commented on previous version of the manuscript. All authors read and approved the final manuscript.

Data Availability The data availability statement is included and reads as follows: Participant data are available upon reasonable request from the corresponding author. Requests must be reasonable and accompanied by research proposals that have received appropriate ethical approval. Data will be provided in an anonymized format, in compliance with applicable privacy and data protection laws.

Declarations

Ethical Approval All procedures of the study are compliant with the ethical standards of Chilean Society of Bariatric and Metabolic Surgery (N°0010/2024), and with the 1964 Helsinki declaration and its later amendments.

Informed Consent Informed consent was obtained from all study participants.

Conflict of Interest The authors declare no competing interests.

References

1. Wolfe BM, Kvach E, Eckel RH. Treatment of obesity: weight loss and bariatric surgery. Circ Res. 2016;118:1844–55. https://doi.org/10.1161/CIRCRESAHA.116.307591.
2. Metcalf B, Rabkin RA, Rabkin JM, et al. Weight loss composition: the effects of exercise following obesity surgery as measured by bioelectrical impedance analysis. Obes Surg. 2005;15:183–6. https://doi.org/10.1381/0960892053268381.
3. Chaston TB, Dixon JB, O'Brien PE. Changes in fat-free mass during significant weight loss: a systematic review. Int J Obes (Lond). 2007;31:743–50. https://doi.org/10.1038/sj.ijo.0803483.
4. Davidson LE, Yu W, Goodpaster BH, et al. Fat-free mass and skeletal muscle mass five years after bariatric surgery. Obesity (Silver Spring). 2018;26:1130–6. https://doi.org/10.1002/oby.22190.
5. Mende C, Einhorn D. Fatty kidney disease: the importance of ectopic fat deposition and the potential value of imaging. J Diabetes. 2022;14:73–8. https://doi.org/10.1111/1753-0407.13232.
6. Mitsushio K, Baden MY, Kagisaki T, et al. Interrelationships among accumulations of intra- and periorgan fats, visceral fat, and subcutaneous fat. Diabetes. 2024;73(7):1122–6. https://doi.org/10.2337/db24-0035.
7. Lee EJ, Song N, Chung ES, et al. Changes in abdominal fat depots after bariatric surgery are associated with improved metabolic profile. Nutr Metab Cardiovasc Dis. 2023;33:424–33. https://doi.org/10.1016/j.numecd.2022.12.017.
8. Merlotti C, Ceriani V, Morabito A, et al. Subcutaneous fat loss is greater than visceral fat loss with diet and exercise, weight-loss promoting drugs and bariatric surgery: a critical review and meta-analysis. Int J Obes (Lond). 2017;41(5):672–82. https://doi.org/10.1038/ijo.2017.31.
9. Verheggen RJ, Maessen MF, Green DJ, et al. A systematic review and meta-analysis on the effects of exercise training versus hypocaloric diet: distinct effects on body weight and visceral adipose tissue. Obes Rev. 2016;17(8):664–90. https://doi.org/10.1111/obr.12406.
10. Recchia F, Leung CK, Yu AP, et al. Dose-response effects of exercise and caloric restriction on visceral adiposity in overweight and obese adults: a systematic review and meta-analysis of randomised controlled trials. Br J Sports Med. 2023;57(16):1035–41. https://doi.org/10.1136/bjsports-2022-106304.
11. Mechanick JI, Apovian C, Brethauer S, et al. Clinical practice guidelines for the perioperative nutrition, metabolic, and non-surgical support of patients undergoing bariatric procedures - 2019 Update: Cosponsored by American Association of Clinical Endocrinologists/American College of Endocrinology, the Obesity Society, American Society for Metabolic & Bariatric Surgery, Obesity Medicine Association, and American Society of Anesthesiologists - Executive Summary. Endocr Pract. 2019;25:1346–59. https://doi.org/10.4158/GL-2019-0406.
12. Stocker R, Ceyhan M, Schönenberger KA, et al. Nutrient and fluid requirements in post-bariatric patients performing physical activity: a systematic review. Nutrition. 2022;97:111577. https://doi.org/10.1016/j.nut.2021.111577.
13. Pino-Zúñiga J, Olivares M, Muñoz G, et al. Early exercise through telerehabilitation after bariatric surgery: is it feasible? Obes Surg. 2024;34(6):2101–10. https://doi.org/10.1007/s11695-024-07185-6.
14. Tabesh MR, Maleklou F, Ejtehadi F, et al. Nutrition, physical activity, and prescription of supplements in pre- and post-bariatric surgery patients: a practical guideline. Obes Surg. 2019;29:3385–400. https://doi.org/10.1007/s11695-019-04112-y.
15. Wackerhage H, Schoenfeld BJ, Hamilton DL, et al. Stimuli and sensors that initiate skeletal muscle hypertrophy following resistance exercise. J Appl Physiol. 2019;126:30–43. https://doi.org/10.1152/japplphysiol.00685.2018.
16. Colleluori G, Aguirre L, Phadnis U, et al. Aerobic plus resistance exercise in obese older adults improves muscle protein synthesis and preserves myocellular quality despite weight loss. Cell Metab. 2019;30:261-273.e6. https://doi.org/10.1016/j.cmet.2019.06.008.
17. Eisenberg D, Shikora SA, Aarts E, et al. American Society for Metabolic and Bariatric Surgery (ASMBS) and International

Federation for the Surgery of Obesity and Metabolic Disorders (IFSO): Indications for Metabolic and Bariatric Surgery. Surg Obes Relat Dis. 2022;18:1345–56. https://doi.org/10.1016/j.soard.2022.08.013.
18. Callaghan P. Exercise: a neglected intervention in mental health care? J Psychiatr Ment Health Nurs. 2004;11:476–83. https://doi.org/10.1111/j.1365-2850.2004.00751.x.
19. Blüher M. Obesity: global epidemiology and pathogenesis. Nat Rev Endocrinol. 2019;15:288–98. https://doi.org/10.1038/s41574-019-0176-8.
20. Borg GA. Psychophysical bases of perceived exertion. Med Sci Sports Exerc. 1982;14(5):377–81.
21. Beato GC, Ravelli MN, Crisp AH, et al. Agreement between body composition assessed by bioelectrical impedance analysis and doubly labeled water in obese women submitted to bariatric surgery: body composition, BIA, and DLW correction appears in Obes Surg. Obes Surg. 2019;29(1):183–9. https://doi.org/10.1007/s11695-018-3505-4.
22. Gómez-Ambrosi J, González-Crespo I, Catalán V, et al. Clinical usefulness of abdominal bioimpedance (ViScan) in the determination of visceral fat and its application in the diagnosis and management of obesity and its comorbidities. Clin Nutr. 2018;37(2):580–9. https://doi.org/10.1016/j.clnu.2017.01.010.
23. Faria SL, Faria OP, Cardeal MD, et al. Validation study of multifrequency bioelectrical impedance with dual-energy X-ray absorptiometry among obese patients. Obes Surg. 2014;24(9):1476–80. https://doi.org/10.1007/s11695-014-1190-5.
24. Lee JK, Park YS, Kim K, et al. Comparison of bioelectrical impedance analysis and computed tomography on body composition changes including visceral fat after bariatric surgery in Asian patients with obesity. Obes Surg. 2021;31(10):4243–50. https://doi.org/10.1007/s11695-021-05569-6.
25. O'Brien PE, Hindle A, Brennan L, et al. Long-term outcomes after bariatric surgery: a systematic review and meta-analysis of weight loss at 10 or more years for all bariatric procedures and a single-centre review of 20-year outcomes after adjustable gastric banding. Obes Surg. 2019;29(1):3–14. https://doi.org/10.1007/s11695-018-3525-0.
26 Maïmoun L, Lefebvre P, Aouinti S, et al. Montpellier Study Group of Bariatric Surgery. Acute and longer-term body composition changes after bariatric surgery. Surg Obes Relat Dis. 2019;15(11):1965–73. https://doi.org/10.1016/j.soard.2019.07.006.
27. Kim B, Tsujimoto T, So R, et al. Changes in muscle strength after diet-induced weight reduction in adult men with obesity: a prospective study. Diabetes Metab Syndr Obes. 2017;9(10):187–94. https://doi.org/10.2147/DMSO.S132707.
28 Sizoo D, de Heide LJM, Emous M, et al. Measuring muscle mass and strength in obesity: a review of various methods. Obes Surg. 2021;31(1):384–93. https://doi.org/10.1007/s11695-020-05082-2.
29. Benotti PN, Wood GC, Carey DJ, et al. Gastric bypass surgery produces a durable reduction in cardiovascular disease risk factors and reduces the long-term risks of congestive heart failure. J Am Heart Assoc. 2017;6(5):e005126. https://doi.org/10.1161/JAHA.116.005126.
30. Brown AM, Yang J, Zhang X, et al. Bariatric surgery lowers the risk of major cardiovascular events. Ann Surg. 2022;276(5):e417–24. https://doi.org/10.1097/SLA.0000000000004640.
31. Schurmans G, Caty G, Reychler G. Is the peri-bariatric surgery exercise program effective in adults with obesity: a systematic review. OBES SURG. 2022;32:512–35. https://doi.org/10.1007/s11695-021-05693-3.
32. Carpenter R, Gilleland D. Impact of an exercise program on adherence and fitness indicators. Appl Nurs Res. 2016;30:184–6. https://doi.org/10.1016/j.apnr.2015.10.007.
33 Armstrong A, Jungbluth Rodriguez K, Sabag A, et al. Effect of aerobic exercise on waist circumference in adults with overweight or obesity: a systematic review and meta-analysis. Obes Rev. 2022;23(8):e13446. https://doi.org/10.1111/obr.13446.
34. Maillard F, Pereira B, Boisseau N. Effect of high-intensity interval training on total, abdominal and visceral fat mass: a meta-analysis. Sports Med. 2018;48(2):269–88. https://doi.org/10.1007/s40279-017-0807-y.
35. Dutheil F, Lac G, Lesourd B, et al. Different modalities of exercise to reduce visceral fat mass and cardiovascular risk in metabolic syndrome: the RESOLVE randomized trial. Int J Cardiol. 2013;168(4):3634–42. https://doi.org/10.1016/j.ijcard.2013.05.012.
36. Hunter GR, Brock DW, Byrne NM, et al. Exercise training prevents regain of visceral fat for 1 year following weight loss. Obesity (Silver Spring). 2010;18(4):690–5. https://doi.org/10.1038/oby.2009.316.
37. Wu FZ, Huang YL, Wu CC, et al. Differential effects of bariatric surgery versus exercise on excessive visceral fat deposits. Medicine (Baltimore). 2016;95(5):e2616. https://doi.org/10.1097/MD.0000000000002616.
38. Mingrone G, Cummings DE. Changes of insulin sensitivity and secretion after bariatric/metabolic surgery. Surg Obes Relat Dis. 2016;12(6):1199–205. https://doi.org/10.1016/j.soard.2016.05.013.
39. Bel Lassen P, Belda E, Prifti E, et al. Protein supplementation during an energy-restricted diet induces visceral fat loss and gut microbiota amino acid metabolism activation: a randomized trial. Sci Rep. 2021;11(1):15620. https://doi.org/10.1038/s41598-021-94916-9.
40. Botta A, Cavallone P, Carbonari L, et al. Rehabilitation machine for bariatric individuals Machines. 2020;8(3):45. https://doi.org/10.3390/machines8030045.

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Authors and Affiliations

Johanna Pino-Zuñiga[1] · Paloma Lillo-Urzua[2] · Mariela Olivares-Galvez[1] · Ana Palacio-Aguero[1,3] · Juan Camilo Duque[1] · Rafael Luengas[1] · Jorge Cancino-Lopez[4,5]

✉ Paloma Lillo-Urzua
plillou@ucsh.cl

✉ Jorge Cancino-Lopez
jcancino@uft.cl

Johanna Pino-Zuñiga
johannakine@gmail.com

Mariela Olivares-Galvez
malevox@gmail.com

Ana Palacio-Aguero
anapalacio@udd.c

Juan Camilo Duque
drcamiloduques@gmail.com

Rafael Luengas
contacto@obesidadydigestiva.cl

1 Bariatric Center BIO, Santiago, Chile

2 School of Kinesiology, Faculty of Health Science, Católica Silva Henríquez, University, Santiago, Chile

3 University of Desarrollo, Faculty of Health Science, Santiago, Chile

4 Exercise Physiology and Metabolism Laboratory, School of Kinesiology, Faculty of Medicine, Finis Terrae University, Santiago, Chile

5 NFT Center, Santiago, Chile