Original Article

A Dark Side of Bariatric Surgery: The Influence of Surgery on Osteopenia and Sarcopenia

O Lado Negro da Cirurgia Bariátrica: A Influência da Cirurgia na Osteopenia e na Sarcopenia

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ABSTRACT

Introduction: Bariatric and metabolic surgery is effective for weight reduction but may induce substantial declines in skeletal muscle and bone mineral content, increasing the risk for sarcopenia and osteopenia.

We aimed to study longitudinal changes in anthropometry, body composition, muscle strength, and bone mineral parameters after MBS, and to identify eventual predictors of postoperative sarcopenia and osteopenia, 18 months after surgery.

Methods: Adults undergoing BMS were evaluated at baseline and 1, 6, 12, and 18 months. Dual-energy X-ray absorptiometry (DEXA) measured fat mass, lean mass, appendicular skeletal muscle mass (ASMM), bone mineral content (BMC), and bone mineral density (BMD). Handgrip strength and biochemical markers (PTH, vitamin D, leptin, ghrelin, NRI) were also evaluated. Regression models identified predictors of sarcopenia and osteopenia.

Results: Body weight decreased from 112.4 ± 17.5 kg to 72.5 ± 10.9 kg at 18 months ($p < 0.001$). Significant reductions occurred in lean mass (56.5 ± 10.1 → 37.5 ± 7.9 kg; $p < 0.001$) and ASMM (23.9 ± 4.7 → 15.4 ± 4.3 kg; $p < 0.001$). Handgrip strength partially

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recovered after an early decline but did not return to baseline. BMC decreased steadily (2459 ± 426 → 2022 ± 365 g; $p < 0.001$), with declines in T-score (0.47 → –0.30; $p = 0.012$). Muscle-related indices (ASMM, ASMMI, ASMM/BMI) were the strongest predictors of both sarcopenia and osteopenia (r^2 up to 0.562; $p < 0.001$). Vitamin D, PTH, leptin, and ghrelin were not significant predictors.

Conclusion: MBS may lead to substantial muscle and bone mineral losses, with ASMM-based indices emerging as key predictors of postoperative sarcopenia and osteopenia. Early interventions, targeting muscle preservation, are essential in postoperative management.

Keywords: Bariatric Surgery; Bone Diseases, Metabolic; Postoperative Complications; Sarcopenia

RESUMO

Introdução: A cirurgia bariátrica e metabólica é eficaz para a redução de peso, mas pode induzir diminuições substanciais na massa muscular esquelética e no conteúdo mineral ósseo, aumentando o risco de sarcopenia e osteopenia.

O nosso objetivo foi estudar as alterações longitudinais na antropometria, composição corporal, força muscular e parâmetros de mineralização óssea após cirurgia bariátrica, e identificar possíveis preditores de sarcopenia e osteopenia pós-operatórias, 18 meses após a cirurgia.

Métodos: Adultos submetidos à cirurgia bariátrica foram avaliados no início do estudo e aos 1, 6, 12 e 18 meses. A absorciometria de raios X de dupla energia (DEXA) mensurou a massa gorda, a massa magra, a massa muscular esquelética apendicular (MMEA), o conteúdo mineral ósseo (CMO) e a densidade mineral óssea (DMO). A força de preensão manual e marcadores bioquímicos (PTH, vitamina D, leptina, grelina, NRI) também foram avaliados. Modelos de regressão identificaram preditores de sarcopenia e osteopenia.

Resultados: O peso corporal diminuiu de 112,4 ± 17,5 kg para 72,5 ± 10,9 kg aos 18 meses ($p < 0{,}001$). Reduções significativas ocorreram na massa magra (56,5 ± 10,1 → 37,5 ± 7,9 kg; $p < 0{,}001$) e na massa muscular apendicular (23,9 ± 4,7 → 15,4 ± 4,3 kg; $p < 0{,}001$). A força de preensão manual recuperou-se parcialmente após o declínio inicial, mas não retornou ao nível basal.

A densidade mineral óssea (DMO) diminuiu progressivamente (2459 ± 426 → 2022 ± 365 g; $p < 0{,}001$), com declínio no escore T (0,47 → –0,30; $p = 0{,}012$). Os índices relacionados à massa muscular (ASMM, ASMMI, ASMM/IMC) foram os preditores mais fortes tanto de sarcopenia quanto de osteopenia (r^2 até 0,562; $p < 0{,}001$). Vitamina D, PTH, leptina e grelina não foram preditores significativos.

Conclusão: A cirurgia bariátrica pode levar a perdas substanciais de massa muscular e óssea, com índices baseados na massa muscular esquelética apendicular (ASMM) emergindo como importantes preditores de sarcopenia e osteopenia pós-operatórias. Intervenções precoces, visando a preservação muscular, são essenciais no manejo pós-operatório.

Palavas-chave: Cirurgia Bariátrica; Complicações Pós-Operatórias; Doenças Ósseas Metabólicas; Sarcopenia

INTRODUCTION

Obesity is a major global health challenge, with its prevalence continuing to rise across diverse populations and age groups. Characterized by excessive adiposity and associated metabolic dysfunction, obesity contributes to increased morbidity, reduced quality of life, and heightened risk for chronic conditions such as type 2 diabetes, cardiovascular disease, and musculoskeletal impairment.[1,2] Recent concepts about obesity, suggest that clinical obesity is a condition that warrants treatment.[3]

Bariatric and metabolic surgery (MBS) has emerged as the most effective long-term treatment for severe obesity, demonstrating substantial and sustained weight reduction as well as improvements in metabolic comorbidities.[4] Despite these benefits, the rapid weight loss and physiological changes following bariatric procedures may have unintended consequences for musculoskeletal health, resulting in significant alterations in body composition, including substantial decreases in lean mass and bone mineral density.[5] These changes may contribute to postoperative sarcopenia and osteopenia, conditions increasingly recognized as important determinants of morbidity and quality of life following bariatric procedures.[6]

Sarcopenia is defined as the loss of skeletal muscle mass and function, and osteopenia is characterized by reduced bone mineral density.[7] Both conditions can undermine physical function, increase bone fracture risk, and may compromise the beneficial overall health outcomes expected from bariatric surgery. Postoperative changes in nutrient ingestion and absorption, in hormonal regulation, and in mechanical loading all contribute to changes in muscle and bone metabolism, making individuals who undergo bariatric surgery particularly vulnerable to these problems.[8] Increasing evidence suggests that the interplay between obesity-related metabolic disturbances and the catabolic environment induced by surgical weight loss may exacerbate musculoskeletal decline.[9]

Loss of lean mass compromises functional capacity, metabolic health, and physical independence, while bone loss increases fracture risk.[10] The mechanisms driving these changes may include reduced mechanical loading, altered nutrient absorption, hormonal shifts, and changes in energy expenditure. However, determinants of postoperative muscle and bone decline remain incompletely understood, are not easily predicted and difficult to manage.

Given the growing use of bariatric surgery and the clinical importance of preserving muscle and bone integrity, understanding the mechanisms, prevalence, and determinants of sarcopenia and osteopenia in this population is essential. Further research is needed to characterize these conditions during the postoperative period and to identify strategies that may help mitigate musculoskeletal deterioration while maintaining the metabolic benefits of surgical weight loss.

This study evaluates longitudinal changes in body composition and bone health after MBS, and identifies predictors of sarcopenia and osteopenia, with a particular focus on the role of skeletal muscle indices.

METHODS

1. STUDY DESIGN AND POPULATION

This longitudinal observational study included adults undergoing MBS. The invitation to participate was made in the context of the preoperative evaluation, and participants who agreed to participate in the study were given the free and informed consent form previously approved by the Hospital Ethics Committee (Hospital Espírito Santo de Évora_Comissaão de Ética – HESE_CE_1917/21). This research included only Roux-en-Y gastric bypass (RYGB) patients and was developed following the Declaration of Helsinki. All experiments were performed following relevant guidelines and regulations. Informed consent was obtained from all subjects.

The sociodemographic characteristics, perioperative, blood tests and body composition were assessed. The data was retrieved from the hospital›s database. DEXA and handgrip test were evaluated in the Exercise and Health Laboratory of the School of Health and Human Development of the University of Évora.

Participants were assessed at baseline and at 1, 6, 12, and 18 months postoperatively.

2. ANTHROPOMETRY

Body weight (in kilograms), height (in centimeters), BMI, and waist circumference were measured following standard clinical protocols.

3. BODY COMPOSITION AND BONE PARAMETERS

The participants' body composition was evaluated using Dual-energy X-ray Absorptiometry (DEXA or DXA) with the Hologic QDR system from Hologic, Inc., located in Bedford, Massachusetts, USA.

DEXA assessed fat mass, body fat percentage, lean mass, appendicular skeletal muscle mass (ASMM), ASMM indices (ASMMI, ASMM/BMI, ASMM/weight). DEXA also measured bone mineral content (BMC), bone mineral density (BMD), total body T-score and Z-score.

Furthermore, the study calculated the total weight loss percentage (%TWL) by comparing the initial and sequential weights of the participants.

4. MUSCLE STRENGTH

To assess upper limb strength, a handgrip test was performed using a standardized dynamometer protocol, using manual pressure dynamometry. Participants stood with their elbows fully relaxed and straight. Each hand was tested twice, and the highest grip strength measurement was recorded as the muscle strength value.

5. BIOCHEMICAL AND NUTRITIONAL MARKERS

Perioperative blood tests were conducted to analyze markers associated with obesity and bone health. Serum analyses included parathyroid hormone (PTHi), total vitamin D, leptin, ghrelin, and parameters to calculate the nutritional risk index (NRI). These tests were performed both prior to surgery and following the surgical treatment. The initial sample was collected during the week of surgical preparation, and the subsequent samples were obtained after MBS.

6. STATISTICAL ANALYSIS

Outcomes were determined by statistical analysis using the computer software JAMOVI version 2.3.19. In descriptive statistics, mean ± standard deviation (SD) was used for parametric data. Data normality was checked using the Shapiro-Wilk test, and paired comparisons evaluated changes at each time point. Linear regression identified predictors of sarcopenia (muscle mass, strength) and osteopenia (T-score, BMC). Statistical significance was set at $p < 0.05$.

RESULTS

A total of 36 adults (mean age 46.9 ± 11.4 years; 77.8% female) were evaluated across five timepoints over 18 months following RYGB (Table 1).

Body weight decreased significantly from 112.4 ± 17.5 kg at baseline to 97.8 ± 15.7 kg at 1 month ($p < 0.001$) and continued to decline through 12 months (72.6 ± 10.8 kg; $p < 0.001$), stabilizing thereafter ($p = 0.930$). BMI fell from 42.9 ± 5.2 to 27.8 ± 4.9 kg/m^2 at 18 months ($p < 0.001$). Waist circumference decreased progressively from 123 ± 12 to 90.6 ± 10.1 cm ($p < 0.001$).

Fat mass declined substantially from 50.5 ± 13.1 to 26.7 ± 10.6 kg, with all reductions up to 12 months reaching significance ($p \leq 0.024$). Lean mass decreased from 56.5 ± 10.1 to 37.5 ± 7.9 kg ($p < 0.001$ for all timepoints). Appendicular skeletal muscle mass (ASMM) and ASMMI showed pronounced reductions (ASMM: 23.9 ± 4.7 to 15.4 ± 4.3 kg; ASMMI: 8.9 ± 1.57 to 5.8 ± 1.45 kg/m^2; all $p < 0.001$). Early postoperative improvements in relative indices (ASMM/weight; ASMM/BMI) were observed at 1–6 months, but both declined again by 18 months ($p < 0.001$).

Handgrip strength decreased sharply at 1 month ($p < 0.001$) and did not return to baseline levels, plateauing at 22.6 ± 8.13 kg at 18 months ($p = 0.940$ *vs* 12 months).

Leptin levels decreased markedly from 52.8 ± 29 to 21.5 ± 22.3 ng/mL at 12 months ($p = 0.003$), paralleling fat loss. Ghrelin increased postoperatively but without statistical significance. PTHi declined non-significantly, while vitamin D rose modestly. The Nutritional Risk Index dropped significantly from 133 ± 8.31 to 109 ± 7.51 by 12 months ($p \leq 0.024$), indicating postoperative nutritional vulnerability.

Total body bone mineral content (BMC) decreased steadily from 2459 ± 426 to 2022 ± 365 g by 18 months, with significant reductions at all evaluations ($p \leq 0.023$). Bone mineral density (BMD) demonstrated modest, non-significant declines. Nonetheless, total body T-score and Z-score decreased significantly beginning at 6 months (T-score: 0.47 ± 1.4 to −0.3 ± 1.17; $p \leq 0.012$), indicating a transition toward osteopenic ranges despite limited changes in BMD values (Fig. 1).

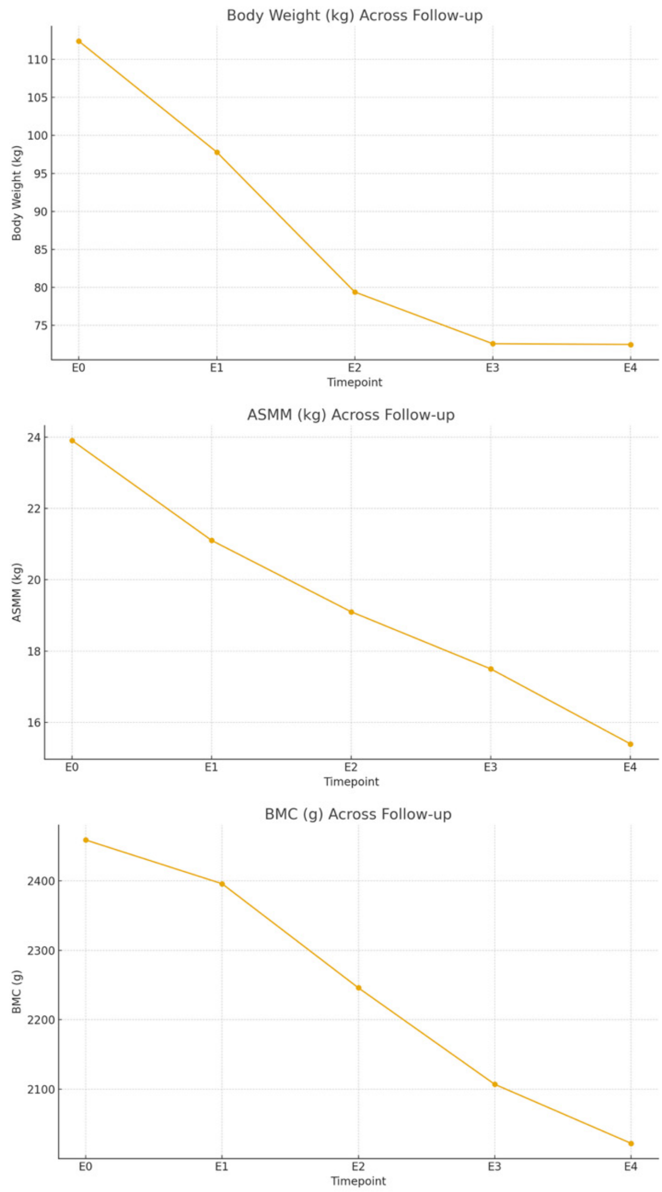

Figure 1 – Parameters evolution during RYGB procedure

Sex was a strong predictor of muscle mass and strength ($r^2 = 0.504$ and 0.398; both $p < 0.001$). ASMM, ASMMI, ASMM/BMI, and handgrip strength were consistently associated with sarcopenia-related outcomes (all $p \leq 0.002$). For bone outcomes, age was a significant predictor of T-score ($r^2 = 0.265$; $p < 0.001$). Handgrip strength was the most robust functional predictor of BMC ($r^2 = 0.704$; $p < 0.001$) (Table 2).

Table 1 – Criteria and variables evolution during metabolic and bariatric surgery process (**N=**36; **Mean age:** 46.9 ± 11.4; **Female:** 77,8%)

Variables (Mean ± SE)	Before Surgery	After Surgery							
	Baseline—E0	1 Month—E1		6 Month—E2		12 Month—E3		18 Month—E4	
			p-value		*p-value*		*p-value*		*p-value*
Body weight (kg)	112.4 ± 17.5	97.8 ± 15.7	**<0.001**	79.4 ± 13.3	**<0.001***	72.6± 10.8	**<0.001***	72.5 ± 10.9	0.930*
Total weight loss (%)	NA	13.1 ± 3.3	NA	29.3 ± 5.3	**<0.001**	35.0 ± 7.3	**<0.001#**	34.9 ± 9.1	0.823*
BMI (kg/m²)	42.9 ± 5.2	37.4 ± 4.53	**<0.001***	30.2 ± 4.17	**<0.001***	27.8 ± 4.34	**<0.001***	27.8 ± 4.93	0.967*
Waist circumference (cm)	123 ± 12	110.9 ± 11.4	**<0.001***	97.2 ± 10.8	**<0.001***	92.2 ± 12.2	**<0.001***	90.6 ± 10.1	0.058*
Fat mass (kg)	50.5 ± 13.1	44.36 ± 10.9	**0.003**	32.2 ± 12.2	**<0.001***	29.5± 9.4	**0.024***	26.7 ± 10.6	0.065*
Body fat (%)	46.8 ± 4.9	44.8 ± 4.9	**<0.001**	38.8 ± 9.5	**<0.001***	34.5 ± 5.1	**<0.001***	33.5 ± 4.6	0.419*
Lean mass (kg)	56.5 ± 10.1	50.2 ± 9.3	**<0.001**	45.9 ± 9.2	**<0.001***	42.6 ± 8.1	**<0.001***	37.5 ± 7.9	**<0.001***
ASMM (kg)	23.9 ± 4.7	21.1 ± 4.5	**<0.001**	19.1 ± 4.11	**<0.001***	17.5 ± 4.32	**<0.001***	15.40 ± 4.32	**<0.001***
ASMMI (kg/m²)	8.9 ± 1.57	7.9 ± 1.48	**<0.001**	7.2 ± 1.22	**<0.001***	6.6 ± 1.28	**<0.001***	5.8 ± 1.45	**<0.001***
ASMM/weight (kg/kg)	20.6 ± 2.36	21.4 ± 3.18	**0.004**	24.1 ± 3.13	**<0.001***	23.1 ± 4.12	0.886*	21.5 ± 4.65	**<0.001**
ASMM/BMI	0.55 ± 0.10	0.57 ± 0.12	**0.003**	0.64 ± 0.11	**<0.001***	0.64 ± 0.19	0.831*	0.57 ± 0.14	**<0.001**
Handgrip (kg)	24.4 ± 9.44	20.4 ± 9.04	**<0.001**	21.1 ± 8.11	0.436*	22.6 ± 7.92	0.051*	22.6 ± 8.13	0.940
BMC (g)	2459 ± 426	2396 ± 412	**0.023**	2246 ± 406	**<0.001***	2107 ± 381	**<0.001***	2022 ± 365	**<0.001***
BMD (g/cm²)	1.16 ± 0.10	1.13 ± 0.12	**0.045**	1.12 ± 0.11	0.113*	1.11 ± 0.19	0.315	1.08 ± 0.14	0.248*
Total Body T-score	0.47 ± 1.4	0.52 ± 1.25	0.371	0.26 ± 1.12	**<0.001**	0.01 ± 1.11	**0.002***	-0.3 ± 1.17	**0.012***
Total Body Z-score	0.46 ± 1.1	0.57 ± 1.1	0.154	0.30 ± 0.8	**0.002**	0.08 ± 0.8	**<0.001***	-0.12 ± 0.9	**0.005***
PTHi	99.6 ± 45.4	-------	-------	82.1 ± 29.6	0.128	70.6 ± 28.1	0.135*	79.8 ± 36.9	0.442
Vitamina DTotal	24.9 ± 9.49	-------	-------	25 ± 8.45	0.961	27.2 ± 8.75	0.534	30.6 ± 8.94	0.095
Leptin (ng/mL)	52.8 ± 29	-------	-------	30.7 ± 35.6	**0.003**	21.5 ± 22.3	0.620*	-------	-------
Ghrelin (pg/mL)	1391 ± 2048	-------	-------	2187 ± 1937	0.096	4194 ± 3873	0.095	-------	-------
Nutritional risk index (NRI)	133 ± 8.31	-------	-------	111 ± 7.97	**<0.001**	109 ± 7.51	**0.024***	109 ± 7.85	0.723*

Notes: BMI: body mass index; BMC: body mineral content; BMD: body mineral density; PTHi: parathyroid hormone; * significantly different relative to first evaluation.

Table 2 – Predictors of sarcopenia and osteopenia after bariatric and metabolic surgery

Variables	Sarcopenia								Osteopenia							
	Muscle Mass				*Strength*				*T-score*				*BMC*			
	r^2	*p-value*	*F*	*t*	r^2	*p-value*	*F*	*t*	r^2	*p-value*	*F*	*t*	r^2	*p-value*	*F*	*t*
Sex	0.504	**<0.001**	34.5	7.37	0.398	**<0.001**	22.5	2.34	0.101	0.058	3.84	-2.37	0.355	**<0.001**	18.7	9.04
Age	0.012	**0.520**	0.423	7.25	0.086	0.082	3.21	5.75	0.265	**<0.001**	12.3	2.99	0.085	0.084	3.17	9.70
Body weight (kg)	0.371	**0.005**	4.60	0.586	0.415	**0.002**	5.50	-1.09	0.371	**0.012**	3.54	-1.98	0.413	**0.002**	5.45	1.651
Total weight loss (%)	0.066	0.700	0.550	3.660	0.128	0.355	1.14	1.460	0.286	**0.029**	3.10	-2.798	0.054	0.776	0.443	4.021
BMI (kg/m²)	0.058	0.753	0.476	2.579	0.136	0.322	1.22	1.75	0.294	**0.025**	3.22	0.459	0.061	0.734	0.503	3.280
Waist circumference (cm)	0.291	**0.027**	3.19	0.085	0.145	0.287	1.31	-0.31	0.118	0.406	1.03	-0.627	0.135	0.328	1.21	1.18
Fat mass (kg)	0.212	0.108	2.08	7.647	0.326	**0.013**	3.74	4.987	0.107	0.460	0.929	0.454	0.300	**0.023**	3.31	9.011
Body fat (%)	0.288	0.028	3.13	6.158	0.177	0.182	1.67	3.991	0.183	0.167	1.74	2.063	0.174	0.191	1.63	5.972
Lean mass (kg)	-------	--------	-------	-------	0.521	**<0.001**	8.41	-1.57	0.350	**0.008**	4.16	-3.629	0.518	**<0.001**	8.34	1.829
ASMM (kg)	0.553	**<0.001**	9.60	3.371	0.562	**<0.001**	9.93	-0.64	0.237	0.071	2.41	-2.927	0.533	**<0.001**	8.83	3.910
ASMMI (kg/m²)	0.409	**0.002**	5.35	2.032	0.409	**0.002**	5.35	-0.67	0.121	0.392	1.06	-1.557	0.350	**0.008**	4.18	2.384
ASMM/weight (kg/kg)	0.335	**0.011**	3.90	1.185	0.430	**0.001**	5.86	0.090	0.160	0.235	1.47	-1.232	0.313	**0.018**	3.53	2.40
ASMM/BMI	0.406	**0.002**	5.31	3.332	0.539	**<0.001**	9,06	0.824	0.217	0.098	2.15	-2.12	0.436	**0.001**	6.00	4.766
Handgrip (kg)	0.530	**<0.001**	8.73	8.740	-------	--------	------	------	0.235	0.073	2.38	-3.26	0.704	**<0.001**	18.4	10.302
BMC (g)	0.453	**<0.001**	6.41	0.983	0.633	**<0.001**	13.3	-2.598	0.391	**0.003**	4.98	-4.657	-------	--------	-------	------
BMD (g/cm²)	0.322	**0.014**	6.69	-0.39	0.180	0.174	1.70	-0.443	0.450	**<0.001**	6.33	-4.646	0.290	**0.027**	3.17	0.261
Total Body T-score	0.193	0.143	1.86	19.08	0.321	**0.015**	3.66	12.85	-------	--------	------	-----	0.411	**0.002**	5.42	27.164
Total Body Z-score	0.131	0.346	1.16	19.05	0.153	0.259	1.39	11.14	0.756	**<0.001**	24.1	-2.284	0.367	**0.006**	4.50	26.887
PTHi	0.202	0.611	0.695	4.634	0.340	0.292	1.42	2.388	0.209	0.592	0.73	-0.276	0.378	0.765	0.143	4.724
Vitamin D Total	0.272	0.351	1.22	4.357	0.085	0.871	0.302	3.321	0.087	0.867	0.31	-0.817	0.087	0.867	0.31	-0.817
Leptin (ng/mL)	0.157	0.599	0.560	8.971	0.047	0.865	0.15	5.711	0.345	0.280	1.58	-1.698	0.098	0.733	0.098	8.851
Ghrelin (pg/mL)	0.019	0.953	0.049	5.635	0.096	0.776	0.26	3.819	0.277	0.444	0.96	-1.732	0.069	0.835	0.187	6.37
Nutritional risk index	0.105	0.307	1.25	0.078	0.036	0.753	0.41	0.264	0.041	0.715	0.46	0.416	0.062	0.556	0.706	0.65

DISCUSSION

In this prospective study of adults undergoing metabolic and bariatric surgery, we observed profound and progressive changes in body composition, muscle function, and bone health over the 18-month follow-up.

The loss of muscle mass and bone mass after bariatric surgery may result from a combination of physiological and biomechanical mechanisms.

One of the central factors appears to be the drastic reduction in body weight, which decreases the mechanical stimulus applied to muscles and bones during mobility. Both muscle tissue and bone tissue are highly sensitive to mechanical loading. Thus, following rapid weight loss, the body may no longer require the same level of muscle strength or bone mineral density to support mobility and previous body weight, progressively leading to muscle atrophy and a reduction in bone mass: mechanical unloading [11]. In addition to reduced mechanical unloading, several other mechanisms may contribute to postoperative losses in muscle and bone mass.

Following surgery, both the intake and absorption of key nutrients necessary for the preservation of lean mass and bone mass are reduced. These may include proteins, calcium, vitamin D, iron, magnesium, and B-complex vitamins. Protein deficiency, in particular, predisposes individuals to muscle loss, whereas impaired absorption of calcium and vitamin D promotes increased bone resorption.[12]

Bariatric surgery also induces substantial modifications in hormonal profiles, including: decreased leptin levels, alterations in ghrelin secretion, increases in GLP-1 and PYY, and, in some cases, reductions in sex hormones. These hormonal shifts influence energy metabolism, appetite regulation, muscle strength, protein synthesis, and bone turnover.[11]

Rapid weight loss and alterations in intestinal absorption may lead to elevated PTH secretion (secondary hyperparathyroidism), enhanced osteoclastic activity, and reduced bone formation. Collectively, these changes accelerate bone turnover, often resulting in a measurable decline in bone mineral density. Finally, reduced physical activity levels due to fatigue, loss of strength, fear of exercise, or prolonged postoperative restrictions may diminish the anabolic stimulus required to maintain muscle and bone tissue.[13]

In our study, as expected, weight loss was rapid and substantial during the first postoperative year, stabilizing thereafter.[5] However, reductions in lean mass and appendicular skeletal muscle mass (ASMM) were proportionally greater, in the later phases, than fat mass losses, underscoring the high vulnerability of skeletal muscle to postoperative catabolic processes.[14] These findings reinforce growing evidence that bariatric surgery, while highly effective for adiposity reduction, carries a significant risk for sarcopenia and musculoskeletal deterioration when not accompanied by preventive and rehabilitative strategies.[15]

Lean mass declined continuously from baseline to 18 months, with ASMM and ASMMI showing reductions exceeding 30%, consistent with previous reports describing accelerated muscle catabolism following surgery.[16] Importantly, handgrip strength, an essential functional marker,[17] dropped sharply during the first postoperative month and failed to recover to baseline values despite partial improvements at later timepoints. This dissociation between weight loss and incomplete functional recovery suggests that the postoperative decline in muscular performance is not solely attributable to reduced body mass, but likely reflects deeper impairments in neuromuscular function, hormonal milieu, nutritional adequacy, and early inactivity,[18–20] that are more clinically relevant than simple mechanical unloading.

The temporary improvement in relative indices such as ASMM/weight and ASMM/BMI at 1–6 months likely reflects disproportionate fat loss relative to muscle loss during the rapid weight loss phase. However, the subsequent decline of these indices at 12–18 months indicates a later shift in the trajectory, where muscle loss becomes more clinically relevant. This pattern suggests a "two-phase" phenomenon: an early dilution effect due to rapid fat loss, followed by a late, true sarcopenic process.[21]

Bone mineral content (BMC) decreased steadily across all postoperative evaluations, representing a clinically meaningful decline in skeletal mass. Although bone mineral density (BMD) showed only modest reductions and remained statistically unchanged at several timepoints, both T-score and Z-score shifted into lower ranges beginning at 6 months. This divergence between BMC and BMD is consistent with known limitations of areal DEXA in the context of rapid weight loss, where changes in soft tissue composition may confound BMD interpretation.[22]

Nevertheless, the significant reductions in T- and Z-scores show that the skeletal system is adversely affected, even in patients who maintain apparently "normal" BMD values. Reduced mechanical loading due to weight loss, nutritional deficiencies, reduced estrogen aromatization, decreased leptin concentrations, and possible alterations in gut–bone hormone axes likely contribute to postoperative osteopenia. Our findings align with previous studies reporting increased fracture risk and progressive bone turnover acceleration in the years following surgery.[23]

Leptin concentrations decreased sharply, reflecting the substantial reduction in fat mass. Given leptin's known anabolic effects on muscle and bone, its postoperative decline may contribute to the concurrent sarcopenic and osteopenic trajectories observed. While vitamin D levels rose modestly, they remained insufficient to counterbalance declines in BMC and bone scores. The sustained reduction in the Nutritional Risk Index during the first year further underscores the importance of early and aggressive nutritional monitoring, as postoperative protein inadequacy and micronutrient deficiencies are well-established catalysts of sarcopenia and bone loss.[24,25]

Sex emerged as a strong predictor of muscle mass and strength, consistent with biological differences in baseline muscle reserves and hormonal environment. ASMM, ASMMI, and ASMM/BMI were among the strongest predictors of both muscle weakness and bone outcomes, reinforcing the interdependence between skeletal muscle and bone health.[26] Notably, handgrip strength was the strongest functional predictor of BMC, supporting the concept of the muscle–bone unit and emphasizing that functional assessments can offer valuable early markers of bone deterioration.[27]

Age was a significant predictor of T-score, in line with established osteoporosis risk patterns, but had a limited association with muscle indices, suggesting that postoperative sarcopenia may be more strongly driven by surgery-induced metabolic changes than age-related decline alone. The associations between fat mass, visceral adiposity (waist circumference), and musculoskeletal outcomes further support the complex interplay between adiposity, inflammation, and musculoskeletal metabolism in the post-bariatric state.[28]

Endocrine markers did not predict postoperative bone or muscle changes, suggesting that mechanical and structural factors dominate postoperative tissue remodeling. These findings support early implementation of resistance training and optimized nutrition to mitigate tissue loss.[29]

These findings highlight the need for early, structured interventions to preserve muscle and bone health following bariatric surgery. While current follow-up protocols emphasize nutritional supplementation, our data underscore the importance of incorporating systematic assessments of muscle function and bone integrity, including handgrip strength, ASMM indices, and periodic DXA measurements. Resistance and combined training and optimized protein intake should be prioritized from the early postoperative period to mitigate the steep decline in lean mass.[29] Furthermore, bone health monitoring should extend beyond BMD alone, incorporating BMC, T-score trends, and clinical risk factors.

1. INTERPRETATION IN CONTEXT OF EXISTING LITERATURE

Our results align with emerging evidence that bariatric-induced weight loss produces a multidimensional musculoskeletal phenotype characterized by sarcopenia, reduced strength, and deteriorating bone quality. The progressive decline in ASMM and BMC in our cohort mirrors findings from long-term cohorts demonstrating increased fracture incidence and reduced muscle contractile function years after surgery. Importantly, the observed decline in muscle strength disproportionate to lean mass loss echoes reports suggesting that neuromuscular adaptations lag behind tissue-level changes, possibly due to hormonal dysregulation, micronutrient deficits, and reduced anabolic signaling pathways.

2. OVERALL INTERPRETATION

Taken together, our data suggest that metabolic and bariatric surgery produces significant improvements in adiposity but simultaneously accelerates losses in muscle and bone tissue, with functional consequences that emerge early and persist throughout follow-up. The coexistence of sarcopenic and osteopenic signatures reinforces the concept of an "osteosarcopenic phenotype" in post-bariatric patients. Early identification and targeted therapeutic strategies are essential to minimize long-term musculoskeletal complications and to ensure that the metabolic benefits of surgery are not undermined by declines in functional capacity and skeletal integrity.

CONCLUSION

Bariatric and metabolic surgery produced significant losses in skeletal muscle mass, muscle strength, and bone mineral content. These losses appear to be more clinically relevant than simple mechanical unloading. ASMM-based indices were the strongest predictors of both sarcopenia and osteopenia, while endocrine biomarkers showed no predictive value. These results underscore the need for targeted postoperative strategies focused on muscle preservation and bone health.

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Conflicts of Interest: The authors have no conflicts of interest to declare.

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Confidentiality of Data: The authors declare that they have followed the protocols of their work center on the publication of patient data.

Protection of Human and Animal Subjects: The authors declare that the procedures followed were in accordance with the regulations of the relevant clinical research ethics committee and those of the Code of Ethics of the World Medical Association (Declaration of Helsinki as revised in 2024).

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MC: Conceptualization, final writing, data analysis.

MS, MIP: Original writing.

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CM: Conceptualization, original and final writing, data analysis

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DECLARAÇÃO DE CONTRIBUIÇÃO

MC: Conceitualização, redação final, análise de dados.

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