



**Metabolic efficiency and cardiorespiratory adaptations to endurance and resistance exercise programs in post-bariatric surgery patients with sub-optimal weight loss**

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**Orientador:** Prof. Doutor Hélder Fonseca

Ingrid Paola Pinzón Tapias  
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*Palavras-chave:* Cirurgia bariátrica, perda de peso insuficiente, exercício resistido, exercício aeróbio, aptidão cardiorrespiratória, eficiência metabólica.



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## **List of Abbreviations**

- 1RM** - One Repetition Maximum
- AE** - Aerobic Exercise
- AGB** - Adjustable Gastric Banding
- AHI** - Apnea-Hypopnea Index
- ANOVA** - Analysis of Variance
- ASMBS** - American Society for Metabolic and Bariatric Surgery
- BcSy** - Bariatric Surgery
- BMI** - Body Mass Index
- CE** - Combined Exercise
- CPET** - Cardiopulmonary Exercise Test
- CRF** - Cardiorespiratory Fitness
- DXA** -Dual Energy X-Ray Absorptiometry technology
- EE** - Energy Expenditure
- EEG** - Endurance Exercise Group
- EEPA** - Energy Expended in Physical Activity
- EWL** - Excess Weight Loss
- FFM** - Fat-Free Mass
- GIP** - Glucose-dependent Insulinotropic Polypeptide
- GLP-1** - Glucagon-like Peptide-1
- HIIT** - High-Intensity Interval Training
- HR** - Heart Rate
- HRo** - Hazard Ratio
- HRR** - Heart Rate Reserve
- HRRe** - Heart Rate Recovery
- IFSO** - International Federation for the Surgery of Obesity and Metabolic Disorders
- LSG** - Laparoscopic Sleeve Gastrectomy
- METs** - Metabolic Equivalent of Task
- OB** - Obesity
- OP** - Oxygen Pulse

**OSA** - Obstructive Sleep Apnea  
**RAAS** - Renin-angiotensin-aldosterone system  
**RelBW** - Relative to body weight  
**RE** - Resistance Exercise  
**REE** - Resting Energy Expenditure  
**REG** - Resistance Exercise Group  
**RER** - Respiratory Exchange Ratio  
**RMR** - Resting metabolic Rate  
**RYGB** - Roux-en-Y Gastric Bypass  
**T2DM** - Type 2 Diabetes  
**TEE** - Total Energy Expenditure  
**TEF** - Thermic Effect of Food  
 **$\dot{V}O_2 \max$**  - Maximum Oxygen Consumption  
**VT1** - First Ventilatory Threshold  
**VT2** - Second Ventilatory Threshold (Respiratory Compensation Point)  
**WHO** - World Health Organization  
**WL** - Weight Loss  
**WR** - Weight Regain

## Abstract

Obesity is a significant and highly prevalent disease with several musculoskeletal, cardiovascular, endocrine and psychological negative consequences and is associated with an increased mortality risk. Bariatric surgery is the mainstay treatment option for patients with severe obesity. Despite its well-recognized benefits, bariatric surgery is associated with substantial decreases in lean mass, namely skeletal muscle mass, which can negatively affect physical function, metabolism, and cardiovascular health. Exercise training effectively tackles some of these limitations of bariatric surgery and increases the long-term sustainability of many bariatric surgery benefits. Nevertheless, it is still not clear what should be the most adequate exercise prescription for post-bariatric surgery patients.

To address this purpose, we performed a single-center, open-label, randomized clinical trial comparing two exercise interventions -endurance (EEG) *vs* resistance (REG) training- for a period of 16 weeks. Analyzing the cardiorespiratory fitness (CRF) and energy metabolism efficiency in adult patients of both genders with obesity that underwent bariatric surgery in the preceding 18 to 24 months and experienced sub-optimal weight loss.

Our results indicate that EEG had significantly higher relative to body weight (RelBW) peak  $\dot{V}O_2$ , maximal heart rate and speed attained during the cardiopulmonary exercise test (CPET), as well as in heart rate and pulse oxygen response at sub-maximal intensities. These findings suggest that, even for this specific population, endurance exercise is not only more effective at increasing cardiorespiratory fitness but also more effective at improving some parameters related to metabolic efficiency, when compared to resistance exercise.

*Keywords:* bariatric surgery, insufficient weight loss, endurance exercise, resistance exercise, cardiorespiratory fitness, energy production, metabolic efficiency.

## Resumo

A obesidade é uma doença significativa e altamente prevalente, com diversas consequências negativas músculo-esqueléticas, cardiovasculares, endócrinas e psicológicas e está associada a um risco acrescido de mortalidade. A cirurgia bariátrica é a principal opção de tratamento para doentes com obesidade severa. Apesar dos seus benefícios bem reconhecidos, a cirurgia bariátrica está associada a diminuições substanciais da massa magra, nomeadamente da massa muscular esquelética, o que pode afetar negativamente a função física, o metabolismo e a saúde cardiovascular. O exercício físico aborda eficazmente algumas destas limitações da cirurgia bariátrica e aumenta a sustentabilidade a longo prazo de muitos benefícios da cirurgia bariátrica. No entanto, ainda não é claro qual deverá ser a prescrição de exercício mais adequada para os doentes pós-cirurgia bariátrica.

Para atender a este propósito, realizámos um ensaio clínico randomizado, aberto e unicêntrico, comparando duas intervenções de exercício por 16 semanas. Especificamente, este estudo propõe-se comparar uma intervenção de exercício de endurance (EEG) versus resistência (REG) na aptidão cardiorrespiratória (CRF) e na eficiência do metabolismo energético em doentes adultos de ambos os sexos com obesidade submetidos a cirurgia bariátrica nos últimos 18 a 24 meses e que experimentaram uma perda de peso subótima.

Os resultados indicam que o EEG apresentou valores significativamente mais elevados no  $\dot{V}O_2$  pico relativo ao peso corporal, na frequência cardíaca máxima e na velocidade atingidas durante o teste de exercício cardiopulmonar (CPET), bem como a frequência cardíaca e a resposta de oxigénio de pulso a intensidades submáximas. Estes resultados sugerem que, mesmo para esta população específica, o exercício de endurance não só é mais eficaz no aumento da aptidão cardiorrespiratória, como também mais eficaz na melhoria de alguns parâmetros relacionados com a eficiência metabólica, quando comparado com o exercício de resistência.

*Palavras-chave:* Cirurgia bariátrica, perda de peso insuficiente, exercício resistido, exercício aeróbio, aptidão cardiorrespiratória, eficiência metabólica.



## **Introduction**

During the first trimester of 2024, the World Health Organization (WHO) estimated that one billion people worldwide were affected by obesity (OB), with its prevalence having more than doubled over the past 30 years (World Health Organization, 2024). To address this growing issue, various treatments have been implemented, the most basic being dieting. However, dieting alone has consistently proven insufficient (Monnier et al., 2021), as OB is the result of complex interactions between biological, environmental, and social factors (Blüher, 2019).

For individuals diagnosed with OB class III or class II associated with a comorbidity resulting from OB, bariatric surgery (BcSy) is recommended. The intervention primarily leads to sustained weight loss (O'Brien et al., 2019). Nonetheless, some patients experience weight regain (WR) after surgery, with the extent varying based on surgical technique, years post-surgery, and individual factors. A 10-year follow-up study found that 41% of BcSy patients experienced WR with the magnitude increasing over time (Monaco-Ferreira & Leandro-Merhi, 2017).

Exercise is recognized as a valuable and clinically effective adjunct therapy for BcSy patients, particularly those who experience WR. Increased physical activity and exercise have been shown to improve insulin sensitivity, preserve muscle mass, and boost daily energy expenditure (Coen et al., 2018). However, the impact of exercise on CRF and metabolic efficiency in the medium and long term after BcSy remains largely unexplored (Ibacache-Saavedra et al., 2022); especially in patients who experienced WR or insufficient weight loss after surgery.

Therefore, the present study aims to elucidate the effects of endurance and resistance exercise on CRF and metabolic efficiency in post-BcSy patients who experienced sub-optimal weight loss 18 to 24 months after the procedure. The study focuses on understanding how each exercise modality influences these outcomes, considering the changes in body composition and metabolic alterations caused by the surgery.

In this study, participants were divided into two groups: one followed an endurance exercise program, and the other adhered to a resistance training regimen.

Both groups trained for 16 weeks with the program being structured into five microcycles. A cardiopulmonary exercise test (CPET) was conducted both before and after the intervention. CRF was assessed based on peak values of relative to body weight (RelBW)  $\dot{V}O_2$ , heart rate, respiratory exchange ratio (RER), speed, and ventilatory threshold timing. Metabolic parameters were evaluated during the final 30 seconds at five speeds common to all participants (3, 4, 5, 6, and 7 km/h), in terms of RelBW  $\dot{V}O_2$ , RER, oxygen pulse, heart rate, and energy expenditure. Comparisons were made within and between groups.

## 1. Literature Review

### 1.1 Obesity Epidemiology

OB is a multifactorial disease defined as an abnormal accumulation of adipose tissue that represents a higher risk for developing other non-communicable diseases such as diabetes or arterial hypertension, resulting in the reduction of disability-free years and life expectancy (Blüher, 2019). Projections suggest that by 2050, excess body weight and related conditions could shorten life expectancy by approximately three years (Cecchini & Vuik, 2019).

OB is usually diagnosed through the Body Mass Index (BMI), a parameter that uses weight and height to categorize the population into four major groups: Underweight is a BMI  $<18.5 \text{ kg/m}^2$ , normal weight is a BMI between 18.5 and  $24.9 \text{ kg/m}^2$ , overweight is a BMI between 25 and  $29.9 \text{ kg/m}^2$ ; and OB is subdivided into three categories, 30 to  $34.9 \text{ kg/m}^2$ , 35 to  $39.9 \text{ kg/m}^2$ , and  $>40 \text{ kg/m}^2$ , of progressive severity (Weir & Jan, 2023).

The WHO, at the beginning of the 21<sup>st</sup> century, published a document giving OB the connotation of “epidemic” to denote its increasing prevalence and growing effect on mortality across different countries around the world (World Health Organization, 2000). Recently, given its widespread prevalence, some academics consider OB as a “pandemic” (Blüher, 2019). The previously mentioned WHO report ends up with recommendations to address the problem that range from focusing on prevention strategies related to physical activity and healthy eating, to highlighting the necessity of new public health policies, and the need for the health care system and community services to adapt and respond adequately to this issue (World Health Organization, 2000, p. 241-251).

Nonetheless, after this robust publication, the number of people classified in the overweight or OB group continued to increase year by year globally. So much so that in 2019, 12% of all deaths from noncommunicable diseases –around 5 million– were attributed to OB (World Health Organization, 2022), of which 1.2 million occurred (WHO Regional Office for Europe, 2022). This is because obesity trends worldwide have continually escalated since 1975. In 2016, it was estimated that 39% of adults ( $\geq 18$

years) had excess weight, of which 13% had OB. While, in the same year, there are reports of prevalence as high as 23.2%, being the severe obesity category the one that seems to grow at a higher pace (Xiao & Graf, 2019). However, children are also affected by a matching trend. By the same year, estimates pointed to 340 million young people (5 to 19 years old) with abnormally high body weight (WHO Regional Office for Europe, 2022).

Specifically, in 2019, 53% of the European Union population had excess body weight with a male-to-female proportion of 60.2% and 45.7% respectively. The tendency is to have more cases in the older cohorts, comparing the 25% of cases with excess body weight in the range from 18 to 24 years old to 65.7% within the age group 65 to 74. Italy is at the bottom of the list with the lowest percentage, 45.7%, while Malta is at the top with 64.8%. Portugal ranks 14<sup>th</sup> out of the 27 countries with three percentage points higher than the average value of 55.9%, with a trend of higher overweight percentage in males (60.9%), compared to females (51.5%) (WHO Regional Office for Europe, 2022).

In terms of OB, specifically, the highest prevalence is presented in women and almost 1/4 of adults in the EU live with OB (WHO Regional Office for Europe, 2022, p. 5). Globally, the number was estimated in 2020 to be around 14% and is expected to increase to 24% by 2035 (World Obesity Federation, 2023, P. 10). Children and adolescents are the population expected to have the steepest increase for the next decade (WHO Regional Office for Europe, 2022, p. 11).

## **1.2 Disease Characterization**

In a simplistic definition, OB is the result of a chronically elevated ratio of energy consumed versus energy spent. Despite this simple perspective, OB results from a complex interplay linking individual physiological susceptibility, such as, but not limited to, inadequate neural activation responses to feeding and energy expenditure, differences in gene expression, abnormal hormonal regulation responses of feeding and hunger, and changes in gut microbiota profile; in conjunction with a constantly changing environment overflowed with physical inactivity and easily accessible, highly

palatable calorie-dense foods. Therefore, OB is caused not by one but by a multiplicity of factors that vary their potency from case to case, hence the adequacy of the term “family of obesities” (Government Office for Science UK, 2007, p. 43).

For this reason, the academic development of the topic has been defining “clusters” in matters of “physiology, individual psychology, individual physical activity, food consumption, food production, social psychology, and physical activity environment” intending to improve the delivery of highly effective and tailored treatment options (Blüher, 2019).

In a population of almost 10.000 individuals with OB, it was possible to determine 7 clusters given health markers such as diabetes, dyslipidemia, or retinopathy, that showed a statistically significant difference in life expectancy between them. The cardiovascular disease/diabetes/surgery subgroup exhibited a significantly higher mortality risk during the 6 years following OB diagnosis and the second highest hazard ratio (HRo) (6.87), while the cluster characterized by not having medical follow-up had the highest HRo (16.87). In contrast, only 9.2% of the sample was categorized in the subgroup of metabolically healthy OB (Takeshita et al., 2024).

Regarding epigenetics, the perinatal period is also a crucial development phase, since the risk of developing OB could be influenced by several factors, some of which include maternal under-nutrition, which reduces growth and negatively affects the fetus's insulin metabolism with consequences regarding the risk of type 2 diabetes and OB development later on life. Maternal exposure to smoking and environmental toxins such as arsenic also influence the future risk of obesity development by the fetus. In fact, several environmental pollutants could be classified as fetal obesogens or endocrine disruptors due to their risk for future obesity development. Also, early life antibiotic exposure has also been linked with a propensity to develop OB (Tirthani et al., 2023).

On the other side, socioeconomic status plays a crucial role in the environmental determinants of risk factors a person may be exposed to since household income seems to have an inverse relationship with OB risk (Kim & Von Dem Knesebeck, 2018). This correlation thought, has been changing over the years. In the late 1900s wealthy people had the highest OB prevalence while in the early 2000s and up to today, middle and low-income countries have had increased OB rates (Templin et al., 2019).

Notwithstanding, education also rises in these countries so the pattern may not be the same as that of wealthier countries at first. In Egypt and Peru, for instance there was no interaction between education, income, and OB, whereas in Jordan and Colombia, higher education combined with income was associated with a 15% lower likelihood of OB (Hruby & Hu, 2015).

At the same time, gender distinctions are also an important aspect of the equation since there might be a correlation between the number of females with excess body weight and the education level attained by them because it is possible to distinguish a decrease in one parameter when the other increases, whereas in the male populations there is not a trend in that regard (Eurostat, 2024). “Indeed, the difference between overweight women with a tertiary education and those with no more than a lower secondary level of education was at least 32 percentage points in Portugal” (Eurostat, 2024). This is replicated in the employment status, out of people not involved in the labor force, women have a definitive higher prevalence of overweight or OB, while in men this factor is not decisive (WHO Regional Office for Europe, 2020, p. 22). Nevertheless, when considering the statistics presented on this topic, it is worth clarifying that, in general, more women than men access health services where data of this nature is collected (WHO Regional Office for Europe, 2020, p. 28).

### **1.3 Diagnosis and Treatment**

The health implications of OB vary according to the degree of excess body weight, as well as the distribution and characteristics of adipose tissue (Ma et al., 2023). Nonetheless, there is a well-established positive association between OB and all-cause mortality (Di Angelantonio et al., 2016). Individuals with a normal BMI tend to have the lowest HRo for mortality, while those in the first half of the overweight category (25 to 27.4 kg/m<sup>2</sup>) have an HRo of 1.08, increasing to 1.2 in the second half. OB grade I is associated with an HRo of 1.45, OB grade II with an HRo of 1.94, and OB grade III with a HRo of 2.76 (Di Angelantonio et al., 2016). Additionally, waist circumference and waist-hip or waist-height ratio are anthropometric measurements that reflect adiposity distribution and are frequently used to further stratify adiposity-related health

risks (De Lorenzo et al., 2019). Total body water, total body counting, neutron activation, hydrodensitometry, dual-energy X-ray absorptiometry, computed tomography, and magnetic resonance imaging (MRI); each have advantages and disadvantages. For example, MRI is optimal for quantifying intra-abdominal fat, nonetheless so far it is not designed to accommodate larger body sizes (Duren et al., 2008). Eventually, if necessary, the diagnostic process could also include specific genetic, metabolic, and hormonal testing.

The treatment of OB encompasses multiple strategies that are often used in combination. These include lifestyle modifications, focusing on dietary and behavioral changes such as increasing daily physical activity, reducing sedentary behavior, and incorporating structured exercise; pharmacological treatments, which in the last years have seen unprecedented advancements in terms of efficacy and security profile; and, finally, bariatric and metabolic surgery-based approaches (Müller et al., 2022).

In the majority of cases, after diagnosis, the first strategy consists of lifestyle intervention with an initial target of 3-5% body weight reduction (Wharton et al., 2020) that could include multiple one-on-one interventions such as a low-calorie diet within the span of 1200 to 1800 kcal/day with a macronutrient distribution according to the patient health history and personal preferences, performing 150-300 min/week of moderate to vigorous intensity physical activity and exercise, and behavioral therapy that includes food diaries, problem-solving, goal setting, cognitive structuring, stimulus control and OB relapse prevention strategies (Wadden et al., 2020). A higher adherence rate is determined by factors such as lower weight loss initial expectations, better mood, and lower BMI at the beginning of the intervention, being male and of older age (Burgess et al., 2017).

With these strategies, some patients can usually achieve 5 to 10% weight loss (WL) initially, but subsequently, most of them experience a progressive weight regain, often returning to pre-treatment levels (Blüher et al., 2023). If behavioral interventions fail to demonstrate improvements in weight or health-related markers within 6 months, and/or the patient has a high BMI associated with OB-related comorbidities, pharmacotherapy is initiated in conjunction with lifestyle intervention (Blüher et al., 2023). For instance, some OB medications are currently considered a long-term weight

management strategy for individuals with a BMI  $\geq 27$  kg/m<sup>2</sup> when associated with comorbidities resulting from excess body fat, such as type 2 diabetes (T2DM) or dyslipidemia, as well as for those with a BMI  $\geq 30$  kg/m<sup>2</sup> (Pedersen et al., 2022).

Pharmacotherapy for the treatment of OB has witnessed a complex historical evolution, starting with medications that exhibited a very unfavorable risk/benefit profile, with several side effects such as nausea, insomnia, suicidal ideation, and even increased cardiovascular risk like arterial hypertension or valvular insufficiency. Typically, a positive correlation existed between the magnitude of the WL and the intensity of the side effects. Nonetheless, the latest approved medications show promising results due to their multi-acting mechanisms of action and favorable risk profile (Müller et al., 2022).

Among these new anti-obesity drugs, glucagon-like peptide-1 (GLP-1) and glucose-dependent insulintropic polypeptide (GIP) receptor agonists, that by acting in central and peripheral structures involved in weight regulation, have been shown to achieve weight losses reaching 25% (Malik et al., 2022). Their promising benefits have been linked to the multiple actions at the CNS and enteroendocrine cells in the gastrointestinal tract (Collins & Costello, 2024).

Bariatric or metabolic surgery (BcSy) is the last line of treatment. There are multiple technical variations of this procedure that combine a reduction of the stomach size, reduction in nutrient absorption, and changes in hormonal signaling that eventually activate satiety signals, favoring reductions in energy intake. Eligibility criteria for BcSy traditionally consist in the presence of class III OB or class II with associated comorbidities caused by OB (Funk et al., 2022), however more recent guidelines have progressively adopted less strict eligibility criteria, due to the long term benefits of tackling obesity at a lower severity degree. In general, BcSy can potentially increase life expectancy by three years compared to patients who undergo different OB treatments, but this is still 5.5 years shorter than the healthy counterparts (Carlsson et al., 2020).

## **1.4 Bariatric Surgery as an Effective Treatment for Severe Obesity**

The first medical community recognition of metabolic and bariatric surgery was in 1954 (Faria, 2017). From there, the techniques were refined year by year until the early 90s when the laparoscopic techniques notably increased the number of procedures performed, still with various negative health consequences and not remarkable WL (Faria, 2017). Currently, the American Society for Metabolic and Bariatric Surgery (ASMBS) endorses five types of bariatric and metabolic procedures for the treatment of OB.

First, the Laparoscopic Sleeve Gastrectomy (LSG) consists of the removal of almost 80% of the stomach contributing to a food intake reduction which, coupled with lower ghrelin secretion, leads to a significant WL. Downsides of this technique include that it is irreversible, and it can cause significant gastric reflux and heartburn. Second, the Adjusted Gastric Band (AGB) is a procedure where an adjustable silicone band is placed at the proximal third of the stomach. Its practice has decreased during the last decade because its results are much less robust and the high rate of long term complications. This technique's disadvantages range from band slippage or erosion, a high re-operation rate, to enlargement of the esophagus. Third, Roux-en-Y Gastric Bypass (RYGB) is a procedure that divides the stomach into two parts. At the top, a smaller gastric pouch is formed and connected directly to the small intestine. The remaining part of the stomach, conveying bile and pancreatic secretions, is also connected to the intestine at a variable distance downstream of the first gastro-intestinal anastomosis. With this method, food skips the first part of the small intestine causing less nutrient absorption. The downsides of this surgery are its higher complexity and surgical time, higher risk of nutrient deficiency, risk of small bowel obstruction, dumping syndrome, and higher risk of stomach ulcer development. Finally, Biliopancreatic Diversion with or without Duodenal Switch (BPD/DS and BPD), and Single Anastomosis Duodeno-Ileal Bypass Sleeve Gastrectomy are also recognized techniques with their own advantages and disadvantages(ASMBS, 2021b).

It is estimated that 279,967 surgeries of this nature were performed in the U.S. in 2022 (ASMBS, 2022). Around 9.2% of adults in the U.S. have severe OB (ASMBS, n.d.), which is represented by almost 24 million people if considering the total 18 years

or older population as 258.3 million (Ogunwole et al., 2021). An estimation would conclude that approximately only 1.18% of people who would be eligible to undergo BcSy end up accessing it in the United States. Nonetheless, from 2015 to 2022, excluding the 2020 data because of the altered values due to the COVID-19 pandemic, this procedure increased by 42.3% with an average annual growth of 5.25% (ASMBS, 2022).

Data on global procedures is still being determined, since just 24 countries provided information for the last 3 years. With this data, it is still possible to conclude that the five countries performing the highest number of surgeries are, in decreasing order, the United States, Brazil, France, China, and Australia. The most frequently performed technique was the LSG (62.5%), followed by RYGB (28.5%), and 81% of the patients were female (Brown et al., 2024).

When analyzing trends from 2016 to 2018, Asia and Central/South America showed a steady increase in bariatric surgeries. In Asia, the number of surgeries rose from 91,000 to 112,000 per year, reflecting a 23% increase. Central and South America experienced a 10% rise, with surgeries increasing from 155,000 to 171,000. Brazil led the region with 56 bariatric surgeries per 100,000 inhabitants, followed by Chile with 42 and Colombia with 37. Conversely, Europe saw a gradual decrease in surgeries, declining from 217,000 to 190,000, a 12% drop. Among European countries, Belgium had the highest rate with 127 surgeries per 100,000 inhabitants, followed by France with 72, while Portugal was at the lower end with 14 surgeries per 100,000 inhabitants (Lazzati, 2023).

The BcSy short term drawbacks include the typical surgical risks of any procedure such as infection, blood clot formation, or bleeding. Also, dumping syndrome, an incompletely understood condition, is characterized by rapid gastric emptying causing sweating, palpitations, dizziness, tremors, diarrhea, and abdominal discomfort. Its incidence is higher with the RYGB technique, at almost 15%, and it appears that fewer cases are reported as years pass post-surgery (D'hoedt & Vanuytsel, 2023). Yet, data available on the matter lacks uniformity and consensus.

Nutrition deficiencies are also a significant issue following BcSy and their treatment depends on the type of procedure: malabsorptive, restrictive, or a combination of both. In general, the highest deficiencies in these patients are iron, copper, zinc,

calcium, folate, and vitamins D and B12. Likewise, protein intake should be at the very least above 60 grams per day, along with the prescription of specific multivitamins and regular check-ups are strategies to keep malnutrition under control (Mohapatra et al., 2020). In closing, elements requiring constant vigilance include the formation of gallstones, the general physiological state, and the readiness to follow the necessary lifestyle changes to sustain the desirable effects.

Furthermore, a key concern is bone health, which tends to decline significantly in the first years following BcSy and continues the same trend even after WL reaches a plateau (Mele et al., 2022). Causes to this decrease are pointed as being related to a mechanical load decrease, reduction of physical activity and micronutrient, and protein deficits together with changes in gastrointestinal physiology affecting the signaling of leptin, ghrelin, estrogen, testosterone, insulin, peptide YY, GLP-1 and adiponectin (Sayadi Shahraki et al., 2022).

A study with a sample of 12.676 patients who underwent BcSy, 38.028 patients with OB that followed non-surgical treatment, and 126.760 controls, showed that after 4 and a half years of follow-up, fracture rates were significantly different between groups, namely 4.1%, 2.7%, and 2.1%, respectively. Moreover, after BcSy, the fracture risk profile changed towards a higher probability of experiencing upper limb, spine, pelvic, or hip fractures, whereas before BcSy the risk was primarily of lower limb fractures. However, more research needs to be conducted on the long-term bone health outcomes of BcSy (Rousseau et al., 2016).

Finally, weight regain (WR) is a major challenge faced by BcSy patients. Irrespective of the lack of uniformity in the measures used, weight regain seems to vary according to the type of surgery performed. Using the 50% excess weight loss (EWL) benchmark, studies show that 10 years after surgery, AGB patients experienced a 38% regain of their peak mass loss recorded in the first 12 months, while LSG patients showed a 27.8% WR after 7 years (El Ansari & Elhag, 2021). In contrast, when defining WR as more than 25% of lost weight regained from the nadir weight, a 5-year follow-up registered a WR in 35.1% of LSG cases and in 14.6% of patients undergoing RYGB (Baig et al., 2019). As a result, comparing WR across different samples is challenging due to the lack of consensus regarding measurement definitions, analytical methods, and the lack of longitudinal profiling of WL trajectories over time. For

instance, in 1.406 RYGB patients 1-year after the procedure, the WR was 5.7%. In the second, third, fourth, and fifth following years, the rate was 10.1%, 12.9%, 14.2% and 15% (Noria et al., 2023). In general, factors associated with WR are positively related to poorly controlled appetite, emotional instability, and problems with the surgical technique; and negatively related to adequate social support, plasma high-density lipoprotein concentrations, and postprandial GLP-1 (Athanasiadis et al., 2021).

Nevertheless, the expansion and refinement of this line of treatment have yielded remarkable outcomes, not only in the short term but also, significantly, in the long term. A follow-up at 10 and 20 years showed that BPD and RYGB resulted in EWL of 71% and 60%, respectively (O'Brien et al., 2019). A research cohort consisting of 65.000 surgical patients compared with 105.000 non-surgical controls followed for almost 6 years revealed that the procedure was associated with a 49.2% reduction in the mortality hazard rate and an increase in 6 years of life expectancy (Syn et al., 2021).

In terms of health markers, undergoing this procedure could prompt type 2 diabetes remission at a rate of 33 to 90% in contrast with pharmacological treatment that induces zero to 39% remission (Affinati et al., 2019). Eleven RCTs showed that BcSy decreased HbA1c by 1.8 up to 3.5% with a tendency to minimize the prevalence of type 2 diabetes every year after surgery, within the first 5 years (Arterburn et al., 2020).

At the same time, there is a cardiovascular risk reduction given that, but not limited to, after surgery there seems to exist a decline in the sympathetic response causing an initial decrease in blood pressure. RYGB resulted in a decrease of 9 mmHg of systolic BP in the first week after surgery in hypertensive and normotensive patients, unassociated with WL. After six to thirteen months there was an additional decrease of 5 mmHg. Some of the mechanisms intervening in this normotensive process come from the renal, muscle, and renin-angiotensin-aldosterone system (RAAS) hypoactivity in conjunction with higher insulin sensitivity and reduced chronic low grade systemic inflammation, among other factors like the gut response (Samson et al., 2020).

The remission rate for hypertension one-year post-surgery is about 43 to 83% yet, in the long term, it seems that almost half of patients (44%) get back into antihypertensive medications. Aging and weight regain seem to be major contributors to this relapse (Arterburn et al., 2020). Almost all bariatric surgical procedures, except for AGB, appeared to have a statistically significant effect on the decrease of total

cholesterol and triglycerides, and an increase in high-density lipoproteins in the first year post-procedure (Nussbaumerova & Rosolova, 2023).

The apnea-hypopnea index (AHI) also shows that, after BcSy, there is a remission rate of 65% for obstructive sleep apnea (OSA), going from an average of 35 apnea events/hour to 14.2 events/hour in the postoperative phase. In addition, the Epworth Sleepiness Scale indicates that a statistically significant reduction in daytime sleepiness was present in those with OSA who underwent BcSy (Al Oweidat et al., 2023). In the long run, those patients who have an increased risk of OSA are characterized by having fewer years of education, a higher BMI, arterial hypertension, and less WL (Barbosa et al., 2022).

In terms of overall cancer risk, patients who underwent BcSy have significantly lower odds of cancer incidence compared to patients of the same OB category treated without a surgical approach (Wiggins et al., 2019). However, focusing only on OB related cancers such as breast, prostate, colorectum, endometrium, ovary, kidney, liver, and pancreas, it is possible to observe that in men there was no association between BcSy and lower odds of incidence of OB-related cancer; while in women there was a trend, with statistical heterogeneity, towards a reduction in OB-related cancer (Wiggins et al., 2019). This trend continues during the first decade post-surgery with a 33% hazard reduction for all types of cancers and a 41% reduction for OB-related cancers. The female population, 80% of the sample, still seems to have a stronger tendency towards protection than males (Schauer et al., 2019).

Patients undergoing BcSy seem to rate their health-related quality of life higher one to two years after the procedure. However, after five years, this improvement shows a decline, though it still remains higher than pre-surgery levels. In general, the score with better outcomes after BcSy is the physical, while the mental health score has modest modifications (Coulman & Blazeby, 2020). As an example, losing weight is related to osteoarthritis symptoms reduction due to less overload as well as less chronic low grade inflammation. It is plausible to argue that BcSy is effective in reducing knee osteoarthritis and pain but to what extent and for how long is not completely established (Üstün et al., 2019). Additionally, of all patients with osteoarthritis who underwent the surgery, those who reported significantly less use of analgesics 12 months after the procedure were those with substantial WL (Zeng et al., 2021).

Despite the persistent benefits observed, there are still barriers to accessing this procedure when necessary. These obstacles could come from multiple aspects, namely the patient itself but also from the primary care physicians, specifically, from their literacy on the matter (Conaty et al., 2020). In a sample of 5982 potential candidates for surgery, the withdrawal rate was 61.2%. Individuals who did not undergo the procedure were characterized as being male, older, single, non-white, living in poorer areas, and unemployed (Hlavin et al., 2023).

In conclusion, BcSy is a very effective treatment for OB, a chronic disabling condition. Its strengths include the effectiveness in WL, and the improvement of type 2 diabetes, joint pain, arterial hypertension, sleep apnea, lifespan, and healthspan. Nevertheless, there are some limitations associated with this procedure. For instance, fat-free mass (FFM), composed of bone, internal organs, water, and muscle; is a concern in patients undergoing this procedure due to its rapid loss and potentially negative effects on metabolic health. FFM is one of the relevant components of resting energy expenditure (REE), the measurement that reflects the cost of all vital physiological functions, such as respiration, body temperature regulation, tissue remodeling, and cardiac output. In general, REE makes up for ~60 to 75% of the total energy expenditure (TEE), which is also composed of ~10% of the thermic effect of food (TEF), and ~15 to 30% of the energy expended in physical activity (EEPA) in a person with normal BMI. Therefore, REE is one of the most determinant factors when contemplating weight management, even more so if it is after BcSy because it is influenced by body size. A reduction of 10 kg in body weight would translate into a TEE reduction of about 200 kcal/day (Johnson & Coward-Mc-Kenzie, 2001). Furthermore, body composition, influenced by factors such as age, sex, physical activity, and diet, plays a significant role in energy expenditure (EE), with changes in these variables having a similar impact on overall metabolic health (Johnson & Coward-Mc-Kenzie, 2001).

Exercise interventions could aid in the mitigation of FFM loss by promoting muscle tissue hypertrophy, bone formation, hormonal regulation, improved mitochondrial metabolism, increased EEPA, and optimized neuromuscular function (Lanza, 2015). An RCT initially including 100 participants divided into three groups, patients who underwent bariatric surgery (RYGB-G), patients who underwent the

procedure and enrolled in the exercise training program lasting 6 months with a frequency of 3 times per week, each session including a first part dedicated to resistance exercises and a second one to aerobic training (RYGB+ET) and an age-matched healthy lean control group. Analysis was performed before surgery (baseline), at the start of the training program, three months after surgery (POST3), and at the end of the intervention (POST9). The latter parameter showed a significant difference in lower limb FFM loss within RYGB-G and RYGB+ET (3.8 and 2.7 kg respectively). RYGB+ET showed values in POST9 analysis of absolute and relative strength closer to or significantly higher than the baseline, while RYGB-G did not evidence positive fluctuations. In terms of muscle remodeling, at POST3, both groups had considerable type I and type II fiber cross-sectional area decreases. However, a difference between groups was found at POST9 with RYGB+ET attaining baseline cross-sectional area. Still, both groups exhibited a statistically significant reduction in type I muscle fiber myonuclei. This analysis emphasizes the necessity of including exercise training bariatric surgery (Gil et al., 2021).

On the other hand, an intervention with 50 subjects starting 3 months after surgery and lasting twelve weeks with training sessions three times per week, including 35 minutes of endurance exercise followed by 25 minutes of resistance exercise, showed that cardiorespiratory fitness (CRF) was improved in the exercising group due to an increase in global longitudinal strain, a proxy of the cardiac stretching magnitude every cycle, from 19.6 to 20.2%, resulting in an improvement in left ventricular systolic and diastolic function. Therefore, left ventricular diastolic dysfunction prevalence was reduced in the exercise group, 58 to 50% while increased in the surgical/non-exercise group from 41 to 53%. Also relevant, the exercise group displayed better scores in the utilization of oxygen during exercise. The differences were statistically significant when comparing  $\dot{V}O_{2peak}$  and were even more relevant when comparing relative aerobic capacity based on  $\dot{V}O_{2peak}$  relative to body mass, and the most notable difference was found when comparing  $\dot{V}O_{2peak}$  relative to mid-thigh muscle mass. After surgery, CRF improved with exercise not just because of the lower cost of moving a lighter body structure but also because there was better oxygen delivery and utilization by the muscle (Auclair et al., 2021).

CRF has a very well-established negative correlation, both in healthy individuals as well as in those with associated comorbidities, with all-cause mortality, cardiovascular disease, and some types of cancer (Gaesser & Angadi, 2021). Given its integrated reflection of oxygen delivery and utilization, CRF can be used as an integrative measure of the functional capacity of pulmonary ventilation and diffusion, systolic and diastolic function of the right and left ventricle, ventricular-arterial interaction, and the blood vessels' capacity to transport and deliver oxygen and nutrients from the heart to meet the needs of muscle cells when they are under stress (Ross et al., 2016).

A study with a sample of 750,000 subjects between 30 to 95 years was analyzed in terms of METs attained during a standardized treadmill exercise test resulting in a stratification adjusted by sex, age, and CRF percentiles. The statistical analysis resulted in the formation of 6 groups: least fit <5 METs, maximal oxygen use capacity of 17.5 ml/kg/min (HR: 4.09), low fit <7 METs (HR: 2.88), moderately fit <9 METs (HR: 2.13), fit <10.5 METs (HR: 1.66), highly fit <12 METs (HR: 1.39), and, above that, extremely fit. Results showed that every 1 MET increase in exercise capacity translated into an adjusted decrease in mortality hazard ratio (HR<sub>o</sub>) of 0.86. At the same time, there could be a 50% mortality risk reduction if ages 30-49 were around 11 METs, 50-59 are around 10 METs, 60-79 are around 8 METs, and >80 are around 7 METs in terms of CRF. In general, men classified in the fit and highly fit groups lived 4.5 years longer compared to the least fit. When compared to the extremely fit, the difference is 6 years. For women, the result is 2.5 and 6.7 years, respectively (Kokkinos et al., 2022).

Stratification of subjects, such as the previous one, is accurately done when using valid and standardized assessment procedures. Therefore, the information veracity relies on the validation of the method applied. For assessment of cardiorespiratory fitness there are a variety of maximal, submaximal, laboratory, and field tests. However, the gold standard to do so is the cardiopulmonary exercise test (CPET), a tool increasingly available to a variety of professionals.

## 1.5 Cardiopulmonary Exercise Testing (CPET)

CPET is a test that applies, usually, progressively escalating exercise intensity until the appearance of symptoms or complete exhaustion with the intention to evaluate the cardiovascular, pulmonary, muscular, and metabolic response to progressively increasing physical effort. The symptoms that prompt stopping the test could range from chest pain, dyspnea, dizziness, and palpitations to intermittent claudication, nausea, or severe fatigue. To perform the test, a treadmill or a cycle ergometer are usually chosen based on local preferences, the patient's expected fitness level, and/or exercise training history. A gas exchange analyzer is also used to determine gas volumes, O<sub>2</sub>, and CO<sub>2</sub> concentration, and an electrocardiograph is also frequently employed to monitor cardiac electrical activity and the potential occurrence of arrhythmias or signs of myocardial ischemia (Tran, 2018).

The most important measurement of the test,  $\dot{V}O_2$  max, reflects the highest rate of oxygen extraction attained during the test. However, not everyone can meet at least two criteria for confirming maximal effort. These criteria include an evident plateau in  $\dot{V}O_2$  consumption, achieving >90% of the age-predicted maximum heart rate, subjective exhaustion, a blood lactate concentration of  $\geq 8$  mmol/L (when measured), or a respiratory exchange ratio (RER)  $\geq 1.15$  when it follows a typical incremental pattern aligned with the applied intensity (Pritchard et al., 2021). When maximal effort cannot be confirmed, oxygen consumption data should be interpreted as  $\dot{V}O_2$  peak rather than  $\dot{V}O_2$  max. An abnormal result is found below 85% of the predicted value for the patient's age and gender and can determine the severity of conditions related to the cardiovascular and respiratory systems, such as pulmonary hypertension, heart failure, or chronic obstructive pulmonary disease (Herdy et al., 2016).

Within many other parameters, for the post-bariatric surgery population, it is important to recognize the first ventilatory threshold (VT1), the moment when there is an increased reliance on anaerobic metabolism. This anaerobic threshold should be around 40 to 65% of the  $\dot{V}O_2$  peak (Herdy et al., 2016). If the exercise intensity continues increasing, another physiological landmark will be attained and is identified in CPET as the respiratory compensation point (VT2). Healthy individuals reach it usually between 70 to 85% of  $\dot{V}O_2$  peak. After VT2, in an attempt to respond to

metabolic acidosis, minute ventilation (VE) and oxygen uptake no longer have the same rising trajectories (Martini et al., 2022). Given that obesity and weight regain are positively associated with type II muscle fibers expression, while BMI is negatively associated with type I fibers, it is relevant to evaluate whether an exercise training program alters in any way VT1 or VT2 in an intention to correlate latter thresholds with an improved muscle response and adaptations to energy demands (Damer et al., 2022).

The respiratory exchange ratio (RER), another parameter recorded during CPET, reflects the relationship between aerobic and anaerobic metabolism. Based on the formula  $VCO_2/VO_2$ , it is associated with the type of macronutrients being oxidized to produce energy. A RER of 0.7 portrays predominantly a metabolism of fatty acids, while RER of 1 reflects that most energy is produced based on glucose oxidation (Patel et al., 2024). In a study group of 419 subjects with similar characteristics in terms of REE, REE/FFM, CRF, energy intake, and physical activity; it was possible to establish two different clusters according to the RER. Low to moderate was  $0.766\pm 0.025$ , and a high RER was  $0.841\pm 0.032$ . A one-year follow-up showed that the latter group had a significant increase in adipose tissue ( $P<0.001$ ) and overall body weight ( $P<0.05$ ) (Shook et al., 2016).

Furthermore, research at the cellular tissue level demonstrated that both glucose and fat oxidation capacity were significantly lower in individuals with OB (Lund et al., 2018). When myotubes from lean individuals were exposed to insulin, there was a significantly higher rate of glucose oxidation, while non-oxidized glycolytic products remained unchanged. In contrast, in samples from patients with severe obesity, results were reversed, showing no significant increase in glucose oxidation but a notable accumulation of non-oxidized glycolytic products (Zou et al., 2019). This suggests that individuals with severe OB have an impaired ability to use substrates like lactate or pyruvate for ATP production, alongside increased  $H^+$  accumulation, which may contribute to an earlier onset of fatigue.

Physiological indicators during recovery after a maximal exercise test are also relevant indicators of cardiorespiratory fitness and health. The difference in heart rate at the maximum workload attained and at the end of the first minute of recovery should be higher than 12 beats (Cole et al., 1999). In a sample of 2443 patients undergoing CPET,

3.6% had an impaired heart rate recovery (HRRe). This finding was three times more prevalent in the obesity group and twice in the overweight group, as well as for those in the cohort divided by hypertension and diabetes. Additionally, every increase in one MET would be reflected in an 11% reduction risk of impaired HRRe (Barbosa Lins et al., 2015). These variables evidence the relevance that assessing CRF has in any population, but even more in those with comorbidities. As an illustration of this, pre-operative VT2 seems to have an inverse relationship with post-operative complications and length of hospital stay in patients who have undergone BcSy (Hennis et al., 2012). On the other hand, a CPET performed one week before BcSy with a follow-up 4 months later, showed that adjusted for new body weight,  $\dot{V}O_2$  peak diminished in the second evaluation, while total oxygen utilization, VT1, HRR2 in minute 2, and  $\dot{V}O_2$  recovery kinetics, significantly improved. It should be also noted that sample data regarding weight loss, lean mass loss, or body composition alteration were not provided. Therefore, caution must be taken when transcribing the expectations derived from these results to all patients who underwent this procedure. Nonetheless, BcSy represents a meaningful improvement in autonomic dysfunction attributed to metabolic and weight changes (Remígio et al., 2018). Compared with controls, patients with OB after BcSy, and even 18 years after, have a significantly lower cumulative incidence of fatal cardiovascular events and total cardiac events (Lee & Cha, 2016).

## **1.6 Exercise Interventions**

Structured physical activity in a population with OB or after BcSy should have the main objective of CRF improvement given its significant role in risk reduction. For instance, according to BMI, the hazard ratio of CVD death in normal-weight unfit men was 3.1. Conversely, those with OB who were fit demonstrated a substantially lower HRo of 1.6, while the unfit group with obesity presented the highest HRo of 5. In general, CRF in the highest categories of BMI has a negative association with emerging psychiatric disorders, certain cancers, disability, heart failure, hepatic steatosis, and white adipose tissue predominance (Ortega et al., 2018).

Because of this, the European Association for the Study of Obesity exposes a compendium of evidence on the effect that various types of exercise could have on a variety of health outcomes in this population. However, the magnitude of each parameter is not yet adequately quantified. Specifically, in regard to physical fitness and with high strength of evidence, it is stated that aerobic (AE), resistance (RE), combined (CE), or high intensity interval training (HIIT) exercise programs can increase  $\dot{V}O_2$  max. Additionally, RE or CE can enhance muscle strength. Finally, evidence with low robustness also suggests that HIIT and AE are superior to other alternatives in improving  $\dot{V}O_2$  max. Regarding cardiometabolic health, all indicators with high credibility declared that all exercise programs improve insulin sensitivity markers, reduce systolic and diastolic blood pressure by around 3mmHg and 2mmHg respectively, and reduce intrahepatic fat accumulation. Particularly regarding BcSy considerations, high strength of evidence shows that AE, RE, or CE generate additional weight loss ( $\pm 2.5$ kg) after surgery, significantly improving  $\dot{V}O_2$ max, walking distance, and muscle strength. Moderate quality of evidence also supports the notion that AE, RE, or CE effectively reduce FFM loss during the first postoperative year. Besides, AE is the ideal strategy to ameliorate insulin sensitivity. Finally, with the least reliable evidence, it is stated that any type of exercise pre-surgery will contribute to weight loss after the procedure. The evidence and its level of certainty are concluded by comparing subjects enrolled in exercise prior to surgery with adequate surgical controls not engaged in exercise (Oppert et al., 2021).

Consensus on exercise prescription guidelines frequently vary according to the entity developing them, yet there seems to exist an agreement on the benefits of integrating both resistance and aerobic exercise in post BcSy patients. To sustain the benefits obtained after BcSy, 150 min/week of moderate physical activity does not seem to be enough, instead, about 300 min/week at 50 to 80% of max heart rate will be required. Lower intensities will require more time to achieve the ideal energy expenditure and vice versa, but this can effectively be achieved by splitting sessions along most days of the week and involving the greatest muscle mass as possible namely with exercises that involve walking or swimming. Likewise, resistance training should be performed at moderate to high intensity ( $\pm 70\%$ RM) for 2 to 3 sets of each exercise

and recruit significant muscle groups within the range of 10 to 15 repetitions three times per week (Hansen et al., 2020; Tabesh et al., 2019).

Probably, RE is the least researched of the exercise types within post-BcSy patients. A systematic review (Morales-Marroquin et al., 2020) composed of nine papers on the matter, showed mixed evidence with five studies concluding that there was no difference in FFM loss, cross-sectional muscle area, or fat mass reduction, while two other papers reported a significant difference in body composition and three concluded the contrary. Despite that, the most relevant result showed a significant increase in strength in seven interventions.

Regarding CRF, RE seems to have little or no effect but as of today, there is limited literature on the matter. On the other hand, what is feasible to conclude is that RE and high intensity RE seem to be safe for post-bariatric surgery patients (Mahmoud et al., 2022). At the same time, CE has been the most widely studied type of intervention in recent years. In a meta-analysis about the role of exercise in post-BcSy patients, 54% of the sample underwent CE (Bellicha et al., 2021). CE might have greater benefits than RE and AE on weight loss (-5.02 kg) and BMI reduction (-1.62 kg/m<sup>2</sup>). On average, each intervention had sessions lasting anywhere from 40 to 60 minutes with a frequency of 2 to 5 days per week in a period of 12 to 26 weeks. The prescription regarding the aerobic component was specified in all papers between 50 and 70%  $\dot{V}O_2$  max, but just one study described in detail the resistance training component, being 60% of 1RM (Boppre et al., 2022).

There appears to be an agreement that CE has a positive impact on CRF. Out of seven trials, 6 reported improvements in  $\dot{V}O_{2peak}$  or in the 6-minute walking test, thus enabling the inference that CE benefits ventilatory efficiency, and functionality and reduces FFM losses. In contrast, AE seems to be the method that may have the highest influence on improving CRF (Mahmoud et al., 2022).

BcSy's inherent benefits, as discussed earlier, include reductions in resting heart rate and blood pressure, but at the same time can exacerbate impaired muscular aerobic function commonly due to a significant and rapid loss of lean mass (Zhou et al., 2022). Limited muscular oxidative capacity is crucially related to a lower REE (Zampino et al., 2020), aging (Migliavacca et al., 2019), mitochondrial capacity (Fleischman et al., 2023), and physical inactivity (Gram et al., 2014), among other aspects. A modest

sample size of thirteen individuals reported a robust structured profile including anthropometric, body composition, metabolic, ventilatory, and physical activity characteristics in relation to the CPET results obtained before surgery and 6 months after. The study's most outstanding conclusion was related to the possible link between a 12% lean mass loss and a significantly lower VT1 achieved after surgery, emphasizing the hypothesis of skeletal muscle energy production dysfunction as a result of rapid weight loss after surgery. In addition, assessment of total and regional body composition via DXA enables establishing a positive correlation between the amount of lean mass in the lower extremities and the level of  $\dot{V}O_2$  at VT1 in a CPET conducted on a cycle-ergometer (Vibarel-Rebot et al., 2023; Zhou et al., 2022).

As a result, bariatric surgery decreases body mass and lean mass, thus negatively affecting  $\dot{V}O_2$  max value. Once it is relativized according to the lean mass or the new weight, the effect stops having a negative trend. In general, AE by itself was not effective in improving weight loss or FFM, yet it had a statistically relevant effect on mitochondrial biogenesis and work capacity. Also, the mechanisms to achieve this significant CRF improvement seem to be varied. AE seems to generate effects at the cardiovascular level, for example by improving heart rate variability, as well as to a metabolic extent given that insulin sensitivity increases through the decrease in intramyocellular triglyceride and ceramide accumulation. A dose-response relationship is verified when performing AE, positive results have been reported with as low as 58 min/week of AE, but with greater benefits being achieved with longer durations (Mahmoud et al., 2022).

On the contrary, a much larger population of N=2351 subjects, 2 years after BcSy, demonstrated a significant increase in  $\dot{V}O_2$ max/FFM, from 41,94 to 49,67 ml/kg FFM/min. Based on the Baecke questionnaire to measure habitual physical activity (Baecke et al., 1982), those who recorded a higher score in the sports factor showed a stronger CRF, while leisure and work activities were not influential (Tettero et al., 2018). Relating two facts, firstly, Baecke reported that the level of education was positively associated with the sport indicator scale just in the female population (Baecke et al., 1982); secondly, since 80% of this Dutch sample was made up of females, it is possible to infer that CRF enhancement and comorbidities reduction would not be the same for patients after BcSy in countries with high, middle or low education rates.

In the mid-term, a five-month HIIT and RE program performed three times per week, each session lasting 50 minutes and with defined progression phases, showed to improve cardiovascular risk factors and physical fitness. Blood glucose, cholesterol, and waist-to-height ratio were also significantly reduced by the end of the intervention. Nonetheless, two months after it, all mentioned values increased significantly. Before, at the end and two months after the intervention, blood glucose changed from 75.9 to 62.5 to 70.7 mg/dL<sup>-1</sup>, cholesterol varied from 212 to 187.4 to 207 mg/dl<sup>-1</sup>, and waist-to-height ratio from 0.634 to 0.621 to almost pre-intervention levels. These findings demonstrate that exercise remains beneficial even if it is started much later after the surgical procedure, three years in this case, but also emphasize how these beneficial effects rapidly fade out once exercise stops (Marc-Hernández et al., 2020).

### **1.7 Research Status and Future Perspectives**

Research on BcSy is extensive and well-established, providing a substantial and reliable foundation for understanding its outcomes and impacts. Mental, physical, and social areas have been studied, as well as advantages, disadvantages, and life expectancy. However, exploration of more detailed aspects is at best in an immature state. Trustworthiness updated statistics on specific continents or global types and the number of procedures is non-existent. For instance, just 42% of the International Federation for the Surgery of Obesity and Metabolic Disorders (IFSO) national associations provided corroborated data on BcSy performance and type in the 2020-2021 global trend analysis (Angrisani et al., 2024).

Health outcomes stratified by socioeconomic background and long-term longitudinal studies on physical activity interaction with bariatric surgery outcomes are topics lacking adequate development. The primary challenge may lie in the small sample sizes, which are often further reduced over the course of a longitudinal study, diminishing the study's overall impact. An eight-year follow-up started with a sample size of 65 patients and at the 96th postoperative month, there were just 4 individuals to assess variables related to weight changes. The attrition rate was 94% (Tan et al., 2022).

Specifically, when evaluating the impact of exercise, the small sample sizes often hinder the ability to establish a definitive exercise prescription for this population. While academic consensus acknowledges the benefits of physical activity, there is a gap in precisely quantifying and characterizing the optimal exercise guidelines for these individuals (ASMBS, 2021a; NHS UK, 2024; Shiao & Biertho, 2020; Yates et al., 2017). Additionally, most research focuses on short-term effects, with limited scrutiny of outcomes several years post-surgery.

Currently, there is a dearth of published research investigating the most appropriate type of exercise for post-BcSy patients. In particular, there is a notable absence of studies exploring the effects of three different types of programs, CE, RE, and AE, within the same pool of subjects. Consequently, any conclusion drawn regarding the benefits and impact of each exercise topic is based on the heterogeneity of different protocols, even less ensuring the replication of the results of a given investigation by mixing exercise technique prescription, along with the sample social and physiological characteristics.

In terms of CRF, the research on the post-BcSy population is conclusive to estimate a decline in absolute  $\dot{V}O_{2peak}$ . Still, when normalized by new body weight or lean mass, relative CRF could be preserved or even improved. However, this tendency has not been studied through a medium or long-term period (Ibache-Saavedra et al., 2022). Given the importance of CRF as a strong predictor of mortality and future cardiovascular disease, it is imperative to extend research to long-term outcomes and distinguish between exercise and physical activity as separate factors. While CRF can improve with as little as 150 minutes of physical activity per week -the general recommendation- it needs to be specifically assessed in post-bariatric patients, who experience significant changes in body composition and metabolic systems following surgery (Ross et al., 2016).

Consequently, meta-analyses on the matter are at the level of  $\dot{V}O_{2peak}$  evaluation, needing further information to conclude statements from more elaborated cardiorespiratory kinetics parameters (Ibache-Saavedra et al., 2022). Whereas the present academic work endeavors to increase the volume of analyses on the more detailed evaluation of CRF in post-BcSy patients considering that developing these

topics is vital to adequately determine the contribution of exercise to enhancing their quality of life.

As CRF involves the interaction between the circulatory system and the efficiency of oxygen utilization by the muscles, this study aims to ascertain the respective impact of AE and RE on overall CRF, in order to determine which could be more effective for these patients. While prevailing technical knowledge suggests that AE is most effective in enhancing CRF, the necessity for adequate FFM to generate positive outcomes prompts consideration of the potential significance of RE in post-BcSy patients. Thus, this study seeks to elucidate the extent to which RE may contribute to enhancing CRF levels in this specific population and to determine if these improvements are comparable to those obtained with AE.

A novel aspect of this study is the CPET detailed analysis, which provides relevant information to delineate post-BcSy patients' CRF profile and the potential effects of different types of exercises. Additionally, this research includes an analysis of cardiac workload behavior at each relevant stage of the test. Findings from this study will furnish valuable information for future integration into the management of patients after the procedure, thereby enriching overall treatment and medical follow-up.

## **2. Aims of the Study**

### **2.1. Main objective**

To evaluate and compare the effects of endurance exercise and resistance exercise on CRF and energy production efficiency in post-BcSy patients who experienced sub-optimal weight loss 18 to 24 months after the procedure. The study focuses on understanding how each exercise modality contributes to the improvement of these aspects, considering changes in body composition and metabolic alterations resulting from the surgery.

### **2.2. Secondary objectives**

1. To analyze the adaptability and response of CRF in post-bariatric patients with sub-optimal WL, by comparing two types of exercise interventions: endurance and resistance training.
2. To determine whether resistance exercise can yield comparable improvements in CRF to endurance exercise, particularly considering the role of FFM, and its alteration due to BcSy.
3. To conduct a detailed CPET analysis to delineate the CRF profile and evaluate cardiac workload behavior and metabolic response at different stages of the test.
4. To provide insights into the clinical management of this population by integrating exercise interventions that optimize CRF, contributing to improved long-term quality of life.

### **3. Materials and Methods**

#### **3.1 Study Design**

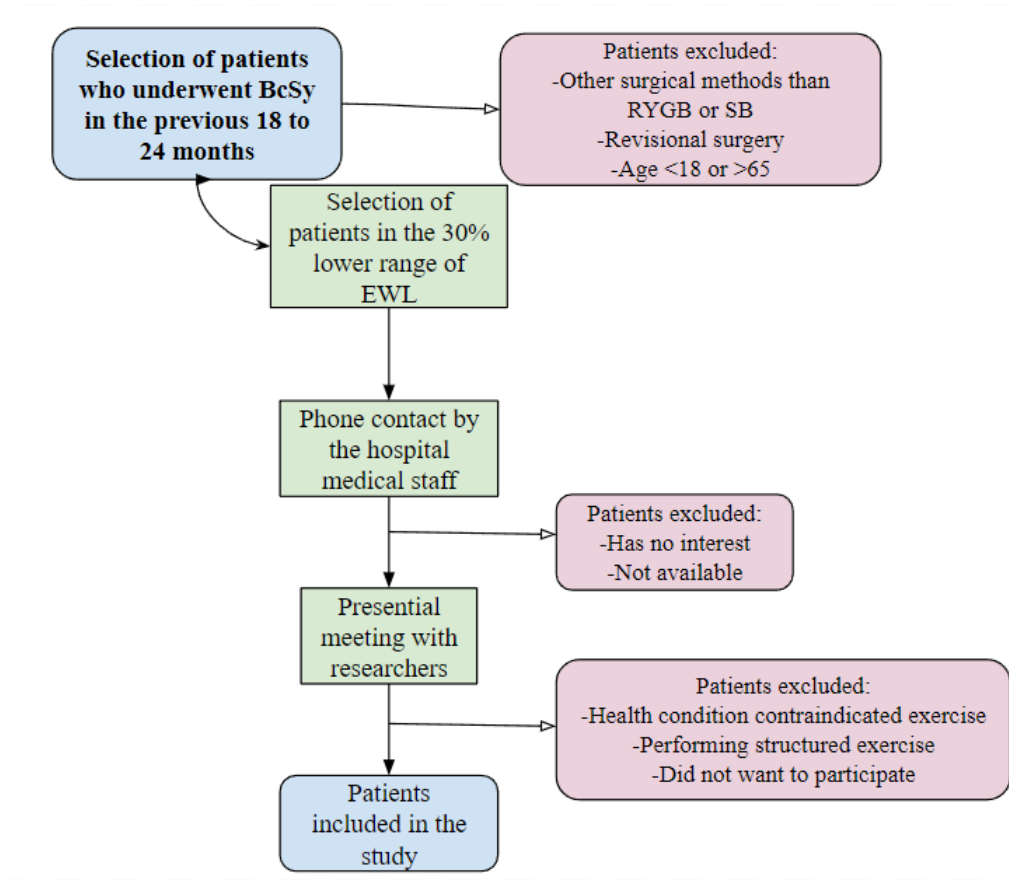
Single center, open label, randomized clinical trial with 2 study arms, [endurance exercise (EEG) and resistance exercise (REG)] performed in adult patients of both genders that underwent bariatric surgery in the preceding 18 to 24 months and displayed a sub-optimal weight loss.

#### **3.2 Recruitment**

Participants were recruited in two cohorts from patients who underwent primary BcSy in the preceding 18 to 24 months at São João Hospital Medical Center. The recruitment process is outlined in *Figure 1*.

In the initial selection phase, all patients who had undergone primary RYGB or LSG were identified. Relevant data such as age, height, and weight at pre-surgery, and at 6, 12, 18, and/or 24 months post-surgery were extracted from follow-up nutrition or endocrinology medical appointment records. Contact information was also recorded for potential follow-up. Inclusion criteria were based on three conditions: a) age between 18 and 65 years at the end of the cohort intervention; b) primary BcSy performed 18-24 months ago, and c) being in the lower 30% range of excess weight loss of the medical records at 18 or 24 months post-BcSy. This metric was established using the upper limit for an ideal BMI (24.9 kg/m<sup>2</sup>). Exclusion criteria included: a) any health conditions contraindicating endurance exercise of moderate to vigorous intensity or resistance exercise; b) participation in structured exercise programs; and c) inability to commit to the exercise intervention classes and assessment schedule. Eligible participants identified through the medical records were afterward contacted by the São João medical staff and informed about the study design and participant roles. Interested patients attended a personal meeting where details regarding study design, potential benefits, risks, and logistics of the assessments and training program were presented. Participants also received a written informed document detailing the study characteristics (*Appendix A*), and an informed consent form (*Appendix B*).

**Figure 1:** Recruitment Process.



*The figure illustrates the exclusion and inclusion criteria from the initial recruitment stage, through the last stage of potential candidates' selection from the Hospital de São João bariatric surgery unit. Each of these phases shows the eligibility evaluation at that point of the recruitment process.*

### **3.3 Randomization, Assessments, and Measurements**

Participants were anonymized upon enrollment by the assignment of a six-digit unique code. After completing the pre-intervention assessments, all subjects willing to participate in the study that met the inclusion criteria were randomly assigned to either the endurance exercise training group (EEG) or the resistance training group (REG). Randomization was done by a team member with no prior patient contact, using a random sequence generated on [www.random.org](http://www.random.org). The allocation list was then

communicated to the participants. Assessments were conducted over two separate visits, seven to ten days apart, at the CIAFEL Physiology Laboratory (Faculty of Sport, University of Porto; FADEUP). The assessment schedule is shown in **Table 1**. The first series of assessments were conducted between 8 a.m. and 12 p.m. after a 12-hour overnight fast. The subsequent assessment took place between 8 a.m. and 5 p.m.

**Table 1:** Assessments distribution.

First assessment round		Second assessment round
<ul style="list-style-type: none"> <li>- Par-Q</li> <li>- Anthropometry</li> <li>- Body Composition</li> <li>- Resting Metabolic Rate</li> </ul>	<i>7 to 10 days interval</i>	<ul style="list-style-type: none"> <li>- Cardiorespiratory fitness test</li> </ul>

*Table 1 describes the overall organization of the assessments to which all participants were submitted. The first round of assessments was scheduled between 8 a.m. and noon after a 12-hour fasting, while the second round took place between 8 a.m. to 5 p.m. All the assessments were carried out at the CIAFEL Physiology Laboratory, Faculty of Sport, University of Porto.*

### 3.4 Pre-exercise Screening

Participants' health status was evaluated through a questionnaire, divided into three sections (**Appendix C**). The first section addressed cardiovascular, pulmonary, endocrine, osteoarticular, and gastrointestinal conditions. The second section focused on symptoms experienced during physical exertion, such as dyspnea, chest pain, and syncope. The third section inquired about current medications and treatments. Cardiometabolic risk factors were also assessed during the second round of evaluations, which included weight, height, waist and hip circumference, BMI, and waist-to-hip ratio. Patients with absolute contraindications to participate in the exercise intervention detected at this stage were excluded.

### **3.5 Anthropometry**

Anthropometric measurements were taken between 8 AM and 12 PM after a 12-hour fasting. Participants wore light clothing and socks and removed all jewelry. Height was measured using a fixed stadiometer (Seca 213) and the measurement was recorded to the nearest 0.1cm. Participants were instructed to place their feet together, knees fully extended, and with their head facing forward in a neutral position. Afterward, the technician would descend the measuring platform until it reached the participant's vertex. Two repeated measurements were taken, and the average was recorded. Body weight was measured with a digital scale (Seca 876, Hamburg, Germany), registering the value to the nearest 0.1kg. Waist and hip circumference were measured while subjects were wearing light clothing, with an anthropometric tape (Seca 201, Hamburg, Germany). The waist was measured at the midpoint between the last palpable rib and the iliac crest. The hip was measured above the greater trochanter, at the largest perimeter at the gluteal region.

### **3.6 Body Composition**

Body composition was assessed using Dual Energy X-ray absorptiometry technology (DXA). The device employed was a Hologic Horizon Wi (Bedford, MA, USA). Total, lean, and fat mass were determined using a whole-body scan. Whenever participants exceeded the limits of the scanning area, the left upper limb was placed outside the scanning area and the right upper-limb values were doubled instead, as suggested by the manufacturer and international guidelines (NHANES, 2018, p. 3-16).

The quality control calibration procedures recommended by the manufacturer were carried out each day and before any assessment was performed. These included calibration with the spinal phantom and, whenever required by the system, the body composition quality control. This was performed to ensure the normal operation of the device and to verify if measurements were within the required standards.

Participants wore light, metal/free clothing and fasted for the previous 12 hours before the exam. Assessments were conducted in a temperature/controlled room (22-

25°C) with dim light. Participants were positioned in supine on the examination table, following the manufacturer's recommendations including feet in a neutral position, hands in a pronated position, and body segments visibly aligned. All data acquisition and analysis were performed by an experienced technician based on standard procedures.

### **3.7 Resting Metabolic Rate**

Resting metabolic rate (RMR) was measured using the indirect calorimetry method (Cosmed CPT, Rome, Italy) with a face mask. Assessments took place between 8 AM and 12 PM following a 12-hour fast. After the body composition assessment, participants rested for 10 minutes before the RMR test. Participants were also instructed to avoid vigorous physical activity and smoking in the 24 hours prior to the assessment. They received a short explanation about the procedure and purpose of the test, were equipped with a face mask and a heart rate monitor strap, and were instructed to not move, stay awake, and in silence. Gas exchange data was collected continuously for 30 minutes, and RMR was calculated from the lowest 5-minute interval of oxygen uptake. Additionally,  $\dot{V}O_2$ ,  $\dot{V}CO_2$ , its coefficient of variation (CV), and RER were also estimated by averaging each 30 seconds of the assessment. All participants were also asked about significant changes in their health status during the previous week, such as fever, respiratory tract infections, allergies, or any other relevant events. If that was the case, the assessment was postponed until at least seven days had passed since full recovery of symptoms.

### **3.8 Cardiorespiratory Fitness**

CRF was assessed using CPET with indirect calorimetry (Cosmed CPT) on a treadmill (h/p/cosmos Quasar). Data on expired gases and ECG were continuously collected during a maximal incremental exercise protocol in steps (h/p/cosmos Quasar, Traunstein, Germany). Testing was supervised by an experienced technician with CPR

training, and a physician was readily available. Participants wore size-adjusted masks with inspiratory valves (Hans Rudolph), and expired gases were collected using the “breath-by-breath” method expressed in averaged intervals of 5 seconds. Maximal oxygen consumption was recorded as the highest 30-second O<sub>2</sub> consumption average during the last completed stage before ending the procedure.

The post-intervention protocol for the first cohort began at a speed 1 km/h higher than the pre-intervention assessment to ensure the protocol remained within the appropriate duration limits, accounting for potential performance improvements. However, participants continued to demonstrate a relatively low CRF, making it unnecessary to maintain this adjustment (*Table 2*).

**Table 2:** Treadmill protocol in the pre- and post-intervention CPET assessment

Phase	Time (min.)	Speed (km/h) at 0% incline	
		Pre-test cohort 1 and 2, and post-test cohort 2	Post-test Cohort 1
Rest	0 - 1	0	0
Warm-up	1 - 4	3	4
	4 - 7	4	5
Exercise	7 - 10	5	6
	10 - 13	6	7
	13-16	7	8
	16 - 19	8	9
	19 - 22	9	10
	22 - 25	10	11
	25 -28	11	12
	28 - 31	12	13
	31 - 34	13	14
	Recovery	3'	3

*Table 2 details the exercise stages used during the cardiopulmonary exercise testing (CPET). CPET consisted of 4 different phases. First, participants were assessed at rest while seated and their heart rate, breathing frequency and expired gases were recorded and analyzed. Next, they*

*began walking at a low, comfortable pace during warm-up. Once they reached the 4-minute mark, the speed increased 1 km/h every 3 minutes. At the end, when participants could no longer cope with the exercise intensity the recovery phase was initiated at an easy pace.*

If the participant was not accustomed to walking on the treadmill, a familiarization session at a low speed was conducted during the first assessment day. On the testing day, participants were informed that the purpose of the test was to assess their cardiorespiratory fitness, and the protocol was thoroughly explained. They were instructed not to speak during the test unless it was strictly necessary, such as in the event of chest or joint pain, dizziness, lack of coordination, or any other relevant symptom. In any of these events, the test would be immediately stopped. The test would conclude regularly if the participant reached exertional fatigue. A test was considered invalid and not included in the statistical analysis if it was prematurely stopped at the participant request due to symptoms (e.g. joint discomfort, dyspnea) or by any adverse effect identified by the researcher (e.g. ECG alterations).

### **3.9 Exercise Training Sessions and Programming**

Training sessions were held at FADEUP facilities on Mondays, Wednesdays, and Fridays from 6:30 to 7:30 PM for 16 continuous weeks. Both groups trained simultaneously under the supervision of the same certified exercise instructors. Sessions included a 5-minute warm-up, consisting of 5 movements that engaged large muscle groups, such as lateral steps or deadlift mimics. Those movements were performed for 20 seconds for 4 rounds with no material or with a light bumper or broomstick. This was immediately followed by 50 minutes of specific training, and 5 minutes cooldown period consisting mainly of stretching exercises.

Participants with arterial hypertension above grade 2 (SBP  $\geq$  160 mmHg and/or DBP  $\geq$  100 mmHg, according to the European Society of Cardiology and European Society of Hypertension) were monitored prior to each exercise session and were not allowed to participate in the exercise session if values were SBP  $\geq$  180 mmHg and/or DBP  $\geq$  110 mmHg. Also, participants with diabetes had their blood glucose checked

before each exercise session. Whenever values were <90 mg/dL participants were instructed to eat a carbohydrate-rich snack, while if values were >250 mg/dL patients were recommended to adjust their usual insulin administration.

The training program for both EEG and REG was divided into five microcycles, each with increasing intensity and complexity. Exercise intensity and internal load were measured differently for each group according to the type of training performed. Training microcycles characteristics for the EEG and the REG are detailed in *Table 3* and *Table 5*, respectively.

### 3.9.1 Endurance exercise (EEG) training protocol

**Table 3:** Description of the endurance training microcycles.

	<b>Phase 1 Adaptation</b>	<b>Phase 2</b>	<b>Phase 3</b>	<b>Phase 4</b>	<b>Phase 5</b>
<b>Weeks</b>	1 - 2	3 - 5	6 - 8	9 - 12	13 - 16
<b>Intensity (% HRR)</b>	40 – 50	50 - 65	65 - 75	75 - 85	≥ 75
<b>Tabata (on:off)</b>	30 / 10 s	30 / 10	30 / 10	40 / 10	40 / 10
<b>Treadmill Exercise type</b>	Continuous	Interval	Interval	Interval	Continuous
<b>Treadmill (on/off)</b>	-	2 / 1 min	3 / 1 min	3 / 1 min	-
<b>Tabata materials</b>	Cones; balls	Cones; balls	Cones; balls; step; agility ladder	Cones; balls; step; agility ladder; medicinal balls	Cones; balls; step; agility ladder; medicinal balls; dumbbells

*Table 3 details the endurance exercise training characteristics progression along the 16-week intervention regarding the specific microcycles intensity and exercise variations. The intensity factor goes in conjunction with alterations in the work-rest ratio.*

EEG sessions were split into two parts. Half of the participants performed Tabata-style exercises (Tabata, 2019), consisting mostly of simple and cyclic movements using own body weight as load, while the other half performed either

interval or continuous treadmill exercises, depending on the microcycle. Halfway through the session, participants would switch stations.

Exercise intensity was controlled using heart rate intervals calculated with the Karvonen equation based on the maximal HR obtained in the CPET and the resting HR established in the RMR test. During the sessions, participants wore HR monitors (Garmin Forerunner 45) and were instructed on how to adjust their exercise intensity according to the target heart rate in each microcycle. HR monitor data was used to adjust external loads weekly. Mean and maximal HR, estimated energy expenditure, and time within the prescribed interval were registered for each training session. **Table 3** presents the characteristics of each implemented microcycle for the EEG training program.

### **3.9.2 Resistance exercise (REG) training protocol**

The REG prescription exercised different body regions on different days, as shown in **Table 4**. Throughout all the microcycles, training intensity increased progressively, and exercise complexity was adjusted based on the participant’s technique. Standardized exercise execution parameters were constantly provided by the supervisors as well as educational posters with specific cues for each movement.

**Table 4:** Weekly organization of workout sessions for the REG group.

	<b>Monday</b>	<b>Wednesday</b>	<b>Friday</b>
<b>Body regions</b>	Scapular waist and upper limbs Core	Scapular waist and upper limbs Pelvic waist and lower limbs	Pelvic waist and lower limbs Core

*Table 4 details the different body regions focused on each exercise training day on the resistance exercise group. The first workout of the week focused on upper body strengthening, the second workout was a full-body session, and the last weekly training session focused on lower limbs.*

Resistance exercise intensity was defined according to the number of repetitions a participant could perform with a predefined load. A range of expected repetitions was specified for each phase. To ensure an adequate familiarization with the materials and

exercises, during the first microcycle, participants performed the exercises simultaneously following the instructor's lead, whereas in all subsequent microcycles participants followed an individualized exercise prescription sheet detailing exercise order, intensity, numbers of sets and repetitions. **Table 5** presents the characteristics of the resistance training program.

**Table 5:** Description of resistance training microcycles.

	<b>Phase 1</b>	<b>Phase 2</b>	<b>Phase 3</b>	<b>Phase 4</b>	<b>Phase 5</b>
<b>Weeks</b>	1 – 2	3 – 5	6 – 8	9 – 12	13 – 16
<b>Intensity</b> (estimated % RM)	40 – 50	50 – 65	65 – 75	75 – 85	80 – 90
<b>Structure of sets</b>	Timed circuit	Classic	Classic	Combined sets	Combined sets
<b>Sets x repetitions/ time</b>	4 x 30 s	3 x 15- 20	3 x 10- 15	4 x 6-10	4 x 4-8
<b>Rest time</b>	20 s	30 s	45 s	60 s	90 s
<b>Exercises per session</b>	12	10	10	10	10
<b>Materials</b>	Rubber bands; mat; TRX; step; dumbbells; barbells; weight plates				

*Table 5 details the resistance exercise intensity characteristics progression. Exercises in the first microcycle were the same for all participants in the REG during the familiarization weeks. Afterward, each participant received a personalized exercise prescription sheet with the estimated load for each exercise. Loads could be adjusted as needed to ensure the participant was training within the pre-defined desired intensity range.*

### 3.10 Statistical Analysis

All statistical analyses were conducted using IBM SPSS Statistics version 28. Prior to analysis, data normality and homogeneity of variance was assessed using the Shapiro-Wilk test. For those that did not meet normality assumptions, non-parametric alternatives were used.

For within-group comparisons (pre- vs post-intervention) of continuous, normally distributed variables, a paired samples t-test was employed to evaluate changes in peak values reached in relative to body weight (RelBW)  $\dot{V}O_{2peak}$ , HR, RER, maximal speed, and percentage of  $\dot{V}O_{2peak}$  at the first ventilatory threshold (VT1). The same test was used for within-group comparisons of submaximal parameters such as RelBW  $\dot{V}O_{2peak}$ , RER, oxygen pulse, HR, and energy expenditure. The data was obtained averaging the last 30 seconds of each speed for those who completed at least two and a half minutes (83.33%) out of the three minutes of each CPET stage. When normality was not satisfied, the Wilcoxon signed-rank test was used as a non-parametric alternative. The effects of the interventions were examined using a two-way repeated measures ANOVA where group-time interactions were analyzed. For categorical variables, such as surgical technique employed, smoking status, diabetes or arterial hypertension status, the Fisher's Exact Test or Pearson Chi-Square were used to assess group differences. A significance level of  $p < .05$  was set for all statistical analyses. This analysis primarily focused on p-values and test statistics rather than confidence intervals, as the latter was not the central emphasis of the study.

## 4. Results

This section presents the results of a study aiming to compare the effectiveness of a 16-week endurance and resistance exercise training intervention in the improvement of CRF and metabolic efficiency. Analysis was made based on the results of a CPET done before and after the exercise intervention. The sample is composed of patients who underwent BcSy 18 to 24 months prior to the enrolment in the study and showed sub-optimal WL.

The sample size initially consisted of 25 participants who completed all pre-tests. Two participants dropped out before the intervention began, leaving a total of 23 participants, who were then randomly assigned to one of two groups: REG or EEG. Over the course of the 16-week training period, no attrition occurred, resulting in 23 participants completing all post-tests. However, 3 participants were excluded from the final analysis due to invalid post-intervention CPET tests. One participant presented a *de novo* supraventricular arrhythmia without symptoms nor hemodynamic changes, another discontinued the test prematurely due to knee pain, and a third participant performed the CPET on a cycle ergometer due to an acute low back pain episode. Consequently, the final analysis included 8 subjects in the EEG and 12 in the REG. Their characterization in terms of demographic variables and health status is presented in **Table 6**. Data is presented as mean  $\pm$  standard deviation, with comparisons made between pre- and post-intervention measurements.

Results related to the CRF were derived from the maximum values achieved in each CPET, pre- and post-intervention. The variables analyzed in this component were  $\dot{V}O_2$  peak RelBW, HR, RER, maximal speed reached, speed at VT1, and % $\dot{V}O_{2peak}$  at VT1. Within-group comparisons revealed a significant increase in the post-intervention maximal speed reached ( $8.6 \pm 1.7$  km/h), compared to pre-intervention ( $7.3 \pm 0.9$  km/h,  $p=0.036$ ), in the EEG. In contrast, no significant differences in maximal speed between pre- and post-intervention were identified in the REG. Meanwhile, the REG group showed a statistically significant decrease in the maximum HR achieved ( $p=0.002$ ) between the pre- ( $158 \pm 21.5$  bpm) *versus* post-intervention ( $150 \pm 20$  bpm), while for the

EEG there were no differences in maximal HR. All the remaining values along with the relevant test statistics for each variable are detailed in *Table 7*.

**Table 6:** Baseline and post-intervention characteristics of each group.

	Endurance Group (EEG)		Resistance Group (REG)		
	PRE	POST	PRE	POST	
	Mean ± S.D.	Mean ± S.D.	Mean ± S.D.	Mean ± S.D.	
<b>N</b>	8		12		
<b>Gender</b>					
Female	75% (6)		75% (9)		<i>p</i> = 0.693
Male	25% (2)		25% (3)		
<b>Age</b> (years)	51.25 ± 5.34		49.67 ± 5.65		<i>p</i> = 0.538
<b>BMI</b> (kg/m <sup>2</sup> )	31.55 ± 5.34	30.96 ± 3.21	32.11 ± 4.01	32.67 ± 4.06	Pre <i>p</i> = 0.733 Post <i>p</i> = 0.331
<b>Attendance</b> (%)	77.47 ± 21.55		76.63 ± 14.28		<i>p</i> = 0.918
<b>Blood Pressure</b> (mmHg) ≥140 SBP or ≥90 DBP	0	0	33.3% (4)	16.7% (2)	Pre <i>p</i> = 0.102 Post <i>p</i> = 0.347
<b>Diabetes Status</b>					
Non-applicable	75% (6)	87.5% (7)	91.7% (11)	100% (12)	Pre <i>p</i> = 0.148 Post <i>p</i> = 0.400
Pre-diabetes	0	12.5% (1)	8.3% (1)	0	
Diabetes	25% (2)	0	0	0	
<b>Surgery Technique</b>					
LSG	25% (2)		33.3% (4)		<i>p</i> = 0.545
RYGB	75% (6)		66.7% (8)		
<b>Menstrual Status</b>					
Non-applicable	25% (2)		25% (3)		<i>p</i> = 0.966
Menstruating	62.5% (5)		58.3% (7)		
Menopause	12.5% (1)		16.7% (2)		
<b>Antihypertensive Medication Use</b>					
β-blockers	12.5% (1)		8.3% (1)		<i>p</i> = 0.514
ARA	12.5% (1)		0		
ACE inhibitor	0		8.3% (1)		
<b>Current smoker</b>	12.5% (1)		0		<i>p</i> = 0.400

Table 6 presents a comparison between the EEG and REG before and after the intervention (PRE vs POST), regarding various clinical and demographic relevant variables. Results are expressed as mean±S.D. for continuous variables, and percentages (with absolute count) for categorical variables.

Afterwards, a two-way Analysis of Variance (two-way ANOVA) was conducted to compare the effect of each training intervention on the maximal and sub-maximal CPET variables. The results indicated a significant difference between the two groups in

terms of RelBW  $\dot{V}O_2$  peak ( $F(1, 18) = 7.690, p = 0.013$ ), in maximum HR ( $F(1, 10) = 5.145, p = 0.036$ ), and in the highest speed reached ( $F(1, 10) = 6.455, p = 0.020$ ) during the CPET test. In-between comparisons for the additional three variables, its F-value, degrees of freedom, and the P-value are detailed in **Table 7**.

**Table 7:** Pre- and post-intervention CPET peak measurements for the EEG and REG.

	Endurance Group (EEG)		Resistance Group (REG)		ANOVA
	PRE	POST	PRE	POST	
	Mean $\pm$ S.D.	Mean $\pm$ S.D.	Mean $\pm$ S.D.	Mean $\pm$ S.D.	
$\dot{V}O_2$ peak <sup>A</sup> (ml.kg.min <sup>-1</sup> )	27.28 $\pm$ 4.64	32.39 $\pm$ 8.70	26.5 $\pm$ 8.53	25.48 $\pm$ 8.65	<b>F (1,18)=7.690,</b> <b>p= 0.013*</b>
HR <sup>B</sup> (beat.min <sup>-1</sup> )	158 $\pm$ 17.3	160 $\pm$ 22.6	158 $\pm$ 21.5	<b>150 <math>\pm</math> 20<sup>†</sup></b>	<b>F (1,10)=5.145,</b> <b>p= 0.036*</b>
RER <sup>A</sup> (vco <sub>2</sub> /vo <sub>2</sub> )	1.03 $\pm$ 0.05	1.03 $\pm$ 0.07	1.02 $\pm$ 0.12	0.98 $\pm$ 0.07	F (1,10)=2.537, p= 0.129
SPEED <sup>B</sup> (km/h)	7.3 $\pm$ 0.9	<b>8.6 <math>\pm</math> 1.7<sup>†</sup></b>	7.2 $\pm$ 1.7	7.3 $\pm$ 2	<b>F (1,10)=6.455,</b> <b>p= 0.020*</b>
VT1 speed <sup>B</sup> (km/h)	5.6 $\pm$ 1.2	6.1 $\pm$ 1	5.8 $\pm$ 1	6 $\pm$ 1	F (1,17)=0.585 p=0.455
% $\dot{V}O_2$ @ VT1 <sup>A</sup>	65.2 $\pm$ 12.2	57.8 $\pm$ 10.7	65.5 $\pm$ 11.6	66 $\pm$ 10.8	F (1,17)=1.818, p= 0.195

Results are presented as Mean  $\pm$  S.D. The asterisk (\*) denotes significance in-between groups and the dagger (†) indicates significant differences within a group. Statistically significant within-group differences were observed in the post-test, with the EEG attaining a higher maximal speed and the REG showing a lower maximum HR. Significant-between-group differences were observed regarding max HR due to a decrease in the REG in the post-test value, but also due to an increase in relative to body weight  $\dot{V}O_2$  peak and speed attained by the EEG.

<sup>A</sup>: Parametric test / <sup>B</sup>: Non-parametric test

Moreover, the analysis regarding energetic efficiency requires a more detailed appreciation. The analysis was based on the five most common speeds achieved during the pre- and post-intervention CPET for all 20 participants, namely 3, 4, 5, 6 and 7 km/h. The data collection was done by averaging the data for the last 30 seconds of each

speed for those who completed at least two and a half minutes (83.33%) out of the three minutes of each level, according to the test protocol used.

The variables analyzed in this context were RelBW  $\dot{V}O_2$ , RER, oxygen pulse (OP), HR, and energy expenditure (EE). Within-group comparisons showed, for the EEG, no statistically significant differences neither for RelBW  $\dot{V}O_2$  nor EE. However, RER at 6 and 7 km/h displayed significant differences ( $p = 0.05$  and  $p = 0.04$ , respectively). Also, OP notably increased at 6 km/h ( $p = 0.02$ ) while HR significantly decreased at 3, 5 and 6 km/h ( $p = 0.04$ ,  $p = 0.05$ , and  $p = 0.03$ , respectively). As for the REG group, comparing the pre- and post-intervention CPET regarding RelBW  $\dot{V}O_2$ , there was a statistically significant decrease at 6 km/h ( $p = 0.001$ ), as well as at 5 km/h for OP ( $p = 0.01$ ). Detailed results for each speed regarding the five variables analyzed are displayed in **Table 8**, as well as specific sample size, mean, and standard deviation for each variable.

Furthermore, the between-group analysis indicated that neither of the two training interventions was superior regarding improvements at submaximal intensities in RelBW  $\dot{V}O_2$ , neither RER showed a significant change towards an increase in aerobic metabolism recruitment. Also, despite the absence of significant results, EE demonstrated a trend for a lower cost at each given exercise intensity for both groups. In contrast, comparing both groups, the amount of oxygen extracted per heartbeat (OP) was significantly different at 4, 5, and 6 km/h with the EEG having the highest values. Furthermore, HR was also significantly lower for the EEG at 3, 4, and 5 km/h. Specific F-values, degrees of freedom, and the P-values are presented in **Table 8**.

**Table 8:** Pre- and post-intervention sub-maximal variables for the CPET in the EEG and REG.

		Endurance Group (EEG)		Resistance Group (REG)		
		PRE	POST	PRE	POST	
	km/h	Mean ± S.D	Mean ± S.D	Mean ± S.D	Mean ± S.D	ANOVA
<b>VO<sub>2</sub></b> (ml.kg .min <sup>-1</sup> )	3	N=3, 13.12 ± 4.41 <sup>B</sup>	N=3, 10.6 ± 1.98	N=5, 11.6 ± 2.52 <sup>A</sup>	N=5, 10.37 ± 2.56	F (1, 6)=0.356, p= 0.572
	4	N=8, 12.97 ± 3.4 <sup>B</sup>	N=8,12.12 ± 1.56	N=12, 12.3 ± 2.37 <sup>A</sup>	N=12, 11.6 ± 2.19	F (1,18)=0.017, p= 0.897
	5	N=8, 14.62 ± 2.09 <sup>A</sup>	N=8, 14.4 ± 1.23	N=12, 14.59 ± 2.58 <sup>A</sup>	N=12, 13.49 ± 2.52	F (1,18)=1.011, p= 0.328
	6	N=8, 19.1 ± 2.22 <sup>A</sup>	N=8, 18.5 ± 1.59	N=11, 18.26 ± 2.98 <sup>A</sup>	<b>N=11, 16.24 ± 2.48 P</b>	F (1,17)=2.710, p= 0.118
	7	N=7, 25.91 ± 1.68 <sup>A</sup>	N=7, 25.36 ± 2.86	N=5, 27.59 ± 5.16 <sup>A</sup>	N=5, 24.02 ± 4.08	F (1,10)=1.800, p= 0.209
<b>RER</b> (vco <sub>2</sub> / vo <sub>2</sub> )	3	.768 ±.038 <sup>A</sup>	.750 ±.061	.778 ± .048 <sup>A</sup>	.757 ± .046	F (1, 6)=0.003, p= 0.956
	4	.810 ± .032 <sup>A</sup>	.735 ± .056	.836 ± .068 <sup>A</sup>	.792 ± .047	F (1,18)=0.947, p= 0.343
	5	.818 ± .024 <sup>A</sup>	.792 ± 0.61	.869 ± .065 <sup>A</sup>	.835 ± .058	F (1,18)=0.054, p= 0.819
	6	.927 ±.061 <sup>A</sup>	<b>.872 ± .085 P</b>	.931 ± .057 <sup>A</sup>	.915 ± .087	F (1,17)=0.925, p= 0.350
	7	1 ± .036 <sup>A</sup>	<b>.924 ± .097 P</b>	1.026 ± .088 <sup>A</sup>	.960 ± .082	F (1,10)=0.087, p= 0.775
<b>OP</b> (ml/ beat)	3	11.08 ± 2.85 <sup>B</sup>	10.63 ± .83	10.43 ± 2.47 <sup>B</sup>	9.44 ± 1.47	F (1, 6)=0.111, p= 0.751
	4	10.15 ± 2.41 <sup>A</sup>	10.93 ± 1.93	10.55 ± 1.96 <sup>A</sup>	9.81 ± 1.55	<b>F (1,18)=5.723, p= 0.028*</b>
	5	10.52 ± 2.21 <sup>A</sup>	11.90 ± 2.23	12.01 ± 2.29 <sup>B</sup>	<b>10.56 ± 1.72 P</b>	<b>F (1,18)=8.159, p= 0.010*</b>
	6	12.09 ± 1.59 <sup>A</sup>	<b>13.06 ± 2.28 P</b>	12.72 ± 2.37 <sup>A</sup>	11.56 ± 2.10	<b>F (1,17)=5.234, p= 0.035*</b>
	7	14.27 ± 2.16 <sup>A</sup>	15.2 ± 2.62	15.35 ± 2.98 <sup>A</sup>	14.68 ± 1.62	F (1,10)=1.639, p= 0.229
<b>HR</b> (bpm)	3	92.62 ± 14.76 <sup>A</sup>	<b>81 ± 15.98 P</b>	93.8 ± 11.52 <sup>A</sup>	93.14 ± 16.9	<b>F (1, 6)=7.279, p= 0.036*</b>
	4	103.93 ± 16.19 <sup>A</sup>	88.48 ± 11.01	97.93 ± 15.48 <sup>A</sup>	100.74 ± 16.15	<b>F (1,18)=4.953, p= 0.039*</b>
	5	114.37 ± 17.11 <sup>A</sup>	<b>96.80 ± 10.46 P</b>	103.24 ± 24.26 <sup>A</sup>	108.68 ± 14.34	<b>F (1,18)=4.953, p= 0.039*</b>

EE (kcal.k g.h <sup>-1</sup> )	6	128.96 ± 17.67 <sup>A</sup>	<b>113.53 ±</b> <b>13.63 <b>‡</b></b>	126.69 ± 21.37 <sup>A</sup>	119.59 ± 24.24	F (1,17)=1.637, p= 0.218
	7	149.61 ± 13.63 <sup>A</sup>	133.71 ± 18.18	142.77 ± 9.97 <sup>A</sup>	132.34 ± 12.18	F (1,10)=0.350, p= 0.567
	3	3.73 ± 1.26 <sup>A</sup>	3 ± 0.51	3.3 ± 0.704 <sup>A</sup>	2.99 ± 0.66	F (1, 6)=0.358, p= 0.572
	4	3.73 ± 0.98 <sup>B</sup>	3.43 ± 0.43	3.55 ± 0.65 <sup>A</sup>	3.32 ± 0.63	F (1,18)=0.055, p= 0.817
	5	4.21 ± 0.58 <sup>A</sup>	4.11 ± 0.33	4.24 ± 0.72 <sup>A</sup>	3.9 ± 0.76	F (1,18)=0.938, p= 0.346
	6	5.66 ± 0.66 <sup>A</sup>	5.39 ± 0.47	5.26 ± 1.06 <sup>A</sup>	4.79 ± 0.77	F (1,17)=0.354, p= 0.560
	7	7.78 ± 0.47 <sup>A</sup>	7.48 ± 0.82	8.31 ± 1.49 <sup>A</sup>	7.16 ± 1.34	F (1,10)=1.497, p= 0.249

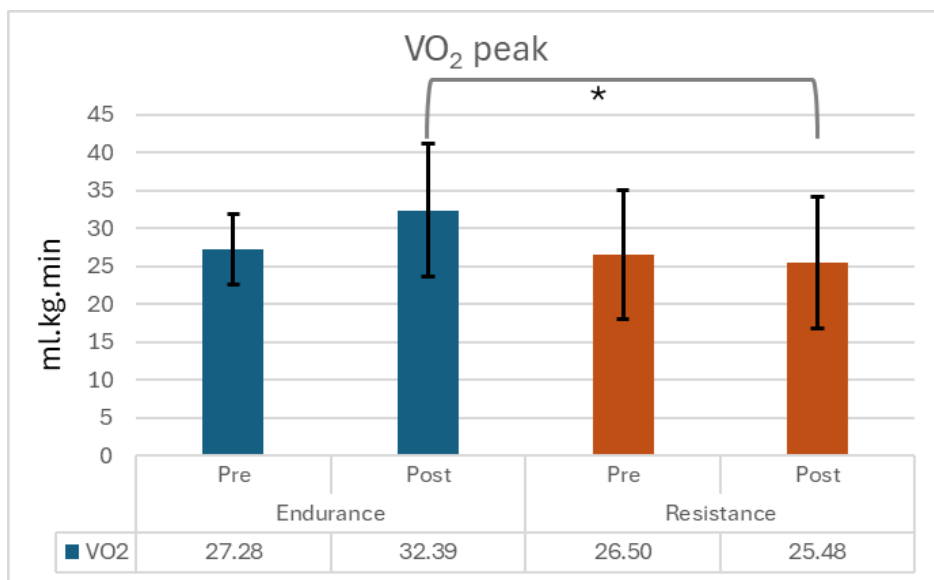
Data were collected as an average of the last 30 seconds of each speed (Mean±S.D). The asterisk (\*) denotes significance in between groups and the dagger (‡) indicates significant differences within a group. Heart rate (HR) and oxygen pulse (OP), variables measuring direct cardiovascular response, were the ones representing the majority of all statistical differences.

<sup>A</sup>: Parametric test | <sup>B</sup>: Non-parametric test

## 5. Discussion

The main purpose of this dissertation was to determine if two distinct exercise interventions, one based on endurance exercise and the other based on resistance exercise, affected differently the maximal and submaximal performance during a CPET in patients with obesity who previously underwent BcSy and displayed sub-optimal weight loss.

**Figure 2:** Relative to body weight  $\dot{V}O_2$  peak in the pre- and post-intervention CPET for the EEG and the REG.



A significant difference was observed between the post-intervention values of the two groups ( $p=0.013$ ), marked with an asterisk (\*).

Our main result shows that RelBW peak  $\dot{V}O_2$  achieved during the CPET did not change differently in any group. Nonetheless, when comparing both groups RelBW  $\dot{V}O_2$  peak, there was a significant difference ( $F(1,18)=7.690$ ,  $p=0.013$ ) in post-intervention values with subjects in the EEG displaying an average improvement of 18.73% ( $M=5.11$ ,  $SD=6.35$ ,  $t(7)=2.28$ ,  $p=.057$ ), while subjects in the REG showed a slight performance decrease of 3.85% ( $M=-1.03$ ,  $SD=3.58$ ,  $t(11)=.99$ ,  $p=.343$ ). This outcome can be attributed to the broader definition of the specificity training

principle (Reilly et al., 2009), suggesting that individuals with altered body composition and health condition still achieve meaningful aerobic adaptations.

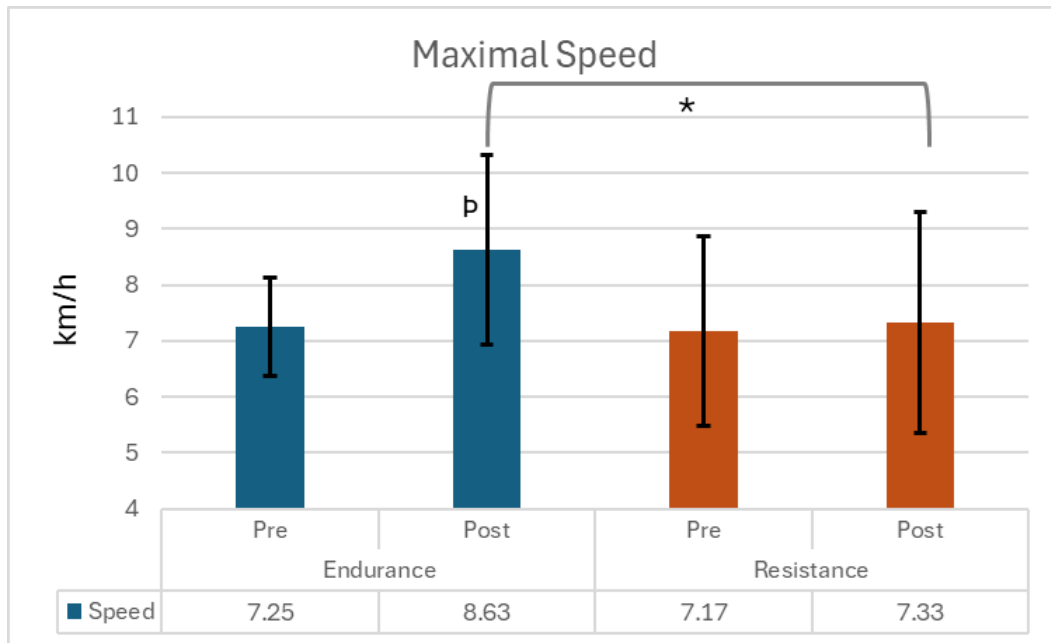
Improvement in this regard was analyzed based on age, sex, and exercise group, resulting in a fitness status change for the male participants in the EEG, from “very poor” to “good” –percentile 20<sup>th</sup> to 80<sup>th</sup>–, and for the females from “very poor” to “poor” –percentile 15<sup>th</sup> to 27<sup>th</sup>–, according to the ACSM stratification cut off values (Liguori, 2018, p. 151-156). On the other hand, based on the mortality risk in relation to the peak exercise capacity, the EEG was classified as being low fit at the beginning of the intervention and as moderately fit at the end, reducing their HRo of mortality from 2.88 to 2.13 –26% decrease–, while the REG stayed in the low fit category (Kokkinos et al., 2022).

Concerning the max HR attained, the EEG displayed no significant difference between the pre- and post-test results. On the contrary, the REG significantly decreased the maximal HR attained in the post-intervention assessment ( $M = 8.50$ ,  $SD = 7.97$ ,  $t(11) = 3.694$ ,  $p = .004$ ), with several patients also failing to reach 85% of the heart rate reserve (HRR). Likewise, the RER remained the same for the EEG in both pre- and post-intervention CPETs, even though their maximum speed reached was significantly higher in the post-test ( $M = 1.37$ ,  $SD = 1.50$ ,  $t(7) = 2.582$ ,  $p = .036$ ). In the same test, the REG did not attain a ratio of 1.0  $VCO_2/VO_2$  at peak performance, nonetheless, the speed reached was equal for both tests.

An RER above 1 and closer to 1.10  $VCO_2/VO_2$  is recognized as the cut-off point to indicate peak performance (Herdy et al., 2016). Therefore, taking into account that the REG in the post-intervention CPET did not achieve a HRR above 85%, and their peak RER was 0.98, suggests that their aerobic capacity was perhaps not expressed maximally. The underlying cause for this may be related to either psychological and/or physiological factors. For instance, insufficient familiarization with the treadmill may have played a role. While the EEG used the treadmill every single session as one of the two milestones of their workout programming, the REG just had a familiarization before each CPET making them, perhaps, reluctant to achieve higher treadmill speeds. Physiologically, individuals with obesity often exhibit impaired ATP synthesis (Zou et al., 2019), and experienced greater cardiovascular, ventilatory, metabolic, and perceived exertion demand on a treadmill because of the elevated BMI (Ricci et al., 2021).

Chronic low-grade inflammation can also exacerbate fatigue through reduced cellular energy availability (Lacourt et al., 2018).

**Figure 3:** Maximal speed attained in the pre- and post-intervention CPET.



A significant difference was observed between the post-intervention values of the two groups ( $p=0.02$ ), marked with an asterisk (\*). The dagger (†) denotes significant within-group differences ( $p=0.036$ ).

The occurrence of VT1 was at the expected  $\dot{V}O_{2max}\%$  for sedentary people (ATS/ACCP, 2003, p. 231), around 65% in the pre-test, and remained in that range for the REG, while for the EEG, it decreased by 7% in the post-test, though not statistically significant. These results are comparable to those reported by Auclair et al. (2021), following 12 weeks of a combined exercise regimen in a group of 36 subjects who had undergone BcSy 6 months earlier and showed VT1 at 65%  $\dot{V}O_2$  peak. The definition of the previously presented variables, with an intend to elucidate the magnitude in which different types of exercise can improve CRF of patients that had undergone BsSy but had not presented an ideal WL, goes hand in hand with how efficient the energy production is, due to the interconnected nature at a muscular, pulmonary and cardiovascular level.

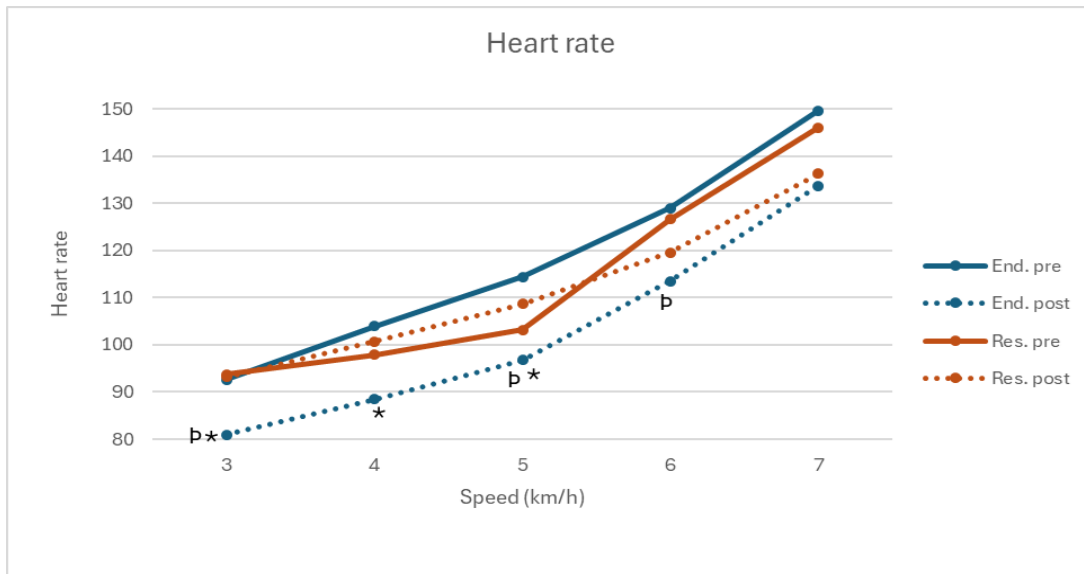
This more detailed analysis encompasses the most common speeds reached regarding RelBW O<sub>2</sub> consumption, HR, OP, RER, and energy expenditure (EE). Even though, it seems that to the present date, there is no other academic approach to the identification of the energy production profile of these patients neither in the short nor in the long term after BcSy (Da Silva et al., 2019; Ibacache-Saavedra et al., 2022).

Firstly, the oxygen consumption relativized by weight at each CPET stage had no statistically significant differences in-between groups nor within each group for the pre- and post-intervention assessments. However, a statistically significant difference was observed at 6km/h for the REG, with RelBW  $\dot{V}O_2$  decreasing from the pre-test (M = 18.26, SD = 2.98) to the post-test (M = 16.25, SD = 2.48,  $t(10) = 3.25$ ,  $p = .009$ ) and an overall non-significant downward trend for both groups, suggesting potential adaptability to a more economic energy system for a given workload, which shows a favorable adaptation and contributes to improved functionality (Sloan et al., 2009), ultimately linked to a higher health-related quality in the post-BcSy patients (Kolotkin et al., 2011).

In terms of HR, the EEG was the one representing all the significant modifications within this variable. From 3 km/h up to 7 km/h they lowered their HR by 12.54% ( $p = 0.040$ ), 15.33% ( $p = 0.057$ ), 15.09% ( $p = 0.049$ ), 11.96% ( $p = 0.027$ ), and 10.63% ( $p = 0.067$ ), respectively. In contrast, the REG registered, without significant changes, at 3 km/h a decrease of less than 1%, at 4 and 5 km/h an increase of 2.87% and 5.27%; and a decrease of 5.63% and 7.3% at 6 and 7 km/h.

The significant impact of HR reduction, specifically on the EEG, is the result of an increased stroke volume (Rowland, 2009) and an enhanced autonomic modulation, expected adaptations in endurance training due to neural and local factors (Carter et al., 2003), and primordial element due to its dysfunction prevalence in OB (Wharton et al., 2020). Although BcSy contributes to under-stimulating the sympathetic nervous system in sync with the vagal prolific excitation, it remains a problem for some post-BcSy patients (Rodriguez et al., 2021) with a prominent importance for those who after the surgical procedure continued with an altered BMI. For instance, out of 99 candidates for the surgery, 59 presented cardiac dysfunction; just 72 of the candidates ended up getting through the procedure of whom 20 still reflected cardiac dysfunction one year after the procedure (Snelder et al., 2023).

**Figure 4:** HR response to incremental speed for the EEG and REG before and after the intervention.

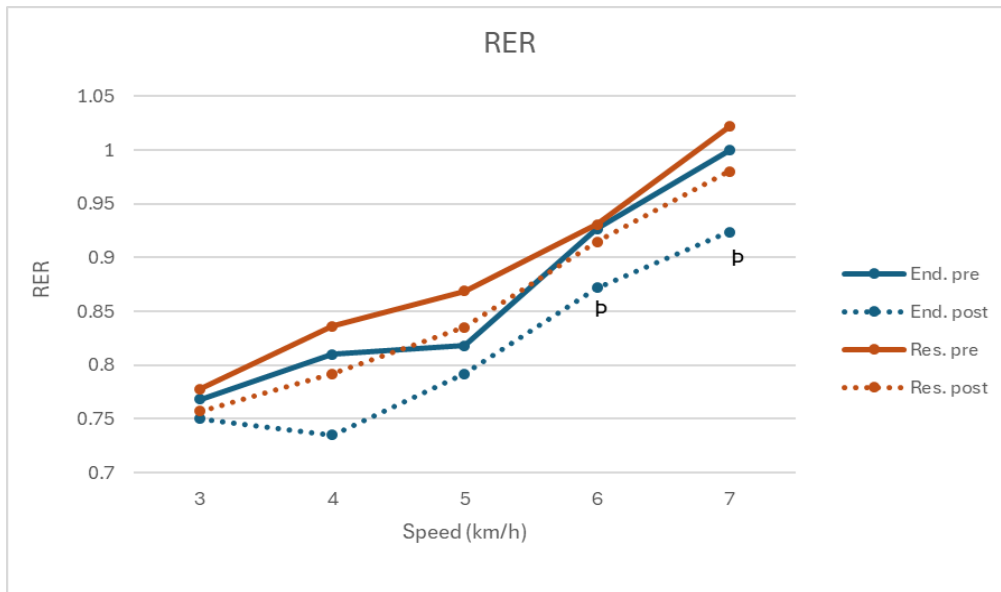


The asterisk (\*) indicates a significant difference between groups (3 km/h  $p=0.036$ , 4 km/h  $p=0.039$ , 5 km/h  $p=0.039$ ), while the dagger (P) denotes significant within-group differences (3 km/h  $p=0.04$ , 5 km/h  $p=0.049$ , 6 km/h  $p=0.027$ ).

In addition, OP data had a tendency to increase in the post-test for the EEG, while the REG demonstrated the opposite, given that an increase in stroke volume and arterio-venous oxygen difference are predictable adaptations to endurance training (Hellsten & Nyberg, 2015). In the backbone of the test, speeds from 4 to 6 km/h, between-group comparisons are significantly different in favor of the EEG performance. Pre- and post-values attained in the population sample studied in this intervention are above peak values previously reported by other authors who focused their studies on the CRF outcomes of BcSy with or without exercise intervention in the short term. Considering peak values reached in a CPET, Onofre et al. (2017) reported that a 12-week combined exercise regime carried out three months after the surgery, modified the OP from 11.4 to 12.7 ml/bet for the 6 females that made part of their exercise group. Likewise, with the same timeline and training method but a significantly bigger sample, 36 participants in the exercise group, the change from 3 to 6 months after the surgery was from 12.3 to 13.1 ml/beat (Auclair et al., 2021). On the other hand, one year after

the procedure with no exercise intervention, a sample of 42 women reported this parameter to be 12 ml/beat (Dereppe et al., 2019). Whereas in the present analysis, at 6 km/h, not peak values, participants in the EEG reached  $13.06 \pm 2.28$  ml/beat.

**Figure 5:** RER response to incremental speed for the EEG and REG before and after the intervention.



The dagger (*P*) denotes significant within-group differences (6 km/h  $p=0.046$  and 7 km/h  $p=0.038$ ).

In terms of RER analysis, for the EEG there were statistically significant values at 6 and 7 km/h, speeds that were not peak but near enough to be challenging for the participants. Indeed, just 30% of the group got to the next test stage; hence, it is notable that before the intervention, at 6 km/h, they were relying on glucose oxidation almost entirely ( $M = 0.927$ ,  $SD = .061$ ), in comparison to the value obtained after the exercise program implementation ( $M = .872$ ,  $SD = .085$ ,  $t(7) = 2.43$ ,  $p = .046$ ). At 7 km/h the values changed from  $1 \pm .036$  to  $.924 \pm .097$  ( $t(6) = 2.66$ ,  $p = .038$ ). The REG reported also lower values in the post-test, but none of them were significant, which could be linked to the adrenergic response evidenced in their HR at each sub-maximal speed, ultimately contributing to an increased reliance on glycolysis to produce energy. Overall, these values suggest that endurance exercise can improve, as well in this

population, the ability to work more efficiently by increasing their reliance on fat oxidation at submaximal intensities. Even though, it is well established that external cofactors in this measure are food intake, macronutrient consumption distribution, energy balance, restrictive diets, and extreme temperatures (Ramos-Jiménez et al., 2008).

Closely linked to the RER, estimation of the EE at submaximal levels for this population is interesting because it better elucidates their profile of energy production. Despite not having significant results in this regard, there is a tendency towards movement economy. It could be hypothesized that a lower EE for a set load or speed goes in detriment for patients who accessed the latest line of treatment for OB, BcSy, and were non-responders. However, physical activity and exercise are not the primordial WL conductors (Strasser & Fuchs, 2016); rather, they provide a comprehensive range of benefits that could eventually contribute to an optimal physiological environment conducive to sustained WL. Those specific benefits have been evidenced at multiple spheres, to name a couple, at a cellular level by improving the size of proteins in charge of cellular replication, and the number of antioxidant and anti-thrombotic pathways; and, metabolically, exercise in patients with OB resulted in reductions in serum triglycerides, decreased arterial stiffness, and reduced liver fat (Pojednic et al., 2022).

Therefore, for the population studied in this intervention, the equation of excess calorie consumption versus limited EE (Löffler et al., 2021) is insufficient, as the current academic consensus highlights a plateau in human EE given the fact that there is not an infinite additive effect but an adaptive metabolic response (Pontzer et al., 2016). What does seem important in relation to EE, strongly related to the FFM, is to be within the ranges expected for each age group, as falling short at some point could create a cascading effect throughout life (Pontzer et al., 2021).

Consequently, the fact that neither of these training methods proved superior in significantly affecting PAEE is relevant, as exercise prescription for most BcSy patients would primarily aim to chronically increase it.

## 6. Conclusion

In conclusion, this intervention has provided new insights into the fitness adaptability of patients with severe OB and sub-optimal WL after BcSy in the medium term. Even though, after surgery, there is a drastic alteration in the body composition, FFM loss can represent up to 23% of the WL within the first year (Nuijten et al., 2022); or in terms of function, there is a significant reduction in type I muscle fiber myonuclei content at 9-months post-surgery (Gil et al., 2021); endurance exercise is significantly more determinant than resistance exercise to generate changes regarding RelBW  $\dot{V}O_2$  peak, maximal HR and speed attained in a CPET performed on a treadmill after a 16-week exercise intervention. In addition, variables characterizing the energy production profile indicated that HR and OP at submaximal loads were significantly more efficient for those who carried out the endurance exercise than the resistance exercise protocol.

While the limitations of this intervention should be acknowledged, such as the relatively small sample size, the absence of a non-exercise control group, and lacking of verification tests for the  $\dot{V}O_2$  peak; it is also true that the majority of the trials integrating exercise as treatment for this population are done within the first year post-surgery (Ibacache-Saavedra et al., 2022), while we presented results that evidence the stage and malleability of the CRF after the algid 2-year mark.

Likewise, it is necessary to continue characterizing the cardiopulmonary-muscular complex over the medium and long term, which remains crucial for understanding the lasting effects of exercise interventions in clinical populations as the one here analyzed. Additionally, it is important to highlight that caution should be used when comparing results between studies with this population because many of them have data from an entirely female sample, while ours presented a distribution of 1 male for every 3 females.

In summary, this study provides valuable insights into the differential effects of endurance and resistance exercise on CRF and metabolic efficiency in post-bariatric surgery patients who experienced sub-optimal weight loss. Notably, significant differences were observed between the exercise groups, with the EEG showing greater improvements in  $\dot{V}O_2$  RelBW ( $F(1,18) = 7.690, p = 0.013$ ), indicating superior adaptations in aerobic capacity. Furthermore, the EEG demonstrated a significantly higher maximum speed ( $F(1,10) = 6.455, p = 0.020$ ), while the REG exhibited a lower

maximum heart rate post-intervention ( $F(1,10) = 5.145, p = 0.036$ ), suggesting differing cardiovascular adaptations between modalities.

In terms of submaximal performance, the EEG also displayed enhanced metabolic efficiency, as reflected by significantly lower RER values at 6 and 7 km/h ( $t(7) = 2.43, p = .046$ ;  $t(6) = 2.66, p = .038$ ). Additionally, significant between-group differences were found in OP at 4 km/h ( $F(1,18) = 5.723, p = 0.028$ ), 5 km/h ( $F(1,18) = 8.159, p = 0.010$ ), and 6 km/h ( $F(1,17) = 5.234, p = 0.035$ ), further supporting the advantage of endurance exercise in improving metabolic efficiency at the muscular level. Also, the heart rate at submaximal intensities was significantly different in both groups in favor of the EEG at 3 km/h ( $F(1,6) = 7.279, p = 0.036$ ), 4 km/h ( $F(1,18) = 4.953, p = 0.039$ ), and 5 km/h ( $F(1,18) = 4.953, p = 0.039$ ), suggesting significant improvement in the cardiovascular efficiency during moderate-intensity exercise.



## References

- Affinati, A. H., Esfandiari, N. H., Oral, E. A., & Kraftson, A. T. (2019). Bariatric Surgery in the Treatment of Type 2 Diabetes. *Current Diabetes Reports*, *19*(12), 156. <https://doi.org/10.1007/s11892-019-1269-4>
- Al Oweidat, K., Toubasi, A. A., Tawileh, R. B. A., Tawileh, H. B. A., & Hasuneh, M. M. (2023). Bariatric surgery and obstructive sleep apnea: A systematic review and meta-analysis. *Sleep and Breathing*, *27*(6), 2283–2294. <https://doi.org/10.1007/s11325-023-02840-1>
- Angrisani, L., Santonicola, A., Iovino, P., Palma, R., Kow, L., Prager, G., Ramos, A., Shikora, S., the Collaborative Study Group for the IFSO Worldwide Survey, Fiolo, F., Harraca, J. L., Hamdorf, J., Langer, F., Beckerhinn, P., Omerov, T., Dillemans, B., Rodriguez, E. H. B., Viegas, F., Grozdev, K., ... Cordova, L. R. L. (2024). IFSO Worldwide Survey 2020–2021: Current Trends for Bariatric and Metabolic Procedures. *Obesity Surgery*, *34*(4), 1075–1085. <https://doi.org/10.1007/s11695-024-07118-3>
- Arterburn, D. E., Telem, D. A., Kushner, R. F., & Courcoulas, A. P. (2020). Benefits and Risks of Bariatric Surgery in Adults: A Review. *JAMA*, *324*(9), 879. <https://doi.org/10.1001/jama.2020.12567>
- ASMBS. (n.d.). *Obesity in America*. American Society for Metabolic and Bariatric Surgery. Retrieved May 24, 2024, from <https://asmbs.org/resources/obesity-in-america/>
- ASMBS. (2021a, February). *Life After Bariatric Surgery*. American Society for Metabolic and Bariatric Surgery. <https://asmbs.org/patients/life-after-bariatric->

surgery/

ASMBS. (2021b, May). *Bariatric Surgery Procedures*. American Society for Metabolic and Bariatric Surgery. <https://asmbs.org/patients/bariatric-surgery-procedures/>

ASMBS. (2022, June 27). *Estimate of Bariatric Surgery Numbers, 2011-2022*.

American Society for Metabolic and Bariatric Surgery.

<https://asmbs.org/resources/estimate-of-bariatric-surgery-numbers/>

Athanasiadis, D. I., Martin, A., Kapsampelis, P., Monfared, S., & Stefanidis, D. (2021).

Factors associated with weight regain post-bariatric surgery: A systematic review. *Surgical Endoscopy*, *35*(8), 4069–4084. <https://doi.org/10.1007/s00464-021-08329-w>

ATS/ACCP Statement on Cardiopulmonary Exercise Testing. (2003). *American Journal of Respiratory and Critical Care Medicine*, *167*(2), 211–277.

<https://doi.org/10.1164/rccm.167.2.211>

Auclair, A., Harvey, J., Leclerc, J., Piché, M.-E., O'Connor, K., Nadreau, É., Pettigrew,

M., Haykowsky, M. J., Marceau, S., Biertho, L., Hould, F.-S., Lebel, S., Biron, S., Julien, F., Bouvet, L., Lescelleur, O., & Poirier, P. (2021). Determinants of Cardiorespiratory Fitness After Bariatric Surgery: Insights From a Randomised Controlled Trial of a Supervised Training Program. *Canadian Journal of Cardiology*, *37*(2), 251–259. <https://doi.org/10.1016/j.cjca.2020.03.032>

Baecke, J., Burema, J., & Frijters, J. (1982). A short questionnaire for the measurement of habitual physical activity in epidemiological studies. *The American Journal of Clinical Nutrition*, *36*(5), 936–942. <https://doi.org/10.1093/ajcn/36.5.936>

Baig, S. J., Priya, P., Mahawar, K. K., & Shah, S. (2019). Weight Regain After Bariatric Surgery—A Multicentre Study of 9617 Patients from Indian Bariatric Surgery

- Outcome Reporting Group. *Obesity Surgery*, 29(5), 1583–1592.  
<https://doi.org/10.1007/s11695-019-03734-6>
- Barbosa, A. C. S. C. S., Ribeiro, H. S., Nakano, E., Botelho, P. B., & De Carvalho, K. M. B. (2022). Biochemical Markers and Obstructive Sleep Apnea Risk in Individuals After Long-Term Bariatric Surgery. *Obesity Surgery*, 32(10), 3272–3279. <https://doi.org/10.1007/s11695-022-06222-6>
- Barbosa Lins, T. C., Valente, L. M., Sobral Filho, D. C., & Barbosa E Silva, O. (2015). Relation between heart rate recovery after exercise testing and body mass index. *Revista Portuguesa de Cardiologia (English Edition)*, 34(1), 27–33.  
<https://doi.org/10.1016/j.repce.2014.07.004>
- Bellicha, A., Van Baak, M. A., Battista, F., Beaulieu, K., Blundell, J. E., Busetto, L., Carraça, E. V., Dicker, D., Encantado, J., Ermolao, A., Farpour-Lambert, N., Pramono, A., Woodward, E., & Oppert, J. (2021). Effect of exercise training before and after bariatric surgery: A systematic review and meta-analysis. *Obesity Reviews*, 22(S4), e13296. <https://doi.org/10.1111/obr.13296>
- Blüher, M. (2019). Obesity: Global epidemiology and pathogenesis. *Nature Reviews Endocrinology*, 15(5), 288–298. <https://doi.org/10.1038/s41574-019-0176-8>
- Blüher, M., Aras, M., Aronne, L. J., Batterham, R. L., Giorgino, F., Ji, L., Pietiläinen, K. H., Schnell, O., Tonchevska, E., & Wilding, J. P. H. (2023). New insights into the treatment of obesity. *Diabetes, Obesity and Metabolism*, 25(8), 2058–2072. <https://doi.org/10.1111/dom.15077>
- Boppre, G., Diniz-Sousa, F., Veras, L., Oliveira, J., & Fonseca, H. (2022). Can exercise promote additional benefits on body composition in patients with obesity after bariatric surgery? A systematic review and meta-analysis of randomized

controlled trials. *Obesity Science & Practice*, 8(1), 112–123.

<https://doi.org/10.1002/osp4.542>

Brown, W. A., Liem, R., Al-Sabah, S., Anvari, M., Boza, C., Cohen, R. V., Ghaferi, A., Våge, V., Himpens, J., Kow, L., Morton, J., Musella, M., Pattou, F., Sakran, N., Clapp, B., Prager, G., Shikora, S., on behalf of the IFSO Global Registry Collaboration, Campbell, A., ... Level, L. (2024). Metabolic Bariatric Surgery Across the IFSO Chapters: Key Insights on the Baseline Patient Demographics, Procedure Types, and Mortality from the Eighth IFSO Global Registry Report. *Obesity Surgery*, 34(5), 1764–1777. <https://doi.org/10.1007/s11695-024-07196-3>

Burgess, E., Hassmén, P., & Pumpa, K. L. (2017). Determinants of adherence to lifestyle intervention in adults with obesity: A systematic review. *Clinical Obesity*, 7(3), 123–135. <https://doi.org/10.1111/cob.12183>

Carlsson, L. M. S., Sjöholm, K., Jacobson, P., Andersson-Assarsson, J. C., Svensson, P.-A., Taube, M., Carlsson, B., & Peltonen, M. (2020). Life Expectancy after Bariatric Surgery in the Swedish Obese Subjects Study. *New England Journal of Medicine*, 383(16), 1535–1543. <https://doi.org/10.1056/NEJMoa2002449>

Carter, J. B., Banister, E. W., & Blaber, A. P. (2003). Effect of Endurance Exercise on Autonomic Control of Heart Rate: *Sports Medicine*, 33(1), 33–46. <https://doi.org/10.2165/00007256-200333010-00003>

Cecchini, M., & Vuik, S. (2019). The heavy burden of obesity. In *The Heavy Burden of Obesity: The Economics of Prevention*. OECD. <https://doi.org/10.1787/67450d67-en>

Coen, P. M., Carnero, E. A., & Goodpaster, B. H. (2018). Exercise and Bariatric

- Surgery: An Effective Therapeutic Strategy. *Exercise and Sport Sciences Reviews*, 46(4), 262–270. <https://doi.org/10.1249/JES.0000000000000168>
- Cole, C. R., Blackstone, E. H., Pashkow, F. J., Snader, C. E., & Lauer, M. S. (1999). Heart-Rate Recovery Immediately after Exercise as a Predictor of Mortality. *New England Journal of Medicine*, 341(18), 1351–1357. <https://doi.org/10.1056/NEJM199910283411804>
- Collins, L., & Costello, R. A. (2024). Glucagon-Like Peptide-1 Receptor Agonists. In *StatPearls*. StatPearls Publishing. <http://www.ncbi.nlm.nih.gov/books/NBK551568/>
- Conaty, E. A., Denham, W., Haggerty, S. P., Linn, J. G., Joehl, R. J., & Ujiki, M. B. (2020). Primary Care Physicians' Perceptions of Bariatric Surgery and Major Barriers to Referral. *Obesity Surgery*, 30(2), 521–526. <https://doi.org/10.1007/s11695-019-04204-9>
- Coulman, K. D., & Blazeby, J. M. (2020). Health-Related Quality of Life in Bariatric and Metabolic Surgery. *Current Obesity Reports*, 9(3), 307–314. <https://doi.org/10.1007/s13679-020-00392-z>
- Da Silva, A. L. G., Sardeli, A. V., André, L. D., Severin, R., De Oliveira, C. R., Hassan, C., Borghi-Silva, A., & Phillips, S. A. (2019). Exercise Training Does Improve Cardiorespiratory Fitness in Post-Bariatric Surgery Patients. *Obesity Surgery*, 29(4), 1416–1419. <https://doi.org/10.1007/s11695-019-03731-9>
- Damer, A., El Meniawy, S., McPherson, R., Wells, G., Harper, M., & Dent, R. (2022). Association of muscle fiber type with measures of obesity: A systematic review. *Obesity Reviews*, 23(7), e13444. <https://doi.org/10.1111/obr.13444>
- De Lorenzo, A., Gratteri, S., Gualtieri, P., Cammarano, A., Bertucci, P., & Di Renzo, L.

- (2019). Why primary obesity is a disease? *Journal of Translational Medicine*, 17(1), 169. <https://doi.org/10.1186/s12967-019-1919-y>
- Dereppe, H., Forton, K., Pauwen, N. Y., & Faoro, V. (2019). Impact of Bariatric Surgery on Women Aerobic Exercise Capacity. *Obesity Surgery*, 29(10), 3316–3323. <https://doi.org/10.1007/s11695-019-03996-0>
- D'hoedt, A., & Vanuytsel, T. (2023). Dumping syndrome after bariatric surgery: Prevalence, pathophysiology and role in weight reduction – a systematic review. *Acta Gastro Enterologica Belgica*, 86(3), 417–427. <https://doi.org/10.51821/86.3.11476>
- Duren, D. L., Sherwood, R. J., Czerwinski, S. A., Lee, M., Choh, A. C., Siervogel, R. M., & Chumlea, Wm. C. (2008). Body Composition Methods: Comparisons and Interpretation. *Journal of Diabetes Science and Technology*, 2(6), 1139–1146. <https://doi.org/10.1177/193229680800200623>
- El Ansari, W., & Elhag, W. (2021). Weight Regain and Insufficient Weight Loss After Bariatric Surgery: Definitions, Prevalence, Mechanisms, Predictors, Prevention and Management Strategies, and Knowledge Gaps—a Scoping Review. *Obesity Surgery*, 31(4), 1755–1766. <https://doi.org/10.1007/s11695-020-05160-5>
- Eurostat. (2024). *Overweight and obesity—BMI statistics*. [https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Overweight\\_and\\_obesity\\_-\\_BMI\\_statistics](https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Overweight_and_obesity_-_BMI_statistics)
- Faria, G. R. (2017). A brief history of bariatric surgery. *Porto Biomedical Journal*, 2(3), 90–92. <https://doi.org/10.1016/j.pbj.2017.01.008>
- Fleischman, J. Y., Van Den Bergh, F., Collins, N. L., Bowers, M., Beard, D. A., & Burant, C. F. (2023). Higher mitochondrial oxidative capacity is the primary

molecular differentiator in muscle of rats with high and low intrinsic cardiorespiratory fitness. *Molecular Metabolism*, 76, 101793.

<https://doi.org/10.1016/j.molmet.2023.101793>

Funk, L. M., Alagoz, E., Jolles, S. A., Shea, G. E., Gunter, R. L., Raffa, S. D., & Voils, C. I. (2022). A Qualitative Study of the System-level Barriers to Bariatric Surgery Within the Veterans Health Administration. *Annals of Surgery*, 275(1), e181–e188. <https://doi.org/10.1097/SLA.0000000000003982>

Gaesser, G. A., & Angadi, S. S. (2021). Obesity treatment: Weight loss versus increasing fitness and physical activity for reducing health risks. *iScience*, 24(10), 102995. <https://doi.org/10.1016/j.isci.2021.102995>

Gil, S., Kirwan, J. P., Murai, I. H., Dantas, W. S., Merege-Filho, C. A. A., Ghosh, S., Shinjo, S. K., Pereira, R. M. R., Teodoro, W. R., Felau, S. M., Benatti, F. B., De Sá-Pinto, A. L., Lima, F., De Cleve, R., Santo, M. A., Gualano, B., & Roschel, H. (2021). A randomized clinical trial on the effects of exercise on muscle remodelling following bariatric surgery. *Journal of Cachexia, Sarcopenia and Muscle*, 12(6), 1440–1455. <https://doi.org/10.1002/jcsm.12815>

Government Office for Science UK. (2007). *Tackling obesities: Future choices—Project report (2nd edition)* (2nd ed.). <https://assets.publishing.service.gov.uk/media/5a759da7e5274a4368298a4f/07-1184x-tackling-obesities-future-choices-report.pdf>

Gram, M., Dahl, R., & Dela, F. (2014, June). *Physical inactivity and muscle oxidative capacity in humans: European Journal of Sport Science: Vol 14 , No 4—Get Access*. <https://www.tandfonline.com/doi/full/10.1080/17461391.2013.823466>

Hansen, D., Decroix, L., Devos, Y., Nocca, D., Cornelissen, V., Dillemans, B., &

- Lannoo, M. (2020). Towards Optimized Care After Bariatric Surgery by Physical Activity and Exercise Intervention: A Review. *Obesity Surgery*, 30(3), 1118–1125. <https://doi.org/10.1007/s11695-020-04390-x>
- Hellsten, Y., & Nyberg, M. (2015). Cardiovascular Adaptations to Exercise Training. In Y. S. Prakash (Ed.), *Comprehensive Physiology* (1st ed., pp. 1–32). Wiley. <https://doi.org/10.1002/cphy.c140080>
- Hennis, P. J., Meale, P. M., Hurst, R. A., O’Doherty, A. F., Otto, J., Kuper, M., Harper, N., Sufi, P. A., Heath, D., Montgomery, H. E., & Grocott, M. P. W. (2012). Cardiopulmonary exercise testing predicts postoperative outcome in patients undergoing gastric bypass surgery. *British Journal of Anaesthesia*, 109(4), 566–571. <https://doi.org/10.1093/bja/aes225>
- Herdy, A. H., Ritt, L. E. F., Stein, R., Araújo, C. G. S. D., Milani, M., Meneghelo, R. S., Ferraz, A. S., Hossri, C. A. C., Almeida, A. E. M. D., Fernandes-Silva, M. M., & Serra, S. M. (2016). Cardiopulmonary Exercise Test: Fundamentals, Applicability and Interpretation. *Arquivos Brasileiros de Cardiologia*. <https://doi.org/10.5935/abc.20160171>
- Hlavin, C., Sebastiani, R. S., Scherer, R. J., Kenkre, T., Bernardi, K., Reed, D. A., Ahmed, B., & Courcoulas, A. (2023). Barriers to Bariatric Surgery: A Mixed Methods Study Investigating Obstacles Between Clinic Contact and Surgery. *Obesity Surgery*, 33(9), 2874–2883. <https://doi.org/10.1007/s11695-023-06761-6>
- Hruby, A., & Hu, F. B. (2015). The Epidemiology of Obesity: A Big Picture. *Pharmacoeconomics*, 33(7), 673–689. <https://doi.org/10.1007/s40273-014-0243-x>

- Ibacache-Saavedra, P., Jerez-Mayorga, D., Carretero-Ruiz, A., Miranda-Fuentes, C., Cano-Cappellacci, M., & Artero, E. G. (2022). Effects of bariatric surgery on cardiorespiratory fitness: A systematic review and meta-analysis. *Obesity Reviews*, 23(3), e13408. <https://doi.org/10.1111/obr.13408>
- Johnson, R. K., & Coward-Mc-Kenzie, D. (2001). Energy Requirement Methodology. In *Nutrition in the Prevention and Treatment of Disease* (pp. 31–42). Elsevier. <https://doi.org/10.1016/B978-012193155-1/50004-0>
- Kim, T. J., & Von Dem Knesebeck, O. (2018). Income and obesity: What is the direction of the relationship? A systematic review and meta-analysis. *BMJ Open*, 8(1), e019862. <https://doi.org/10.1136/bmjopen-2017-019862>
- Kokkinos, P., Faselis, C., Samuel, I. B. H., Pittaras, A., Doumas, M., Murphy, R., Heimall, M. S., Sui, X., Zhang, J., & Myers, J. (2022). Cardiorespiratory Fitness and Mortality Risk Across the Spectra of Age, Race, and Sex. *Journal of the American College of Cardiology*, 80(6), 598–609. <https://doi.org/10.1016/j.jacc.2022.05.031>
- Kolotkin, R. L., LaMonte, M. J., Litwin, S., Crosby, R. D., Gress, R. E., Yanowitz, F. G., Hunt, S. C., & Adams, T. D. (2011). Cardiorespiratory Fitness and Health-Related Quality of Life in Bariatric Surgery Patients. *Obesity Surgery*, 21(4), 457–464. <https://doi.org/10.1007/s11695-010-0261-5>
- Lacourt, T. E., Vichaya, E. G., Chiu, G. S., Dantzer, R., & Heijnen, C. J. (2018). The High Costs of Low-Grade Inflammation: Persistent Fatigue as a Consequence of Reduced Cellular-Energy Availability and Non-adaptive Energy Expenditure. *Frontiers in Behavioral Neuroscience*, 12, 78. <https://doi.org/10.3389/fnbeh.2018.00078>

- Lanza, I. R. (2015). Enhancing the Metabolic Benefits of Bariatric Surgery: Tipping the Scales With Exercise. *Diabetes*, *64*(11), 3656–3658.  
<https://doi.org/10.2337/dbi15-0018>
- Lazzati, A. (2023). Epidemiology of the surgical management of obesity. *Journal of Visceral Surgery*, *160*(2), S3–S6. <https://doi.org/10.1016/j.jviscsurg.2022.12.004>
- Lee, G. K., & Cha, Y.-M. (2016). Cardiovascular benefits of bariatric surgery. *Trends in Cardiovascular Medicine*, *26*(3), 280–289.  
<https://doi.org/10.1016/j.tcm.2015.07.006>
- Liguori, G. (Ed.). (2018). *ACSM's health-related physical fitness assessment manual* (Fifth edition). Wolters Kluwer.
- Löffler, M. C., Betz, M. J., Blondin, D. P., Augustin, R., Sharma, A. K., Tseng, Y.-H., Scheele, C., Zimdahl, H., Mark, M., Hennige, A. M., Wolfrum, C., Langhans, W., Hamilton, B. S., & Neubauer, H. (2021). Challenges in tackling energy expenditure as obesity therapy: From preclinical models to clinical application. *Molecular Metabolism*, *51*, 101237.  
<https://doi.org/10.1016/j.molmet.2021.101237>
- Lund, J., S. Tangen, D., Wiig, H., Stadheim, H. K., Helle, S. A., B. Birk, J., Ingemann-Hansen, T., Rustan, A. C., Thoresen, G. H., Wojtaszewski, J. F. P., T. Kase, E., & Jensen, J. (2018). Glucose metabolism and metabolic flexibility in cultured skeletal muscle cells is related to exercise status in young male subjects. *Archives of Physiology and Biochemistry*, *124*(2), 119–130.  
<https://doi.org/10.1080/13813455.2017.1369547>
- Mahmoud, A. M., Gonçalves da Silva, A. L., André, L. D., Hwang, C.-L., Severin, R., Sanchez-Johnsen, L., Borghi-Silva, A., Elokda, A., Arena, R., & Phillips, S. A.

- (2022). Effects of Exercise Mode on Improving Cardiovascular Function and Cardiorespiratory Fitness After Bariatric Surgery: A Narrative Review. *American Journal of Physical Medicine & Rehabilitation*, *101*(11), 1056–1065. <https://doi.org/10.1097/PHM.0000000000001946>
- Malik, I. O., Petersen, M. C., & Klein, S. (2022). Glucagon-like peptide -1, glucose-dependent insulintropic polypeptide, and glucagon receptor poly-agonists: A new era in obesity pharmacotherapy. *Obesity*, *30*(9), 1718–1721. <https://doi.org/10.1002/oby.23521>
- Marc-Hernández, A., Ruiz-Tovar, J., Aracil, A., Guillén, S., & Moya-Ramón, M. (2020). Effects of a High-Intensity Exercise Program on Weight Regain and Cardio-metabolic Profile after 3 Years of Bariatric Surgery: A Randomized Trial. *Scientific Reports*, *10*(1), 3123. <https://doi.org/10.1038/s41598-020-60044-z>
- Martini, A. D., Dalleck, L. C., Mejuto, G., Larwood, T., Weatherwax, R. M., & Ramos, J. S. (2022). Changes in the Second Ventilatory Threshold Following Individualized versus Standardized Exercise Prescription among Physically Inactive Adults: A Randomised Trial. *International Journal of Environmental Research and Public Health*, *19*(7), 3962. <https://doi.org/10.3390/ijerph19073962>
- Mele, C., Caputo, M., Ferrero, A., Daffara, T., Cavigliolo, B., Spadaccini, D., Nardone, A., Prodam, F., Aimaretti, G., & Marzullo, P. (2022). Bone Response to Weight Loss Following Bariatric Surgery. *Frontiers in Endocrinology*, *13*, 921353. <https://doi.org/10.3389/fendo.2022.921353>
- Migliavacca, E., Tay, S. K. H., Patel, H. P., Sonntag, T., Civiletto, G., McFarlane, C.,

- Forrester, T., Barton, S. J., Leow, M. K., Antoun, E., Charpagne, A., Seng Chong, Y., Descombes, P., Feng, L., Francis-Emmanuel, P., Garratt, E. S., Giner, M. P., Green, C. O., Karaz, S., ... Feige, J. N. (2019). Mitochondrial oxidative capacity and NAD<sup>+</sup> biosynthesis are reduced in human sarcopenia across ethnicities. *Nature Communications*, *10*(1), 5808.  
<https://doi.org/10.1038/s41467-019-13694-1>
- Mohapatra, S., Gangadharan, K., & Pitchumoni, C. S. (2020). Malnutrition in obesity before and after bariatric surgery. *Disease-a-Month*, *66*(2), 100866.  
<https://doi.org/10.1016/j.disamonth.2019.06.008>
- Monaco-Ferreira, D. V., & Leandro-Merhi, V. A. (2017). Weight Regain 10 Years After Roux-en-Y Gastric Bypass. *Obesity Surgery*, *27*(5), 1137–1144.  
<https://doi.org/10.1007/s11695-016-2426-3>
- Monnier, L., Schlienger, J.-L., Colette, C., & Bonnet, F. (2021). The obesity treatment dilemma: Why dieting is both the answer and the problem? A mechanistic overview. *Diabetes & Metabolism*, *47*(3), 101192.  
<https://doi.org/10.1016/j.diabet.2020.09.002>
- Morales-Marroquin, E., Kohl, H. W., Knell, G., De La Cruz-Muñoz, N., & Messiah, S. E. (2020). Resistance Training in Post-Metabolic and Bariatric Surgery Patients: A Systematic Review. *Obesity Surgery*, *30*(10), 4071–4080.  
<https://doi.org/10.1007/s11695-020-04837-1>
- Müller, T. D., Blüher, M., Tschöp, M. H., & DiMarchi, R. D. (2022). Anti-obesity drug discovery: Advances and challenges. *Nature Reviews Drug Discovery*, *21*(3), 201–223. <https://doi.org/10.1038/s41573-021-00337-8>
- NHANES. (2018). *Body Composition Procedures Manual*. CDC.

- [https://www.cdc.gov/nchs/data/nhanes/2017-2018/manuals/Body\\_Composition\\_Procedures\\_Manual\\_2018.pdf](https://www.cdc.gov/nchs/data/nhanes/2017-2018/manuals/Body_Composition_Procedures_Manual_2018.pdf)
- NHS UK. (2024, February 12). *Recovering from weight loss surgery*. Nhs.Uk.  
<https://www.nhs.uk/conditions/weight-loss-surgery/recovering/>
- Noria, S. F., Shelby, R. D., Atkins, K. D., Nguyen, N. T., & Gadde, K. M. (2023).  
Weight Regain After Bariatric Surgery: Scope of the Problem, Causes,  
Prevention, and Treatment. *Current Diabetes Reports*, 23(3), 31–42.  
<https://doi.org/10.1007/s11892-023-01498-z>
- Nuijten, M. A. H., Eijsvogels, T. M. H., Montpellier, V. M., Janssen, I. M. C.,  
Hazebroek, E. J., & Hopman, M. T. E. (2022). The magnitude and progress of  
lean body mass, fat-free mass, and skeletal muscle mass loss following bariatric  
surgery: A systematic review and meta-analysis. *Obesity Reviews*, 23(1),  
e13370. <https://doi.org/10.1111/obr.13370>
- Nussbaumerova, B., & Rosolova, H. (2023). Obesity and Dyslipidemia. *Current  
Atherosclerosis Reports*, 25(12), 947–955. <https://doi.org/10.1007/s11883-023-01167-2>
- O'Brien, P. E., Hindle, A., Brennan, L., Skinner, S., Burton, P., Smith, A., Crosthwaite,  
G., & Brown, W. (2019). 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. *Obesity Surgery*, 29(1), 3–14.  
<https://doi.org/10.1007/s11695-018-3525-0>
- Ogunwole, S., Rabe, M., Roberts, A., & Caplan, Z. (2021, August 12). *Adult Population  
Grew Faster Than Total Population From 2010 to 2020*.

<https://www.census.gov/library/stories/2021/08/united-states-adult-population-grew-faster-than-nations-total-population-from-2010-to-2020.html>

Onofre, T., Carlos, R., Oliver, N., Felismino, A., Fialho, D., Corte, R., Da Silva, E. P., Godoy, E., & Bruno, S. (2017). Effects of a Physical Activity Program on Cardiorespiratory Fitness and Pulmonary Function in Obese Women after Bariatric Surgery: A Pilot Study. *Obesity Surgery*, 27(8), 2026–2033.  
<https://doi.org/10.1007/s11695-017-2584-y>

Oppert, J., Bellicha, A., Van Baak, M. A., Battista, F., Beaulieu, K., Blundell, J. E., Carraça, E. V., Encantado, J., Ermolao, A., Pramono, A., Farpour-Lambert, N., Woodward, E., Dicker, D., & Busetto, L. (2021). Exercise training in the management of overweight and obesity in adults: Synthesis of the evidence and recommendations from the European Association for the Study of Obesity Physical Activity Working Group. *Obesity Reviews*, 22(S4), e13273.  
<https://doi.org/10.1111/obr.13273>

Ortega, F. B., Ruiz, J. R., Labayen, I., Lavie, C. J., & Blair, S. N. (2018). The Fat but Fit paradox: What we know and don't know about it. *British Journal of Sports Medicine*, 52(3), 151–153. <https://doi.org/10.1136/bjsports-2016-097400>

Patel, H., Kerndt, C. C., & Bhardwaj, A. (2024). Physiology, Respiratory Quotient. In *StatPearls*. StatPearls Publishing.  
<http://www.ncbi.nlm.nih.gov/books/NBK531494/>

Pedersen, S., Manjoo, P., & Wharton, S. (2022). *Pharmacotherapy in Obesity Management—Clinical Practice Guidelines*. [https://obesitycanada.ca/wp-content/uploads/2022/10/Pharmacotherapy-CPG-2022\\_final.pdf](https://obesitycanada.ca/wp-content/uploads/2022/10/Pharmacotherapy-CPG-2022_final.pdf)

Pojednic, R., D'Arpino, E., Halliday, I., & Bantham, A. (2022). The Benefits of

- Physical Activity for People with Obesity, Independent of Weight Loss: A Systematic Review. *International Journal of Environmental Research and Public Health*, 19(9), 4981. <https://doi.org/10.3390/ijerph19094981>
- Pontzer, H., Durazo-Arvizu, R., Dugas, L. R., Plange-Rhule, J., Bovet, P., Forrester, T. E., Lambert, E. V., Cooper, R. S., Schoeller, D. A., & Luke, A. (2016). Constrained Total Energy Expenditure and Metabolic Adaptation to Physical Activity in Adult Humans. *Current Biology*, 26(3), 410–417. <https://doi.org/10.1016/j.cub.2015.12.046>
- Pontzer, H., Yamada, Y., Sagayama, H., Ainslie, P. N., Andersen, L. F., Anderson, L. J., Arab, L., Baddou, I., Bedu-Addo, K., Blaak, E. E., Blanc, S., Bonomi, A. G., Bouten, C. V. C., Bovet, P., Buchowski, M. S., Butte, N. F., Camps, S. G., Close, G. L., Cooper, J. A., ... IAEA DLW Database Consortium§. (2021). Daily energy expenditure through the human life course. *Science*, 373(6556), 808–812. <https://doi.org/10.1126/science.abe5017>
- Pritchard, A., Burns, P., Correia, J., Jamieson, P., Moxon, P., Purvis, J., Thomas, M., Tighe, H., & Sylvester, K. P. (2021). ARTP statement on cardiopulmonary exercise testing 2021. *BMJ Open Respiratory Research*, 8(1), e001121. <https://doi.org/10.1136/bmjresp-2021-001121>
- Ramos-Jiménez, A., Hernández-Torres, R. P., Torres-Durán, P. V., Romero-Gonzalez, J., Mascher, D., Posadas-Romero, C., & Juárez-Oropeza, M. A. (2008). The Respiratory Exchange Ratio is Associated with Fitness Indicators Both in Trained and Untrained Men: A Possible Application for People with Reduced Exercise Tolerance. *Clinical Medicine. Circulatory, Respiratory and Pulmonary Medicine*, 2, CCRPM.S449. <https://doi.org/10.4137/CCRPM.S449>

- Reilly, T., Morris, T., & Whyte, G. (2009). The specificity of training prescription and physiological assessment: A review. *Journal of Sports Sciences*, 27(6), 575–589.  
<https://doi.org/10.1080/02640410902729741>
- Remígio, M. I., Santa Cruz, F., Ferraz, Á., Remígio, M. C., Parente, G., Nascimento, I., Brandão, D., Dornelas De Andrade, A. D. F., De Moraes Neto, F., & Campos, J. (2018). The Impact of Bariatric Surgery on Cardiopulmonary Function: Analyzing VO<sub>2</sub> Recovery Kinetics. *Obesity Surgery*, 28(12), 4039–4044.  
<https://doi.org/10.1007/s11695-018-3469-4>
- Ricci, P. A., André, L. D., Jürgensen, S. P., De Oliveira, C. R., Ortega, F. P., Di Thommazo-Luporini, L., & Borghi-Silva, A. (2021). Responses of different functional tests in candidates for bariatric surgery and the association with body composition, metabolic and lipid profile. *Scientific Reports*, 11(1), 22840.  
<https://doi.org/10.1038/s41598-021-02072-x>
- Rodriguez, R. J., Badin, A., Panday, M., Anderson, A., & Pillarisetti, J. (2021). AUTONOMIC DYSFUNCTION FOLLOWING BARIATRIC SURGERY. *Journal of the American College of Cardiology*, 77(18), 327.  
[https://doi.org/10.1016/S0735-1097\(21\)01686-7](https://doi.org/10.1016/S0735-1097(21)01686-7)
- Ross, R., Blair, S. N., Arena, R., Church, T. S., Després, J.-P., Franklin, B. A., Haskell, W. L., Kaminsky, L. A., Levine, B. D., Lavie, C. J., Myers, J., Niebauer, J., Sallis, R., Sawada, S. S., Sui, X., & Wisløff, U. (2016). Importance of Assessing Cardiorespiratory Fitness in Clinical Practice: A Case for Fitness as a Clinical Vital Sign: A Scientific Statement From the American Heart Association. *Circulation*, 134(24). <https://doi.org/10.1161/CIR.0000000000000461>
- Rousseau, C., Jean, S., Gamache, P., Lebel, S., Mac-Way, F., Biertho, L., Michou, L., &

- Gagnon, C. (2016). Change in fracture risk and fracture pattern after bariatric surgery: Nested case-control study. *BMJ*, i3794.  
<https://doi.org/10.1136/bmj.i3794>
- Rowland, T. (2009). Endurance Athletes' Stroke Volume Response to Progressive Exercise: A Critical Review. *Sports Medicine*, 39(8), 687–695.  
<https://doi.org/10.2165/00007256-200939080-00005>
- Samson, R., Ayinapudi, K., Le Jemtel, T. H., & Oparil, S. (2020). Obesity, Hypertension, and Bariatric Surgery. *Current Hypertension Reports*, 22(7), 46.  
<https://doi.org/10.1007/s11906-020-01049-x>
- Sayadi Shahraki, M., Mahmoudieh, M., Kalidari, B., Melali, H., Mousavi, M., Ghourban Abadi, M., Mirhosseini, S., & Mirhosseini Dehabadi, S. (2022). Bone health after bariatric surgery: Consequences, prevention, and treatment. *Advanced Biomedical Research*, 11(1), 92.  
[https://doi.org/10.4103/abr.abr\\_182\\_21](https://doi.org/10.4103/abr.abr_182_21)
- Schauer, D. P., Feigelson, H. S., Koebnick, C., Caan, B., Weinmann, S., Leonard, A. C., Powers, J. D., Yenumula, P. R., & Arterburn, D. E. (2019). Bariatric Surgery and the Risk of Cancer in a Large Multisite Cohort. *Annals of Surgery*, 269(1), 95–101. <https://doi.org/10.1097/SLA.0000000000002525>
- Shiau, J., & Biertho, L. (2020). Bariatric Surgery: Postoperative Management. In *Canadian Adult Obesity Clinical Practice Guidelines*.  
<https://obesitycanada.ca/guidelines/postop>
- Shook, R. P., Hand, G. A., Paluch, A. E., Wang, X., Moran, R., Hébert, J. R., Jakicic, J. M., & Blair, S. N. (2016). High respiratory quotient is associated with increases in body weight and fat mass in young adults. *European Journal of Clinical*

*Nutrition*, 70(10), 1197–1202. <https://doi.org/10.1038/ejcn.2015.198>

Sloan, R. A., Sawada, S. S., Martin, C. K., Church, T., & Blair, S. N. (2009).

Associations between Cardiorespiratory Fitness and Health-Related Quality of Life. *Health and Quality of Life Outcomes*, 7(1), 47.

<https://doi.org/10.1186/1477-7525-7-47>

Snelder, S. M., Aga, Y., De Groot - De Laat, L. E., Biter, L. U., Cabezas, M. C., Pouw, N., Birnie, E., Boxma - De Klerk, B., Klaassen, R. A., Zijlstra, F., & Van Dalen, B. M. (2023). Normalization of Cardiac Function After Bariatric Surgery Is Related to Autonomic Function and Vitamin D. *Obesity Surgery*, 33(1), 47–56.

<https://doi.org/10.1007/s11695-022-06336-x>

Strasser, B., & Fuchs, D. (2016). Diet versus Exercise in Weight Loss and Maintenance:

Focus on Tryptophan. *International Journal of Tryptophan Research*, 9,

IJTR.S33385. <https://doi.org/10.4137/IJTR.S33385>

Syn, N. L., Cummings, D. E., Wang, L. Z., Lin, D. J., Zhao, J. J., Loh, M., Koh, Z. J.,

Chew, C. A., Loo, Y. E., Tai, B. C., Kim, G., So, J. B.-Y., Kaplan, L. M., Dixon, J. B., & Shabbir, A. (2021). Association of metabolic–bariatric surgery with

long-term survival in adults with and without diabetes: A one-stage meta-analysis of matched cohort and prospective controlled studies with 174 772 participants. *The Lancet*, 397(10287), 1830–1841.

[https://doi.org/10.1016/S0140-6736\(21\)00591-2](https://doi.org/10.1016/S0140-6736(21)00591-2)

Tabata, I. (2019). Tabata training: One of the most energetically effective high-intensity

intermittent training methods. *The Journal of Physiological Sciences*, 69(4),

559–572. <https://doi.org/10.1007/s12576-019-00676-7>

Tabesh, M. R., Maleklou, F., Ejtehad, F., & Alizadeh, Z. (2019). Nutrition, Physical

Activity, and Prescription of Supplements in Pre- and Post-bariatric Surgery Patients: A Practical Guideline. *Obesity Surgery*, 29(10), 3385–3400.

<https://doi.org/10.1007/s11695-019-04112-y>

Takeshita, S., Nishioka, Y., Tamaki, Y., Kamitani, F., Mohri, T., Nakajima, H., Kurematsu, Y., Okada, S., Myojin, T., Noda, T., Imamura, T., & Takahashi, Y. (2024). Novel subgroups of obesity and their association with outcomes: A data-driven cluster analysis. *BMC Public Health*, 24(1), 124.

<https://doi.org/10.1186/s12889-024-17648-1>

Tan, M. M. C., Jin, X., Taylor, C., Low, A. K., Le Page, P., Martin, D., Li, A., Joseph, D., & Kormas, N. (2022). Long-Term Trajectories in Weight and Health Outcomes Following Multidisciplinary Publicly Funded Bariatric Surgery in Patients with Clinically Severe Obesity ( $\geq 3$  Associated Comorbidities): A Nine-Year Prospective Cohort Study in Australia. *Journal of Clinical Medicine*, 11(15), 4466. <https://doi.org/10.3390/jcm11154466>

Templin, T., Cravo Oliveira Hashiguchi, T., Thomson, B., Dieleman, J., & Bendavid, E. (2019). The overweight and obesity transition from the wealthy to the poor in low- and middle-income countries: A survey of household data from 103 countries. *PLOS Medicine*, 16(11), e1002968.

<https://doi.org/10.1371/journal.pmed.1002968>

Tettero, O. M., Aronson, T., Wolf, R. J., Nuijten, M. A. H., Hopman, M. T. E., & Janssen, I. M. C. (2018). Increase in Physical Activity After Bariatric Surgery Demonstrates Improvement in Weight Loss and Cardiorespiratory Fitness. *Obesity Surgery*, 28(12), 3950–3957. <https://doi.org/10.1007/s11695-018-3439->

x

- Tirthani, E., Said, M. S., & Rehman, A. (2023). Genetics and Obesity. In *StatPearls*. StatPearls Publishing. <http://www.ncbi.nlm.nih.gov/books/NBK573068/>
- Tran, D. (2018). Cardiopulmonary Exercise Testing. In P. C. Guest (Ed.), *Investigations of Early Nutrition Effects on Long-Term Health* (Vol. 1735, pp. 285–295). Springer New York. [https://doi.org/10.1007/978-1-4939-7614-0\\_18](https://doi.org/10.1007/978-1-4939-7614-0_18)
- Üstün, I., Solmaz, A., Gülçiçek, O. B., Kara, S., & Albayrak, R. (2019). Effects of bariatric surgery on knee osteoarthritis, knee pain and quality of life in female patients. *Journal of Musculoskeletal & Neuronal Interactions*, 19(4), 465–471.
- Vibarel-Rebot, N., Asselin, M., Amiot, V., & Collomp, K. (2023). Short-Term Effect of Bariatric Surgery on Cardiorespiratory Response at Submaximal, Ventilatory Threshold, and Maximal Exercise in Women with Severe Obesity. *Obesity Surgery*, 33(5), 1528–1535. <https://doi.org/10.1007/s11695-023-06550-1>
- Wadden, T. A., Tronieri, J. S., & Butryn, M. L. (2020). Lifestyle modification approaches for the treatment of obesity in adults. *American Psychologist*, 75(2), 235–251. <https://doi.org/10.1037/amp0000517>
- Weir, C. B., & Jan, A. (2023). BMI Classification Percentile And Cut Off Points. In *StatPearls*. StatPearls Publishing. <http://www.ncbi.nlm.nih.gov/books/NBK541070/>
- Wharton, S., Lau, D. C. W., Vallis, M., Sharma, A. M., Biertho, L., Campbell-Scherer, D., Adamo, K., Alberga, A., Bell, R., Boulé, N., Boyling, E., Brown, J., Calam, B., Clarke, C., Crowshoe, L., Divalentino, D., Forhan, M., Freedhoff, Y., Gagner, M., ... Wicklum, S. (2020). Obesity in adults: A clinical practice guideline. *Canadian Medical Association Journal*, 192(31), E875–E891. <https://doi.org/10.1503/cmaj.191707>

- WHO Regional Office for Europe. (2020). *Gender and noncommunicable diseases in Europe. Analysis of STEPS data*.  
<https://iris.who.int/bitstream/handle/10665/337471/WHO-EURO-2020-1664-41415-56457-eng.pdf?sequence=1&isAllowed=y>
- WHO Regional Office for Europe. (2022, May 2). *WHO European Regional Obesity Report 2022*. WHO.  
<https://www.who.int/europe/publications/i/item/9789289057738>
- Wiggins, T., Antonowicz, S. S., & Markar, S. R. (2019). Cancer Risk Following Bariatric Surgery—Systematic Review and Meta-analysis of National Population-Based Cohort Studies. *Obesity Surgery*, 29(3), 1031–1039.  
<https://doi.org/10.1007/s11695-018-3501-8>
- World Health Organization (Ed.). (2000). *Obesity: Preventing and managing the global epidemic: report of a WHO consultation*. World Health Organization.
- World Health Organization. (2022). Acceleration plan to support Member States in implementing the recommendations for the prevention and management of obesity over the life course. In *WHO acceleration plan to stop obesity* (pp. 81–85). <https://www.who.int/publications-detail-redirect/9789240075634>
- World Health Organization. (2024, March 1). *Obesity and overweight*. WHO.  
<https://www.who.int/news-room/fact-sheets/detail/obesity-and-overweight>
- World Obesity Federation. (2023). *World Obesity Atlas 2023*.  
<https://data.worldobesity.org/publications/?cat=19>
- Xiao, C., & Graf, S. (2019). Overweight, poor diet and physical activity: Analysis of trends and patterns. In *The Heavy Burden of Obesity: The Economics of Prevention*. OECD. <https://doi.org/10.1787/67450d67-en>

- Yates, N., Liew, victor, Mouton, J.-M., Turner, J., White, A., & Smith, J. (2017).  
Management of bariatric patients beyond the scalpel. *Australian Journal for  
General Practitioners*, 46, 918–921.
- Zampino, M., Semba, R. D., Adelnia, F., Spencer, R. G., Fishbein, K. W., Schrack, J.  
A., Simonsick, E. M., & Ferrucci, L. (2020). Greater Skeletal Muscle Oxidative  
Capacity Is Associated With Higher Resting Metabolic Rate: Results From the  
Baltimore Longitudinal Study of Aging. *The Journals of Gerontology: Series A*,  
75(12), 2262–2268. <https://doi.org/10.1093/gerona/glaa071>
- Zeng, C., Lane, N. E., Li, X., Wei, J., Lyu, H., Shao, M., Lei, G., & Zhang, Y. (2021).  
Association between bariatric surgery with long-term analgesic prescription and  
all-cause mortality among patients with osteoarthritis: A general population-  
based cohort study. *Osteoarthritis and Cartilage*, 29(10), 1412–1417.  
<https://doi.org/10.1016/j.joca.2021.05.063>
- Zhou, N., Scoubeau, C., Forton, K., Loi, P., Closset, J., Deboeck, G., Moraine, J.-J.,  
Klass, M., & Faoro, V. (2022). Lean Mass Loss and Altered Muscular Aerobic  
Capacity after Bariatric Surgery. *Obesity Facts*, 15(2), 248–256.  
<https://doi.org/10.1159/000521242>
- Zou, K., Hinkley, J. M., Park, S., Zheng, D., Jones, T. E., Pories, W. J., Hornby, P. J.,  
Lenhard, J., Dohm, G. L., & Houmard, J. A. (2019). Altered tricarboxylic acid  
cycle flux in primary myotubes from severely obese humans. *International  
Journal of Obesity*, 43(4), 895–905. <https://doi.org/10.1038/s41366-018-0137-7>





## Appendix A

Study characteristics.

Foi convidado para participar no estudo de investigação científica com o título **“Qual o regime de exercício mais adequado na prevenção do reganho de peso em pacientes pós-cirurgia bariátrica com perda de peso insuficiente? - BariOptimize”**. Leia cuidadosamente a descrição do estudo e, sempre que achar necessário, coloque as suas dúvidas ao investigador.

1. Qual o objetivo do estudo?

O objetivo deste estudo é comparar dois programas diferentes de exercício físico – exercício resistido e exercício de endurance – para determinar qual é o mais eficaz na perda de peso e na prevenção do reganho de peso após cirurgia bariátrica.

2. Qual será o meu papel no estudo?

Se aceitar participar, será aleatoriamente alocado a um de 3 grupos possíveis – grupo de treino resistido (TR), grupo de treino de endurance (TE) ou grupo de controle (C). Se ficar alocado nos grupos TR ou TE, participará num programa de exercício físico supervisionado ao longo de 16 semanas. Se for alocado ao grupo C, não participará nas sessões de exercício supervisionadas mas continuará a receber o tratamento médico habitual pós-cirurgia bariátrica e participará nas sessões de avaliação da aptidão física.

Independentemente do grupo a que ficar alocado, será avaliado em 2 momentos – antes de iniciar o estudo e na 17<sup>a</sup> semana do estudo.

3. Qual será a duração da minha participação?

A duração total será de 17 semanas. Este período de tempo engloba as sessões de treino e avaliação final.

4. Onde se vai realizar o estudo?

Nas instalações da Faculdade de Desporto da Universidade do Porto (FADEUP), na rua Dr. Plácido Costa, 91, Porto.

5. Qual é o horário dos treinos?

Os treinos serão realizados às segundas, quartas e sextas, das 18h às 19h.

6. Estarei acompanhado durante os treinos?

Sim. Caso seja alocado ao grupo TR ou TE, será sempre acompanhado nos treinos por técnicos de exercício certificados. O seu plano de treino será individualizado de acordo com a sua aptidão física e problemas de saúde. Adicionalmente, irá realizar o treino inserido num grupo que terá até 8 participantes.

7. Que avaliações serão realizadas?

Pode encontrar esta informação em baixo, na Tabela 2.

8. Terei acesso aos dados das avaliações efetuadas?

Sim. Todos os relatórios das avaliações efetuadas ser-lhe-ão fornecidos.

9. Como serão protegidos os meus dados?

Os seus dados pessoais, assim como os resultados recolhidos durante as avaliações, serão associados a um código identificador anónimo. Apenas o investigador responsável terá acesso à associação entre o código identificador e a sua identidade. **Nenhum trabalho científico ou apresentação irá conter qualquer referência à identidade individual dos participantes.** Os seus dados serão conservados por um período máximo de 4 anos para fins de tratamento estatístico e posteriores trabalhos científicos.

Se tiver alguma dúvida sobre a forma como os seus dados pessoais são tratados ou queira saber mais sobre os seus direitos no âmbito da proteção de dados, pode entrar em contacto com o Encarregado de Proteção de Dados do CHUSJ através do endereço de email: **epd@chs.min-saude.pt**

Caso considere que os seus dados não estão a ser objeto de tratamento legítimo, pode, a todo o momento, apresentar uma reclamação junto da autoridade competente, a Comissão Nacional de Proteção de Dados ([www.cnpd.pt](http://www.cnpd.pt)).

10. Que vantagens tenho em participar?

Ao integrar um programa de exercício poderá beneficiar de controlo do peso, melhoria da composição corporal, diminuição da glicemia, controlo do perfil lipídico (colesterol e triglicéridos), diminuição da pressão arterial e aumento da aptidão física. Ao participar no programa estará também a cumprir com as recomendações para a prática de atividade física da Organização Mundial de Saúde (OMS).

Irá também realizar exames (descrição na tabela 2), sem qualquer custo associado, que fornecem informações importantes sobre o seu estado de saúde e que podem auxiliar o seu médico no seu acompanhamento.

11. Terei algum seguro?

Sim. Caso aceite participar no estudo, estará segurado/a relativamente às atividades realizadas no âmbito do estudo.

12. A minha participação tem algum custo?

Não. Todo o processo, desde as sessões de treino às avaliações realizadas serão gratuitas. Eventualmente, os únicos custos que ficarão a seu cargo serão aqueles relacionados com as deslocações para as sessões de treino. Poderá estacionar o seu veículo no parque da FADEUP gratuitamente..

13. E se quiser desistir a meio do programa?

Poderá fazê-lo a qualquer momento e sem qualquer prejuízo. O seu acompanhamento médico habitual e acesso aos cuidados de saúde não será, de forma alguma, afetado se a qualquer momento decidir que não quer mais integrar o projeto. A sua participação é voluntária. Se, a determinado momento, não desejar mais fazer parte do projeto, deverá informar o gestor de projeto (Tiago Montanha) através dos contactos que se encontram no final deste documento. Alternativamente, poderá contactar o Dr. Eduardo Lima Costa através do e-mail: [elimadacosta@me.com](mailto:elimadacosta@me.com)

Para informação mais detalhada sobre o estudo, recomendámos que leia atentamente o texto que se segue.

## **Desenho do estudo**

A fase do estudo em que irá participar terá a duração total de 32 semanas. Se aceitar participar, será aleatoriamente selecionado para um de três grupos possíveis: controlo (C), treino resistido (TR), ou treino de endurance (TE). Em termos práticos, a principal diferença entre grupos encontra-se nas primeiras 16 semanas, em que os grupos TR e TE participarão em programas de treino distintos. O grupo C continuará a receber o acompanhamento médico habitual que já recebia previamente. Nas últimas 16 semanas, não terá lugar qualquer intervenção. Este será o período em que pretendemos verificar se as alterações alcançadas com o treino perduram no tempo.

Nas 32 semanas estão contemplados 3 momentos de avaliação, que serão realizados no início, meio e final do programa. A estrutura do estudo encontra-se exemplificada na Tabela 1.

### **Tabela 1 – Desenho do estudo**

#### **16 semanas**

<b>Controlo</b>	<b>Avaliação 1</b>	<b>Avaliação 2</b>
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**Treino**

**Resistido**

#### **Avaliações**

Nos 2 momentos de avaliação iremos recolher informações relacionadas com vários parâmetros do seu estado de saúde e aptidão física. Na Tabela 2 pode encontrar uma breve descrição dos testes que iremos realizar.

**Tabela 2 – Breve descrição das avaliações a ser realizadas**

<b>Parâmetro</b>	<b>Designação</b>	<b>Descrição</b>
<b>Antropometria</b>	-	<b>Medição do peso, altura, perímetros da cintura e anca</b>
<b>Pressão arterial</b>	-	<b>Medição com aparelho digital</b>
<b>Força</b>	<b>Dinamometria a isocinética</b>	<b>Avaliação da força dos membros superiores e inferiores</b>
<b>Taxa metabólica de repouso</b>	<b>Oximetria indireta</b>	<b>Permanecer em deitado por 15 min. enquanto os gases respirados são analisados</b>
<b>Aptidão cardiorespiratória</b>	<b>Oximetria indireta</b>	<b>Teste com intensidade progressiva realizado no tapete rolante</b>
<b>Composição corporal</b>	<b>Avaliação por DEXA</b>	<b>Avaliação da quantidade de gordura e massa magra através de imagiologia</b>
<b>Atividade física diária</b>	<b>Avaliação por <i>smartwatch</i></b>	<b>Utilizar um <i>smartwatch</i> durante 7 dias consecutivos</b>
<b>Avaliação da ingestão nutricional</b>	<b>Diário alimentar</b>	<b>Registrar a ingestão alimentar durante 3 dias</b>
<b>Parâmetros cardiometabólicos</b>	<b>Análise bioquímica</b>	<b>Recolha de uma pequena quantidade de sangue através de uma picada no dedo</b>
<b>Qualidade de vida</b>	<b>Questionários</b>	<b>Responder a questionário sobre a qualidade de vida</b>

Para algum esclarecimento adicional, não hesite em contactar:

**Tiago Montanha: 918913418 / lmontanha@fade.up.pt**



## Appendix B

### Informed consent form

Designação do Estudo: “**Qual o regime de treino ideal para a prevenção do ganho de peso após cirurgia bariátrica?**”

Eu, \_\_\_\_\_, nascido/a em \_\_\_\_\_/\_\_\_\_\_/\_\_\_\_\_, e detentor/a do cartão de cidadão com o nº \_\_\_\_\_ declaro que compreendi o objetivo do estudo, assim como as minhas responsabilidades como participante. Tomei conhecimento dos riscos e benefícios que podem advir da minha participação e tive a oportunidade de expôr as dúvidas que achei necessárias, tendo todas sido devidamente esclarecidas. Tenho conhecimento que posso, a qualquer momento e sem qualquer prejuízo, abandonar o estudo. Autorizo a utilização dos dados recolhidos nas avaliações realizadas para efeitos académicos ou científicos, tais como apresentações em eventos e artigos científicos. Fui também informado/a que será preservada a confidencialidade acerca da minha identidade, assim como dos meus dados pessoais. Assim sendo, aceito de livre e espontânea vontade participar nesta investigação nos moldes em que me foi apresentada pelo investigador.

Data

\_\_\_\_\_ de \_\_\_\_\_ de 2023

O/A participante

\_\_\_\_\_

O Investigador responsável

\_\_\_\_\_



## Appendix C

### Participants' health status questionnaire

Condições de saúde pré-existent				
Condição	Exemplo	Sim	Não	Qual?
Neurológicos	Tonturas; tremores			
Oculares	Glaucoma; retinopatia			
Auditivos	Má audição			
Pulmonares	DPOC; enfisema; asma			
Gastrointestinais	Refluxo; azia; úlcera			
Osteoarticulares	Osteoartrose; tendinite			
Tabagismo	-			
Outras condições	Alterações do sono, edemas			
Cirurgias prévias	-			

Sintomas com o exercício / esforço				
Dispneia em esforço	Falta de ar a subir escadas			
Dor pré-cordial	Pressão ou ardor no peito			

Palpitações	Sente os batimentos?			
Síncope	Desmaio ou tonturas			
Doença vascular da periférica	Cansaço ou dor na barriga da perna ao caminhar			

Medicação habitual			
Nome / princípio ativo	Dose	Frequência	Duração