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Impact of Bariatric Surgery on Sarcopenia Related Parameters and Diagnosis—The Preliminary Results of EXPOBAR Study

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Abstract Introduction: Obesity affects over 650 million individuals worldwide and it is a major public health problem. Bariatric surgery is the most effective treatment for severe obesity, resulting in significant weight reduction and improvement in obesity-related conditions. However, the weight loss achieved through bariatric surgery often correlates with a notable decrease in skeletal muscle. This correlation suggests an elevated risk of sarcopenia among patients after surgery. The aim of this study was to evaluate the effects of obesity and bariatric surgery on sarcopenia-related indicators and diagnosis before and after surgery. Methods: A total of 17 bariatric surgery patients were included in this prospective study. The parameters to diagnose sarcopenia were determined for each participant, based on EWGSOP2 and EASO/ESPEN consensuses. All evaluations were performed on the five moments of this study: before surgery and at 1, 6, 12 and 18 months after surgery. Results: In this study, 88.2% of the subjects were female, the mean BMI was 42.9 kg/m² and the mean weight was 105.9 kg. After surgery, the mean weight consistently decreased, with all differences from baseline being statistically significant ($p<0.001$). When using the SARC-F questionnaire for screening, the risk of sarcopenia increased post-surgery, and decreased at 12 months, declining to zero at 18 months. Muscle strength decreased significantly ($p=0.002$) at the 1 month after surgery assessment, with slight variations thereafter, none statistically significant. Muscle mass was normal before surgery but decreased significantly post-surgery ($p<0.001$). When applying the ESPEN/EASO consensus cut-off criteria for sarcopenic obesity, 35.3% of the patients met the criteria preoperatively. After surgery, the results increased to 70.6% in the first month but decreased afterward to 41.2% at 6 months. Discussion: This study evaluated the impact of bariatric surgery on sarcopenia and sarcopenic obesity, for a duration of up to 18 months after surgery, using the EWGSOP2 and ESPEN/EASO consensuses criteria. Bariatric surgery, the most effective treatment for severe obesity, often results in muscle mass loss alongside fat loss. Handgrip strength, a key sarcopenia indicator, showed a significant early post-surgery decline, whereas the weight-dependent sit-to-stand test did not. This suggests weight loss impacts different muscle function tests variably. Muscle mass decreased continuously after surgery. However, other indicators had mixed results. Applying ESPEN/EASO guidelines, the study found a temporary post-surgery increase in sarcopenic obesity, peaking at one month and returning to pre-surgery levels by six months. However, different criteria led to different results. Conclusion: The results indicate a clear deleterious impact of bariatric surgery on muscle strength and mass, the most important indicators of sarcopenia. Also, the impact seems to occur very early after surgery, indicating that the

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appropriate timeframe to try to prevent this effect may be the prehabilitation period followed by the post-surgery timeframe.

Keywords: bariatric surgery; fat-free mass; sarcopenia; sarcopenic obesity; skeletal muscle mass; muscle mass

1. Introduction

Obesity is a multifactorial disease and a significant public health issue as it is closely linked to higher mortality rates and numerous comorbidities (1,2). Bariatric surgery has emerged as the most treatment for severe obesity and is known for its ability to reduce weight and associated diseases (3). Surgical management has the highest evidence-based approach to achieve sustained weight loss and improve associated medical conditions. However, it is important to note that bariatric surgery-induced weight loss can also lead to a significant decrease in skeletal muscle mass, eventually increasing the risk of sarcopenia (4).

Sarcopenia is a clinical condition characterized by a significant loss of muscle mass and strength, that is generally studied in elderly patients (5,6). However, it also appears to be present in patients with obesity, conditioned not by age but by metabolic, physical and lifestyle changes (7). Muscle tissue plays a critical role in overall health, and its loss is linked to various adverse outcomes. Recognizing the importance of sarcopenia, several international study groups have recently published consensuses on its definition and diagnosis (8).

As suggested in the European Working Group on Sarcopenia in Older People (EWGSOP2), sarcopenia is a muscle disease that may occur at any age. Sarcopenia is common in older age but may also occur earlier in life (9). The group identified the need to update its initial definition and the new EWGSOP-2 consensus focuses on low muscle strength as a key for diagnosing sarcopenia, as well as muscle quantity and quality to confirm the diagnosis (6). The EWGSOP-2 introduces a novel algorithm for identifying sarcopenia. Unlike the traditional method, which relies on a diminished skeletal muscle mass (SMM) alongside a decreased walking speed or muscle strength decline, this algorithm adopts the Find-Assess-Confirm-Severity (F-A-C-S) approach. Muscle strength is evaluated after screening yields positive results or clinical suspicion arises. If muscle weakness is detected, sarcopenia is suspected and muscle mass is addressed. SMM, appendicular skeletal muscle mass (ASMM), and index (ASMMI) are assessed, and any observed decrease confirms the presence of sarcopenia. Furthermore, severe sarcopenia is identified by a decline in physical performance, such as gait speed (6,10,11).

In this context, sarcopenia may have a complex relationship with obesity. Despite the importance of understanding the consequences of substantial weight loss after bariatric surgery and the development of sarcopenia, there is limited documentation and research on this topic. Existing studies also present varying results, emphasizing the need for further investigation.

To answer these limitations, the European Association for the Study of Obesity (EASO) and the European Society for Clinical Nutrition and Metabolism (ESPEN) developed a consensus for evaluating sarcopenia in obese patients (6). This document is similar to the EWGSOP2 but introduces also obesity diagnosis tools, like weight, BMI and waist circumference.

Sarcopenic obesity is a complex clinical condition that presents a unique challenge due to the combination of obesity and sarcopenia. As a result, individuals with sarcopenic obesity face a higher risk for metabolic diseases, functional impairment, and other adverse clinical outcomes compared to those with either condition alone (7,12). However, if eating disorders and excess fat mass can have negative consequences on muscle mass and its function, on the other hand, patients who with obesity may have needed to developed previously more muscle mass to be able to carry out their activities of daily living, such as simply walking (13), further confounding the interpretation of the post-surgical data.

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Moreover, screening and diagnostic procedures for sarcopenic obesity need to be practical, affordable, and time-efficient, with a focus on assessing altered skeletal muscle functional parameters and body composition. Staging of sarcopenic obesity based on the presence of complications related to altered body composition and muscle function may be essential for guiding treatment and follow-up (7,8,14).

Studies evaluating sarcopenia after bariatric surgery are limited and consider mainly compromised muscle mass. In this study, we prospectively evaluated the impact of bariatric surgery on sarcopenia-related parameters over an 18-month period after surgery in patients undergoing the procedure. Specifically, the study aims to assess changes in muscle strength, muscle mass, and the prevalence of sarcopenic obesity at various time points before and after surgery. We hypothesize that while bariatric surgery will result in significant weight loss, it will also lead to a concomitant reduction in muscle mass and strength, thereby increasing the risk of sarcopenia shortly after surgery. Additionally, we aim to determine whether these changes persist or diminish over an 18-month follow-up period. The significance of this study lies in its potential to inform clinical practice and improve the management of patients undergoing bariatric surgery, possibly influencing guidelines and recommendations for post-bariatric surgery monitoring and rehabilitation programs.

2. Methods

2.1. Study Design

This prospective study of patients undergoing bariatric surgery was conducted at a single surgical center: the Center for Integrated Responsibility for Bariatric Surgery and Metabolic Diseases (CRI.COM) at a Portuguese Hospital (ULSAC). The entire protocol has been previously described (15).

The invitation to participate was made in the context of an outpatient appointment, and participants who agreed to participate in the study were delivered the free and informed consent form previously approved by the University and Hospital Ethics Committee (HESE_CE_1917/21).

As inclusion criteria, patients should be enrolled for bariatric surgery at the hospital, both men and women, aged between 18 and 65, with a Body Mass Index (BMI) of more than 35 kg/m^2, with medical-associated morbidities, who agree to participate in the study. Patients with previous bariatric surgery were excluded. Participants were recruited during outpatient appointments, where the study was explained, and they were invited to participate. Screening included a detailed medical history and physical examination to ensure eligibility. All patients underwent bariatric and metabolic surgery between December 2021 and December 2022.

During the study period, all patients were followed using standard follow-up by bariatric surgeons, nutritionists, psychologists and nurses.

2.2. Perioperative Management

The multidisciplinary team evaluated and performed the surgery in all patients according to a standard protocol. The surgical procedure was a Roux-en-Y Gastric Bypass (RYGB). After surgery, the participants received similar support from the different team specialists from the team, with standard follow-up appointments and consultations.

2.3. Outcomes Definition and Data Collection

According to the study plan, all parameters were evaluated at the five moments before surgery and at 1, 6, 12, and 18 months after surgery.

Weight evaluation was measured using a scale. The patients were without shoes or heavy clothing. Height was determined by a manual stadiometer. BMI was calculated (weight/height^2), and the abdominal circumference was determined by a measuring tape (16,17). To evaluate body composition, the Dual-energy X-ray absorptiometry - DEXA (DXA, Hologic QDR, Hologic, Inc., Bedford, MA, USA) was used (18).

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For screening, both the EWGSOP2 and the ESPEN/EASO consensuses recommend the use of the SARC-F questionnaire (FIND) in clinical practice (6,10,11).

The SARC-F is a self-reported questionnaire with five questions: Strength (S), Assistance walking (A), Rising from a chair (R), Climbing stairs (C), and Falls (F). Each answer is rated on a scale of 0 to 2, ranging from "not at all" to "very difficult." A total score is calculated out of 10. The recommended cutoff value for positive screening for sarcopenia is ≥4 points (19–21).

All participants completed the SARC-F scale at the five moments.

In both documents, the first diagnostic criteria (ASSESS) for sarcopenia is low muscle strength. In our study, muscle strength was determined by two tests: the handgrip strength test and the five-times-to-stand test.

The handgrip strength test was conducted using manual pressure dynamometry for measuring grip strength (Jamar®) to evaluate muscle strength of the upper limbs. Participants were instructed to stand with their elbows fully relaxed and straight. Each hand was tested twice, and the maximum grip strength value obtained was recorded as the muscle strength test value (22,23). The dynamometer was calibrated before each testing session to ensure accuracy, and all tests were administered by trained personnel to minimize inter-rater variability.

The sit-to-stand test evaluated the muscle strength of the lower limbs, in which participants were instructed to stand and sit for 30 seconds as many times as possible (25). The timed chair stand test is a variation that counts how many times a patient can rise and sit on the chair over a 30-second interval (24,25). Because the chair stand test evaluates both strength and endurance, it offers a reliable yet practical measure of strength.

The cut-off used for hand-grip strength was set <27 kg for males and <16 kg for females (26) and >15s for five rises on the chair rise test (5-times sit-to-stand) (27).

Confirmation of sarcopenia (*CONFIRM*) based on muscle quantity or mass can be reported by appendicular skeletal muscle mass (ASMM) using dual-energy X-ray absorptiometry-DEXA. DEXA has been chosen because it is a common method for measuring skeletal muscle mass (11). SMM refers to the amount of muscle that is attached to the skeleton and helps in systemic movement and posture maintenance, whereas ASMM is the sum of muscle mass of the four limbs (28).

To estimate ASMMI, it was used the sum of the muscle mass of the upper and lower extremities (muscle mass of arms [kg] + muscle mass of legs [kg]) dividing for height squared (m^2) (ASMMI= ASMM/height^2) (29). The ASMMI value has been used to assess sarcopenia in different populations, but there is still an ongoing debate about the preferred parameter to represent muscle mass (6). As suggested by ESPEN/EASO consensus, in the present study we also considered the values of ASMM/weight for male (cut-off < 28.27%) and female patients (cut-off <23.47%) were considerate (7).

The severity (SEVERITY) of sarcopenia using the 400-m walk test to assess walking ability and endurance and the staging level by the presence of at least one complication attributable to sarcopenic obesity. Participants were asked to complete 20 laps of 20 meters each as fast as possible and were allowed up to two rest stops during the test (30,31). Low physical performance was considered when the test was not completed or when it took more than 6 minutes to complete (6).

2.4. Algorithm to Diagnose Sarcopenia and Sarcopenic Obesity - F-A-C-S

According to EWGSOP-2, sarcopenia diagnosis is based on low muscle strength combined with decreased muscle mass (male grip strength < 27 kg, ASMM < 20 kg, ASMMI < 7.0 kg/m^2; female grip strength < 16 kg, ASMM < 15 kg, ASMMI < 5.7 kg/m^2,) (6). Sarcopenia is considered severe when low physical performance is identified (400m walk test ≥ 6min) (6). For Sarcopenic Obesity (ESPEN/EASO) all previous cut-off values were considered, adding the ESPEN/EASO consensus parameters BMI (BMI > 30 kg/m^2), waist circumference (WC) (WC ≥ 102 cm for male and ≥ 88 cm for Female) and ASMM/weight (ASMM/Weight < 28.27% for Male and < 23.47% for Female) (7).

2.5. Statistical Methods

Statistical software was performed with the SPSS version 27.0 (IBM SPSS Inc., Chicago, IL, USA) to determine the parameters and outcomes. Categorical variables are expressed as frequencies and

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percentages, and continuous variables are expressed as mean and standard deviation. Data normality was assessed using the Shapiro-Wilk test. For group comparisons, we employed independent t-tests for normally distributed continuous variables and Mann-Whitney U tests for non-normally distributed variables. Repeated measures ANOVA was used to evaluate changes over time within the same group, with post-hoc tests conducted using Bonferroni correction to adjust for multiple comparisons.

For categorical variables, Chi-square tests were used to compare proportions between groups, with Fisher's exact test applied when expected frequencies were low. Statistically significant results were considered for p-values ≤ 0.05.

3. Results

3.1. Weight

A total of 17 participants (88.2% female) were enrolled in this study with a mean age of 46.9 (± 11.4) years, a mean BMI of 42.9 (± 5.14) kg/m², a mean weight of 105.9 (± 17.5) kg and a mean waist circumference of 123 (± 12) cm (Table 1).

Table 1. Baseline characteristics of participants.

Variables (*Mean ± SE)	Total (n=17)
Age (years)	50 ± 11.0
Sex (female/male) %	88.2/11.8
Body weight (kg)	106 ± 17.5
BMI (kg/m²)	42.6 ± 5.00
Waist circumference (cm)	123 ± 12.0
Handgrip (Kg)	20.4 ± 6.44
Sit-to-stand test (s)	12.6 ± 3.55
Fat mass (Kg)	46.3 ± 15.11
Body fat (%)	47.1 ± 3.90
Lean mass (Kg)	53.46 ± 10.48
ASMM (Kg)	21.92 ± 5.13
ASMM/Weight (%)	20.6 ± 2.36
ASMMI (Kg)/m²)	8.79 ± 1.57
ASMMI/BMI	0.514 ± 0.096
400-m walk test (m)	7.61 ± 2.81

BMI: Body Mass Index, SMM: Skeletal Muscle Mass, ASMM: Appendicular Skeletal Muscle Mass, ASMMI: Appendicular Skeletal Muscle Mass Index.

After surgery and throughout the study period, the mean weight decreased and was always significantly lower than the baseline, namely 91.8Kg at 1-month post-surgery ($p<0.001$), 75.4Kg at 6 months ($p<0.001$), 69.9Kg at 12 months ($p<0.001$) and 70.8Kg at 18 months ($p<0.001$). The comparison between the weight observed at each assessment point and the preoperative weight (baseline) was always statistically significant.

When the several assessment moments were compared sequentially, the differences between the baseline weight and the weight at 1 month, the weight at 1 month and the weight at 6 months, and the difference between 6 and 12 months all showed a decrease with statistical significance ($p<0.001$). On the other hand, between 12 months and 18 months, weight remained practically stable, with no statistically significant difference (Table 2). BMI and waist circumference assessments showed similar evolutions.

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Table 2. Comparative analysis of sarcopenia algorithm parameters before surgery and 1,6,12 and 18 months after surgery.

Variables (*Mean ± SE)	Before Surgery	After Surgery									
	Baseline - E0	*1month - E1*		*6month - E2*			*12month - E3*			*18month - E4*	
			E1*E0 p-value		*E2*E0 p-value*	*E2*E1 p-value*		*E3*E0 p-value*	*E3*E2 p-value*		*E4*E0 p-value*	*E4*E3 p-value*
Anthropometry												
Body weight (kg)	105.9 ± 17.5	91.8 ± 14.7	**< 0.001**	75.4 ± 14.70	**< 0.001**	**< 0.001**	69.9± 12.1	**< 0.001**	**< 0.001**	70.8 ± 12	**< 0.001**	0.438
Total weight loss (%)	NA	NA	NA	13.1 ± 4.32	NA	NA	29 ± 4.58	NA	**<0.009**	32.5 ± 9.76	NA	0.251
BMI (kg/m²)	42.6 ± 5	37 ± 4.53	**< 0.001**	30.2 ± 4.17	**< 0.001**	**< 0.001**	28.2 ± 4.34	**< 0.001**	**0.008**	28.7 ± 4.93	**< 0.001**	0.313
Waist circumference (cm)	123 ± 12	110 ± 11.4	**< 0.001**	97.2 ± 12.8	**< 0.001**	**< 0.001**	94.2 ± 12.2	**< 0.001**	**0.016**	93.6 ± 11	**< 0.001**	0.575
Physical function and strength												
Handgrip (Kg)	20.4 ± 6.44	18.1 ± 6.44	**0.002**	16.8 ± 5.25	**0.002**	0.358	17.7 ± 5.11	**0,016**	0.257	17.3 ± 5.44	**0.005**	0.479
Sit-to-stand (STS) (n)	12.6 ± 3.55	12.8 ± 3.33	0.415	13.2 ± 2.88	0.105	0.120	13.1 ± 2.45	0.073	0.956	12.8 ± 2.70	0.259	0.157
Body composition												
Fat mass (Kg)	46.34 ± 15.1	44.47 ± 9.97	**0.003**	37.42 ± 7.92	**0.003**	**< 0.001**	34.19± 6.99	**0.002**	**< 0.001**	30.45 ± 11.6	**< 0.001**	0.098
Body fat (%)	47.1 ± 3.90	45.5 ± 4.99	**0.023**	40.6 ± 7.26	**< 0.001**	**< 0.001**	37.4 ± 6.34	**< 0.001**	**< 0.001**	37 ± 7.71	**< 0.001**	0.711
Lean mass (Kg)	53.45 ± 10.48	48.01 ± 9.47	**< 0.001**	44.65 ± 9.54	**< 0.001**	**< 0.001**	39.98 ± 5.08	**< 0.001**	**< 0.001**	37.14 ± 4.6	**< 0.001**	**< 0.001**
ASMM (Kg)	21.92 ± 5.13	19.72 ± 4.79	**< 0.001**	17.53 ± 4.11	**< 0.001**	**< 0.001**	15.90 ± 4.06	**< 0.001**	**< 0.001**	14.40 ± 4.32	**< 0.001**	**< 0.001**
ASMMI (Kg/m²)	8.79 ± 1.57	7.91 ± 1.48	**< 0.001**	7.03 ± 1.22	**< 0.001**	**< 0.001**	6.39 ± 1.28	**< 0.001**	**< 0.001**	5.79 ± 1.45	**< 0.001**	**< 0.001**
ASMM/Weight (Kg/kg)	20.6 ± 2.36	21.4 ± 2.18	**0.039**	23.3 ± 3.13	**< 0.001**	**< 0.001**	21.1 ± 3.12	0.328	**< 0.001**	20.5 ± 5.65	0.517	0.538
ASMM/BMI	0.514 ± 0.10	0.535 ± 0.12	**0.034**	0.580 ± 0.11	**< 0.001**	**< 0.001**	0.496 ± 0.19	**0.003**	0.515	0.570 ± 0.14	0.535	**0.002**
Physical performance												
400-m walk test (min)	7.61 ± 2.81	8.79 ± 3.40	**0.016**	8.74 ± 3.05	**0.005**	0.890	9.58 ± 3.58	**< 0.001**	**0.019**	10.1 ± 4.12	**< 0.001**	0.134

BMI: Body Mass Index, SMM: Skeletal Muscle Mass, ASMM: Appendicular Skeletal Muscle Mass, ASMMI: Appendicular Skeletal Muscle Mass Index, 400-m: 400 meters.

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3.2. Screening

The application of the SARC-F questionnaire before and after surgery showed an increase in the SARC-F result between the preoperative and postoperative assessments. This increase may reflect an increase in the risk of developing sarcopenia during the peri-operative period and may be a result of the surgical intervention.

Applying the EWGSOP2 sarcopenia screening criteria (SARC-F), 70.6% of patients had a positive screening at the preoperative assessment. During the post-operative period the number of positive screenings was 88.2%, 70.6%, 58.8% and 0% at 1 month, 6, 12 and 18 months respectively. Only the result at 18 months showed a statistically significant difference compared to baseline (Table 3).

Table 3. Algorithm to Diagnose Sarcopenia – EWGSOP2.

F-A-C-S	**Before Surgery**	**After Surgery**			
	Baseline - E0	***1month - E1***	***6month - E2***	***12month - E3***	***24month - E4***
FIND CASES - *Screening* **SARC-F**	70.6%	88.2%	70.6%	58.8%	**0%***
ASSESS - Skeletal muscle strength **HANDGRIP**	35.3%	**70.6%***	**64.7%***	52.9%	52.9%
CONFIRM - Skeletal muscle quantity **ASMMI**	0%	0%	**11.8%***	**29.4%***	**52.9%***
DIAGNOSIS - assess^confirm	0%	0%	**11.8%***	**29.4%***	**52.9%***
SEVERITY - Physical Performance **400-m WALK TEST**	58.8%	70.6%	76.5%	**82.4%***	**94.1%***

*McNemar test; p-value<0,050 significant result relative to E0. ASMMI: Appendicular Skeletal Muscle Mass Index.

Using the ESPEN/EASO screening criteria for sarcopenic obesity (assessed using also BMI, waist circumference and the SARC-F questionnaire), the result was positive at the preoperative assessment in 70.6% of patients. This percentage was 88.2% in the first month after surgery, but the difference was not statistically significant. After the first month, the screening was considered positive in a decreasing percentage of patients (35.3% at 6 and 12 months and 0% at 18 months) and these differences were considered significant (Table 4).

Table 4. Algorithm to Diagnose Sarcopenia – EASO and ESPEN.

DIAGNOSE PROCEDURES	**Before Surgery**	**After Surgery**			
	Baseline – E0	***1month - E1***	***6month - E2***	***12month - E3***	***24month - E4***
SCREENING 1. High BMI	100%	100%	35.3%	35.3%	41.2%
SCREENING 2. High Waist circumference	100%	100%	82.4%	58.8%	58.8%
SCREENING 3. SARC-F	70.6%	88.2%	70.6%	58.8%	0%
SCREENING 1^2^3	70.6%	88.2%	**35.3%***	**35.3%***	**0%***
DIAGNOSIS 1. Altered skeletal muscle functional - Handgrip	35.3%	**70.6%***	**64.7%***	52.9%	52.9%

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DIAGNOSIS **2.** Altered body composition - ASMM/Weight	94.1%	88.2%	70.6%	88.2%	94.1%
DIAGNOSIS ***1^2***	35.3%	**70.6%***	41.2%	52.9%	52.9%
STAGING – *STAGE I: No complications*	0	0	0	0	0
STAGING – *STAGE II: Whit complications*	100%	100%	100%	100%	100%

*McNemar test; p-value<0,050 significant result relative to E0. ASMMI: Appendicular Skeletal Muscle Mass Index.

3.3. Muscle Strength

The handgrip assessments at 1 month, 6 months, 12 months and 18 months were 18.1 Kg, 16.8 Kg, 17.7 Kg and 17.3 Kg respectively. All these results were lower than the handgrip assessed before surgery (20.4 kg), showing a statistically significant difference. When comparing handgrip strength between consecutive assessment times, there was a reduction between the baseline value and the 1st post-operative month (20.4Kg *versus* 17.8Kg) with a statistically significant difference. Subsequent comparisons, between the first month and six months (17.8Kg *versus* 16.8Kg), between six months and 12 months (16.8Kg *versus* 17.7Kg) and between 12 months and 18 months (17.7Kg *versus* 17.3Kg), showed only slight variations without statistical significance.

The Sit-to-stand test showed results at 1 month, 6 months, 12 months and 18 months of 12.8, 13.2, 13.1 and 12.8 respectively. None of these evaluation moments showed a statistically significant difference when compared to the preoperative (baseline) value of 12.6.

The cut-offs to classify as normal or abnormal the results of the hand-grip strength by the EWGSOP2 and the ESPEN/EASO consensus are the same. When we use these criteria were used for the handgrip test evolution before and after surgery, 35.3% of the patients already met the criterion for compromised muscle strength before surgery. At 1-month post-surgery, 70.6% met the criterion and at 6 months 64.7%. These differences with the baseline were statistically significant. At 12 and 18 months, 52.9% of patients were positive, and these differences from baseline were not significant.

3.4. Muscle Mass

The ASMM parameter showed decreasing post-operative results: 19.72kg, 17.53kg, 15.90kg and 14.40kg, respectively. The difference when compared with the preoperative baseline result (21.92kg) was always statistically significant ($p<0.001$). The sequential comparison between assessment moments throughout the postoperative period, between the 1st month and 6 months (19.73Kg *versus* 17.53Kg), between 6 and 12 months (17.53Kg *versus* 15.90Kg) and between 12 and 18 months (15.90Kg *versus* 14.40Kg) always showed a statistically significant decrease.

The ASMMI (Kg/m^2) also showed a constant decrease from the baseline result (8.79) to 7.91, 7.03, 6.39 and 5.79 respectively at one month, 6, 12 and 18 months after surgery. All differences were statistically significant ($p<0.001$).

ASSM/weight (Kg/Kg) increased significantly between the preoperative assessment (20.6%) and the assessments carried out at 1 month ($p=0.039$) and 6 months ($p<0.001$) after surgery (21.4% and 23.3%). On the other hand, the assessments carried out at 12 and 18 months (21.1% and 20.5%) showed no significant difference when compared to the baseline assessment. In terms of progress, there was a significant difference between the preoperative assessment and the first month (20.6% versus 21.4%) and between the first month and six months (21.4% versus 23.3%). Between six and 12 months there was also a significant difference, but in the opposite direction (23.3 Kg/Kg versus 21.1%). There was no difference between 12 and 18 months (21.1% versus 20.5%).

Applying the EWGSOP-2 suggested cut-off for ASSMI (Kg/m^2), all patients had a normal index at baseline and one month after surgery. After that evaluation, 11.8%, 29.4% and 52.9% of patients had an abnormal index at 6, 12 and 18 months respectively, and this difference was statistically significant.

When the ESPEN/EASO recommended cut-off for ASMM/weight (Kg/Kg) was applied at the different evaluation moments, we found out that 94.1% of patients had already an abnormal result at

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baseline. This number was 88.2%, 70.6%, 88.2% and 94.1% at one month, 6, 12 and 18 months respectively.

3.5. Severity

The results of the 400-m walk test showed an increase in test time in all assessments 8.79min, 8.74min, 9.58min and 10.1min respectively at the first month, 6 months, 12 months and 18 months, when compared to the baseline value (7.61min).

Over time, there was a significant increase (p=0.016) in the test value between the preoperative assessment and the first month (7.61min *versus* 8.79min) and stability between the first month and six months (8.79min *versus* 8.74min). Again, a significant difference between six and twelve months (p=0.019) (8.74min *versus* 9.58min) and stable between 12 and 18 months (9.58min *versus* 10.1min).

3.6. Sarcopenia Diagnosis

Applying the two cumulative EWGSOP2 criteria for diagnosing sarcopenia (criteria 1: reduced strength assessed by handgrip test and criteria 2 reduced muscle mass measured by decreased ASMM/height^2) and its proposed cut-offs, allow to be found that at baseline 35% of the patients had probable sarcopenia but no patients met both criteria for achieving a diagnosis. At one month after surgery the result was the same. Beyond that moment, 11.8%, 29.4% and 52.9% of the patients met both criteria to attain a diagnosis of sarcopenia.

When we applied the two ESPEN/EASO cut-offs for diagnosing sarcopenia associated with obesity, both of muscle function (handgrip) and body composition (ASSM/weight), in a cumulative way, led to a result of 35.3% of patients already with sarcopenia at baseline. After surgery, the patients that met the same criteria for sarcopenia were 70.6%, 41.2%, 52.9% and 52.9% at 1 month, 6, 12 and 18 months respectively. This increase, when compared to the baseline, was only statistically significant up to 6 months ($p<0.05$).

4. Discussion

This study provides valuable insights into the impact of bariatric surgery on sarcopenia and sarcopenic obesity over an 18-month period, utilizing EWGSOP2 and ESPEN/EASO consensus criteria. The findings indicate significant weight loss post-surgery, accompanied by reductions in muscle mass and strength, particularly evident in the early post-operative period. Notably, handgrip strength declined significantly one month after surgery, while other muscle function tests, such as the sit-to-stand test, did not show significant deterioration. The prevalence of sarcopenic obesity increased immediately post-surgery, peaking at one month and returning to pre-surgery levels by six month.

Bariatric surgery is currently the most effective type of treatment for moderate and severe obesity. On the other hand, the weight loss caused by bariatric surgery represents not only fat mass loss but is often accompanied by muscle mass loss. Addressing this subject is not an easy task due to the different muscle function and body composition study methods and the absence of a clear consensus on the preferred tools and cut-offs to be used to establish a diagnosis of sarcopenic obesity. Also, different surgical procedures and other variables may impact on muscle mass and function differently.

In this study, were used the assessment tools recommended by both the EWGSOP2 group and the EASO/ESPEN consensus, including muscle function and mass assessments, with a focus on the handgrip test as a surrogate for muscle function and ASMM, ASMM/weight, ASMMI and ASMM/height^2 to represent muscle mass. This data allowed to evaluate the patients according to the algorithms proposed by both those consensuses. The decision to perform multiple assessments, before and after surgery to better elucidate this complex relationship between weight, adiposity, muscle mass, and muscle function after bariatric surgery.

Considering the specific bariatric surgery results on weight management, there was, as expected, a reduction in the patient's median weight, BMI, and waist circumference up to the first year of

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follow-up, with no relevant change at 18 months. Besides reducing weight and adiposity, the eventual loss of muscle mass and muscle function is a concern in bariatric surgery. This effect may be an undesired side-effect of surgery.

4.1. Screening

Using the cut-offs for positive results, screening for sarcopenic obesity was already positive in most patients before surgery. When we apply the EWGSOP2 criteria were used, the number of patients at risk for this condition decreases only 18 months after surgery, but when the ESPEN/EASO criteria was applied, the decrease is already present 6 months after surgery. This result shows that patients who are candidates for bariatric surgery already have a significant risk for sarcopenic obesity before surgery and that bariatric surgery may take some time to decrease that risk as evaluated by the screening tool.

4.2. Muscle Strength

Muscle strength, one of the key aspects of sarcopenia, was assessed by different tests, but with a special focus on hand-grip strength. This test is recommended both by the EWGSOP2 (6) and the ESPEN/EASO consensus (7). Previously, the FNIH recommendations also stated that grip strength was the preferred method to assess muscle strength (using a cut-off of 26 Kg for males and 16 Kg for females) (34).

The sit-to-stand test did not show identical results. There was no difference when the results before or after surgery were compared, or even during follow-up. It is interesting to note that the test in which muscle strength is analyzed without interference from the patient's weight, the handgrip, was the test that showed a clear and significant change, while the test that is dependent on weight did not. It can be argued that, in the specific context of patients with obesity who have undergone surgery and whose weight has decreased significantly between each two assessments, this reduction in weight could have interfered with the results of the 5-times sit-to-stand test since decreasing body weight also decreases the muscular effort assessed in this test. On the other hand, weight loss is not expected to interfere with the handgrip muscle strength test, so the best test to show sarcopenia in this context is the handgrip.

The impact of bariatric surgery on the hand-grip test has been debated. A recent meta-analysis by Jung et al. (35)concerning muscle strength after bariatric surgery could not show a muscle strength loss when all the data was pooled. Nevertheless, the aggregated number of subjects was not very large (n=301), and the authors stated that their analysis had several limitations, namely that the studies were heterogeneous and represented only specific populations. Also, the timing of the assessments after surgery was heterogeneous with most studies being performed only after 6 months of the surgical procedure. In none of those studies strength was assessed one month after surgery as in the current studie. Other variables that are probably relevant are gender and the surgical procedure chosen for each patient because these factors may also impact weight and muscle loss.

Nevertheless, even if the global pooled data did not indicate, some of the included studies in the meta-analysis showed a clear absolute decrease in muscle strength decrease. Alba et al., showed a significant decrease from preoperative values ($p= 0.001$). The mean 12-month change in absolute strength showed a decline of 2.6 kg, with all the decline occurring in the first 6 postoperative months (41). Oppert et al., also showed a 21 Kg muscle strength decrease (36), and Cole et al., showed a 2.8 Kg decline (37). It is worth mentioning that these three studies were the only ones included in the meta-analysis where the only surgical procedure used was the RYGB.

Stegen et al.,, in 2010, already showed a 7% or 18% reduction in hand-grip strength in RYGP patients (38). Another study, not included in the meta-analysis, by Crispim Carvalho et al.,, where the great majority of patients were RYGP patients (16/21), also showed a significant decrease in hand-grip strength at one-year follow-up (39). Another study published in 2019 also showed a reduction from 34.18 Kg to 31.91Kg in hand-grip strength 6 months after surgery (40), even though it is unclear what surgical procedure was performed.

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In the present study, contrary to the overall result of the meta-analysis, the hand-grip test did show a clear decrease in strength as early as one month after surgery, with no further changes or deterioration afterwards and up to 18 months.

If we look closely into the data of the meta-analysis by Jung et al., (35), only three papers included, like in this study, exclusively RYGP patients. These three papers (37,41–43) all showed the same result: a decrease in hand-grip strength, that was also found by other papers (38–40) also in RYGP patients also showed the same results as ours.

Gender also seems to be a factor in muscle strength loss. Jung et al. performed a sub-group analysis of the pooled data in their meta-analysis based on the percentage of men below or above 30%. They concluded that in the studies where over 70% of women were present, handgrip strength was reduced by 1.5 Kg. This is in accordance with the current results, where 80% of the patients were women, and we found a reduction in muscle strength was found (35).

The results show that the decline in muscle function in RYGP patients after surgery is clear. It also appears very early in the postoperative period, at the one-month evaluation. It can be speculated that the first assessments performed in other studies, after 6 months, may not capture this early effect.

The relationship between post-bariatric surgery status and the strength assessed by the hand-grip test is not yet clear. The differences in results of several studies may result from different patient selection and methodology. Attention must be given to the type of surgical procedure, gender, and the time elicited after surgery.

4.3. Muscle Mass

Muscle mass loss is one of the critical components of sarcopenia and of sarcopenic obesity. Bariatric surgery causes significant weight loss. This is dependent mainly on fat mass loss, but muscle mass loss is also present. In this setting, muscle mass loss can be present before surgery and be caused or aggravated by surgery, resulting in a new onset sarcopenic obesity or worsening of a previous condition.

Nujten et al. performed a meta-analysis studying lean body mass, skeletal muscle mass, and fat-free mass losses after bariatric surgery. They concluded that there is a clear loss of muscle mass – 8.13Kg LBM - one year after surgery (44). They also studied the impact of different procedures and found that the gastric band had a lesser impact, but the other procedures (RYGP, Sleeve, BPD) all had similar outcomes.

Han Na Jung et al. performed a Systematic Review and Meta-analysis of muscle strength and muscle mass after bariatric surgery. They found a decrease in lean mass in all studies except for two. The pooled data showed a reduction of 7.4 Kg in this parameter. Rodrigues studied Skeletal muscle mass in three groups of bariatric patients, divided according to BMI levels. In all groups, there was a loss of SMM between 5.8 and 6.8 Kg one year after surgery (45).

There is debate about which parameter should be used to define sarcopenic obesity. In this study, ASMM, ASMMI and ASMM/weight over 18 months were studied. These parameters were chosen because they are recommended by the EWGSOP2 consensus (6,10) or by the ESPEN/EASO consensus (7). Another option would have been to assess ALM/BMI, previously proposed by the FNIH Sarcopenia Project (34).

In the current study, the loss of muscle mass was somewhat more profound than in other investigations. This decrease was in line with the decrease in total body weight. Nevertheless, ASMM/weight, a parameter less dependent on weight and recommended by ESPEN/EASO guidelines as a representation of muscle mass in bariatric patients, did not show any decrease.

Other authors found similar results. Alba et al., observed a decline of 14% in lean mass and of 16% on ALM 12 months after surgery (41). Pekar et al. (18) found a decrease in ALMI from 9.7 to 7.7 Kg/m^2 18 months after surgery.

Vassilev et al., found a decrease in lean body mass from 63.38 to 58.87 Kg 24 weeks after surgery. With MRI, those authors observed a decrease in skeletal muscle index from 52.65 to 42.48 cm^2/m^2 in the same time span (46). Using BIA, Martinez el al., found a decrease in fat-free mass from 66.47 Kg to 55.48 Kg 24 months after surgery (13).

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4.4. Severity

The test used to determine severity, the 400-m walk, showed contradictory results in patients of the present study. However, we must remember that this context corresponds to bariatric surgery patients. In this treatment, there is a significant weight loss between the time of the preoperative assessment and the time of the postoperative assessment. This marked weight loss achieved with bariatric surgery could compromise the reliability of the 400m-walk physical performance test since performance in this test will depend not only on the quantity and quality of skeletal muscle but also on the physical effort required for walking. This effort in these patients after surgery may be facilitated due to the weight loss achieved.

4.5. Sarcopenia Diagnosis

The consensus from EWGSOP-2 and ESPEN/EASO aim to define Sarcopenia and Sarcopenic Obesity (7). They advance a set of tests that can be chosen to determine the presence of this condition and suggest cut-offs to get a clear diagnosis. This will be essential to facilitate research on the predisposing factors, consequences, prevention and treatment of this condition.

However, presently few studies have yet been published using both these consensuses as it was made in the present research, where hand-grip strength was used to assess muscle function and ASMM, ASMMI and ASMM/weight for body composition. As cut-offs, were chosen 27 kg for males and 16 kg for females for hand-grip strength; < 7.0 kg/m^2 for males and < 5.7 kg/m^2 for females for ASMMI; and 28.27% for males, and 23.47% for females for ASMM/weight.

According to these results, one-third of the patients already presented sarcopenic obesity before surgery when the complete ESPEN/EASO criteria was used but the result was 0% when the EWGSOP-2 criteria was applied.

After surgery, there were clear differences in the results of the function and muscle mass tests over time. However, when applying the cut-offs for the diagnosis pathway only one month after surgery, there was also a clear difference in diagnosis when using the different consensuses. In fact, using EWGSOP-2, the percentage of patients that met diagnostic criteria increased from 6 months onwards, affecting half the patients 18 months after surgery. However, when the ESPEN/EASO criteria were used, the percentage of patients classified as sarcopenic obesity increased one month after surgery (from 35.3% to 70.6%) when one-third of the patients develop new-onset OS. Afterwards, from 6 to 18 months, this percentage was not different from baseline.

Future research should focus on larger, multicenter studies to confirm these findings and examine the long-term effects of bariatric surgery on sarcopenia and sarcopenic obesity. Investigating the efficacy of targeted interventions, such as resistance training programs and nutritional support, in preventing muscle loss post-surgery is also essential. Moreover, studies exploring the underlying mechanisms of muscle loss and recovery in bariatric patients will help develop more effective strategies for maintaining muscle health. Understanding the role of different bariatric procedures and patient characteristics in influencing these outcomes will further refine post-operative care protocols.

5. Conclusion

A short-term consequence of obesity surgery, specifically in the post-operative period, may be an increase in sarcopenia. This is shown by a clear decrease in muscle function when assessed by the handgrip test. On the other hand, this effect does not appear in tests whose performance is influenced by the patient's weight: the 5-times sit-to-stand and the 400m walk tests results did not suffer any deterioration. One possible interpretation is that, in these tests, the effects of the reduction in muscle mass and strength are masked by the reduction in the degree of physical demand of these three tests caused by the reduction in body weight resulting from the surgery.

Also, muscle quantity, as measured by ASMM or ASMMI, decreased continuously after surgery. However, when ASMM is adjusted by weight or BMI the results are equivocal. This could probably be a result of a lack of a clear understanding of the relative influence of surgery and of weight loss itself on muscle mass.

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When both muscle strength and muscle mass criteria and cut-offs are used in a cumulative way, and according to both consensuses, antagonistic results were observed. This may be a consequence of the present lack of a clear-cut definition of sarcopenia, despite the different studies, reviews and other papers that have been published on this subject. Nevertheless, the present results seem to indicate a significant deleterious impact of bariatric surgery on muscle strength and mass, the most important indicators of sarcopenia. This is very clear in the hand-grip test, ASMM and ASSMI. Considering the relevance of muscle strength and muscle mass for health and well-being, it could be considered that these indicators should be preferred for sarcopenic obesity diagnosis. Also, the impact seems to occur very early after surgery, which may indicate that the appropriate timeframe to try to prevent this effect may be the prehabilitation period followed by the post-surgery timeframe.

Limitations

One limitation of this study is its small sample size of 17 patients, which may affect the generalizability and statistical power of the findings. The limited sample size might have restricted our ability to detect smaller yet clinically significant differences. Additionally, most participants were female, which may not fully represent the broader bariatric surgery population. Future studies with larger, more diverse samples are needed to validate these findings and explore potential gender differences in the impact of bariatric surgery on muscle mass and strength. Despite these limitations, our study provides important preliminary insights into the changes in muscle function and mass post-surgery.

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