2020

Diet and physical activity behaviors associated with weight maintenance in bariatric surgery patients

BOSTON UNIVERSITY

SCHOOL OF MEDICINE

Thesis

DIET AND PHYSICAL ACTIVITY BEHAVIORS ASSOCIATED WITH WEIGHT MAINTENANCE IN BARIATRIC SURGERY PATIENTS

by

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B.S., University of California Davis, 2017

Submitted in partial fulfillment of the

requirements for the degree of

Master of Science

2020

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DEDICATION

I dedicate my hard work and persistence to my mother and father, who have supported me every step of the way to achieve success in every aspect in my life. Camerin Rencken, my partner, who inspires and encourages me to be the best version of myself and to never waver in the face of adversity. My two best friends from a small town in California, Riley Everett and Aaron Fleming, growing up together and having your support even from afar means more than words can describe. Finally, to my niece, Nylah, whom I have not had the luxury of getting to know, I hope my absence will someday inspire you to be someone great.

I owe my all success to those whom I have encountered throughout my years on Earth, thank you for not letting me fail.

ACKNOWLEDGMENTS

I would like to begin first by thanking my director, Dr. Lynn Moore, for taking a chance on me and giving me the opportunity to complete my graduate studies at Boston University. Without Dr. Moore, I would not have the opportunity of attending veterinary school at Kansas State University.

I am thankful for my primary mentor, Dr. Nicole Spartano, who guided me with consistent positivity and a wealth of suggestions that helped bring this study into success. As I am writing this, we are in the midst of a pandemic. Despite a chaotic time period Dr. Spartano hopped on Zoom chats with me to go over results and played a pivotal role in the fruition of this project.

I would also like to thank Dr. Jude Deeney for his stories, teachings, and guidance. Dr. Deeney would always stay late to answer questions, talk about life, and ensure our well-being. Whether he knows it or not, my experience at Boston University would not have been the same without him.

Finally, I would like to thank my Boston Veterinary Clinic team. Working at Boston Veterinary Clinic while a student was one of the most challenging and rewarding tasks to date. However, having team members as passionate and dedicated to veterinary medicine constantly inspired me to be the best possible version of myself.

DIET AND PHYSICAL ACTIVITY BEHAVIORS ASSOCIATED WITH WEIGHT MAINTENANCE IN BARIATRIC SURGERY PATIENTS

TARUN R. MEHTA

ABSTRACT

Background

One of the most common long-term problems after bariatric surgery is weight regain, occurring between 18 and 24 months after surgery in 30% of patients.[1] Weight regain after bariatric surgery supports the concept that obesity is a chronic, progressive disease that needs constant follow-up.[2] To ensure long-term post-operative success, patients are recommended to adopt comprehensive lifestyle changes, which include adhering to a diet of at least 60-120 g/day of protein and engaging in mild exercise 20 min/day 3-4 days/week.[3–7] Based on the current literature there is growing evidence that patients' health behaviors, including physical activity and protein intake, may play a significant role in weight loss and other postoperative outcomes.[8–11] However, there is little long-term evidence for behaviors important for sustained weight loss following bariatric surgery.

Objective

The purpose of our research initiative was to determine whether protein intake and physical activity have an effect on maintaining weight loss in patients who underwent bariatric surgery 1-2 years earlier.

Methods

Our study included 368 patients who underwent bariatric surgery at Boston Medical Center from 06/01/2016-05/31/2017. We extracted baseline clinical data from electronic medical records (EMR), including gender, self-identified race, weight, height, date of birth, date of enrollment in the bariatric surgery program, and surgery date. We also collected self-reported physical activity (calculated as active metabolic equivalent [MET]-hours) and 24-hour dietary recall information from patients who had this data available in their EMR at least 1-year post surgery (n=121, 80.2% female), and assessed weight status through 06/01/2019. We conducted a retrospective analysis to observe the association of lifestyle factors with weight maintenance post-bariatric surgery. Prevalence and odds ratio (OR) were calculated for % weight regain (<2% vs. ≥2%) by active MET-hours & percent protein in diet, with adjustment for age, gender, race, and time to nadir weight. We ran additional analysis to test the combined effect of physical activity and high protein diet by comparing percent weight regain in those consuming a low protein diet (with any activity level) to those consuming moderate-high protein & lower active METS-hour vs. moderate-high protein & higher active METS-hour.

Results

Our study implemented two novel ways to examine physical activity and dietary recalls in the context of bariatric surgery patients, and how they influenced percent weight regain of nadir weight. Our results show that patients had an average of 84.4 pounds of weight loss at 1-year post operation, the average nadir weight was 179.0 pounds. However, many participants experienced weight regain after achieving their nadir weight. In fact, the average weight regain was 5.8 pounds. Patients who had active MET-hours <1.5 (n=78) had an average of 5.77 pounds regained after reaching nadir weight, compared to patients who had an active MET-hour ≥1.5 (n=43) who had an average of 5.89 pounds regained. But after adjusting for age, gender, and race, those who were less active (active MET-hours <1.5) did not have significantly higher odds of gaining more that 2% of their nadir weight back during out follow-up period (OR = 0.71 [CI 0.32-1.60]). Protein intake was defined as either a low protein intake (<26.7% protein of total diet) or moderate-high protein intake (≥26.7% protein of total diet). A patient consuming a low protein diet had 2.71 (CI 1.16 – 5.29) times the odds gaining ≥ 2% of their weight back from nadir compared to patients who consumed a moderate-high protein diet, after adjusting for age, sex, and race (p-value <0.05). After adjustments, those with moderate-high protein and low activity had 1.84 (CI 0.69-4.94) times the odds of ≥2% weight regain of nadir weight compared to patients who were moderate-high protein and higher activity, which, although not statistically significant, may be an important relationship to explore further.

Conclusion

The findings indicate that consuming a moderate-high protein diet while engaging in physical activity tend to gain less weight after bariatric surgery in comparison to consuming less protein. There is also some evidence that those achieving moderate-high protein levels see an added benefit on weight maintenance if they are physically active. Future prospective longitudinal studies and strategies are needed to investigate implications further and define the magnitude of the association between protein intake, physical activity and bariatric surgery, as well as targeting various demographic subpopulations who might stand to benefit more from certain lifestyle interventions post-bariatric surgery.

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LIST OF ABBREVIATIONS

ACT24..Activities Completed Over Time in 24-hours

ASA24...Automated Self-Administered Dietary Assessment Tool

ASMBS.. American Society for Metabolic and Bariatric Surgery

BMI..Body Mass Index

BMR.. Basal Metabolic Rate

BU.. Boston University

CDC ....Centers for Disease Control

DLW ....Doubly Labeled Water

EE.. Energy Expenditure

EMR..Electronic Medical Records

FFM...Fat Free Mass

GLP-1...Glucagon-Like-Petide-1

METs.. Metabolic Equivalents

MVPA... Moderate-Vigorous Physical Activity

NIH ....National Institute of Health

PA ....Physical Activity

PYY..Peptide YY

RYGB .... Roux-en-Y Gastric Bypass

WL .... Weight Loss

WR .... Weight Regain

INTRODUCTION

Obesity is a public health problem that has reached unprecedented proportions. Overall, there is around 13% of the world's population who were categorized as obese in 2014.[12,13] Bariatric surgery has been used as a therapeutic tool to manage obesity worldwide, the National Institutes of Health (NIH) set eligibility criteria for bariatric surgery which included a body mass index (BMI) (kg/m^2) ≥ 40 without coexisting medical problems or a BMI ≥ 35 with ≥ 1 severe obesity related comorbidities.[5,12] In populations with morbid obesity (BMI ≥ 40 kg/m^2), bariatric surgery has been shown to sustain weight loss as well as show improvements in physical function and an improved quality of life.[14] Bariatric surgery is a generally safe and effective treatment option for patients with a BMI ≥ 40 kg/m^2 and there are a variety of different procedures offered. In the United States, the most commonly performed procedures include the sleeve gastrectomy and the Roux-en-Y gastric bypass (RYGB).[15] Weight loss depends specifically on the individual and the type of surgery they had, but those who undergo RYGB specifically lose an average of 90 pounds.[16] While the data on optimal weight loss following bariatric surgery varies, according to the Mexico Bariatric Center peak weight loss occurs around 6-12 months post operation.[17] Studies have shown significant improvements in cardiovascular risk factors, diabetes, and hypertension.[18] Weight loss is different for individuals, as it is important to account that reaching a healthy weight depends not just on the surgery but also sticking to healthy lifestyle habits.

Diet induced caloric restriction alone is a well-recognized problem, in terms of weight management long-term, 12-18 months following weight loss 33-50% of initial weight loss is regained.[19] For this reason alone, surgery teams need to veer away from the caloric restriction model post-surgery. In patients who have recently undergone bariatric surgery, specifically RYGB, little is known about the effects that physical activity (PA) has on long-term post bariatric surgery health outcomes, including body composition and physical strength. Earlier research suggests that increased involvement in PA following bariatric surgery is associated with increased weight loss in the short term.[20] However, there is limited research that has assessed the effects of long-term PA in the months after bariatric surgery, making it increasingly difficult for health care providers to recommend PA requirements to patients. Previous studies have compared participants who maintained a high level of PA with those who maintained a low activity level and found no significant difference.[21] Although, there is speculation that it may be the magnitude of preoperative to postoperative increase in PA that may be most important for increasing the amount of weight loss produced by bariatric surgery.[20] This suggests that higher levels of PA are required to maintain and improve significant weight losses.[22–24] Data also suggest that increase in energy intake in RYGB patients may also be due to dilatation of the gastric pouch[25], however this complication has only been described in a 10-15% of bariatric patients[26], implying that other factors may be involved in weight regain post bariatric surgery.[27]

Preoperative Dietary and Physical Activity Management

Prior to bariatric surgery, a supervised weight-management program, which includes a low-calorie diet is highly recommended. Studies have found a positive relationship between preoperative and postoperative weight loss,[28] including improved cardiovascular risk factors in diabetic patients.[29] But long term outcomes are still inconclusive,[28,30] and, therefore, preoperative weight loss is not often a condition for approving surgery.[31] There is also no agreement with regard to the suggested period of preoperative diet and its macronutrient composition.[32,33] According to the American Society for Metabolic and Bariatric Surgery, the maximum length of a preoperative diet is 3 months, in order to maintain a strong compliance rate amongst patients.[34]

Postoperative Dietary Progression After Bariatric Surgery

Postoperative dietary recommendations are based on gradually introducing various food consistencies and textures over the course of 1-2 months.[35] In the first 24-48 hours after surgery, patients are instructed to consume clear liquids at room temperature, increasing the volume to reach approximately 2 liters. Patients should consume liquids in small portions, with no more than half a cup per serving. At 1-2-week post-surgery, patients are advised to progress to a pureed diet. At 2-week post operation, patients can add soft foods to their diet. One-month post-surgery, patients are instructed to begin adding solid foods. At 2 months post-surgery, patients may consume a regular solid diet, which is important because this promotes the most satiety and enhanced nutritional composition.[35,36]

RYGB procedures lead to changes in absorption of nutrients due to the food stream being rerouted such that approximately 60% of the small intestine, the primary site of absorption of nutrients, is bypassed.[37,38] Meaning that food is in contact with the absorptive surface of the intestine for less time, leaving less opportunity for nutrients to be extracted by the body. Since food is being rerouted, there is less mixing with bile and pancreatic enzymes. Bile is necessary for absorption of fat, and pancreatic enzymes are crucial for the breakdown of proteins, fats, and complex carbohydrates. Therefore, only a small amount of protein and fat are absorbed efficiently. Around 18%-25% of patients develop a protein deficiency post bariatric surgery. In addition, there can be deficiencies in vitamins and minerals, specifically fat-soluble vitamins (A, D, E, and K). Deficiencies are more common after RYGB in comparison to a laparoscopic sleeve procedure.[5,7,36,39,40] Therefore, lifetime supplement intake post-surgery becomes necessary, in addition to vitamins and minerals.[7,41] Supplementation should begin at the time of discharge from the hospital, and includes a multivitamin-plus-mineral supplement, 1200-2400 mg calcium, ≥ 3000 IU vitamin D, and 250-350 mg vitamin B-12/d.[5] An additional concern post-operatively is protein deficiency (serum albumin levels <3.5 mg/dL), and it is likely attributed to the food intolerance for protein-rich foods. [42] Hair loss, poor wound healing, and loss of lean body mass are various clinical manifestations associated with protein deficiency.[43] After surgery the protein intake requirement is around 60-80 g/d or 1.1-1/5 g/kg of ideal body weight and increases to 90-120 g/d. [5–7] In order to achieve these recommendations, protein-rich foods should be favored over foods rich in fats or carbohydrates.[41,43] Quality of protein is an important consideration, particularly with respect to the quantity of leucine, an amino acid which helps maintain lean tissue.[43]

Macronutrient Intake Recommendations Post Surgery

The role of the dietitian is to estimate the value of macronutrients consumed, advise the patient on needed behavioral changes, and construct a balanced diet.[34] Dietitian should note if the patient is at risk of developing protein deficiency, as well as other deficiencies, and provide a catered list of foods rich in protein and/or protein supplementation as needed. Previous observational studies have shown that macronutrient intake of carbohydrate and fat should range from 35-48% and 37-42%, respectively.[44–46] In addition, the avoidance of simple carbohydrates is recommended, and the consumption of food rich in dietary fibers should be increased. Fiber-rich foods should be consumed starting 1-month post-surgery to enable adequate weight loss. Fat intake recommendations after bariatric surgery are similar to those for the general population.[47]

Progression of Increasing Physical Activity After Bariatric Surgery

Despite recognition that PA promotion is an important component of a comprehensive surgical weight loss program[3,48,49], there are currently no evidence based pre- or postoperative PA guidelines.[50] However, several organizations have issued recommendations. The American Society for Metabolic and Bariatric Surgery recommends mild exercise 20 min/day 3-4 days/week prior to surgery to improve cardiorespiratory fitness and facilitate healing and enhance postoperative recover.[4] The American Heart Association recommends a similar preoperative exercise regimen.[3] PA is associated with a decrease in many chronic diseases.[51] The promotion of PA is crucial to participants post bariatric surgery. Engaging in regular PA is an important factor in weight loss maintenance. According to one survey conducted in RYGB patients with a mean follow up time of 7 years, those who maintained ≥74% of their initial weight loss, exercised regularly.[52] There is also evidence that suggests that high levels of sedentary time increase the risk of chronic disease and mortality.[53,54] Evidence between the association of PA and health outcomes are typically self-reported by participants.[51] The issue with PA, like diet, is that it is often being overreported and thus needs to be evaluated as objectively as possible. There is data which suggests that maintaining a positive balance of more light intensity PA and less sedentary time may decrease mortality in older adults, as well as alleviate certain comorbidities.[55,56] In addition, there are disruptions in energy intake, and even energy expenditure, seen post bariatric surgery. This may be due to modifications in gut and adipocyte hormones.

Interestingly, around two thirds of participants between one- and three-years post-operation do not meet the minimum recommended levels of PA which are linked to health benefits and chronic disease prevention.[57] These individuals also participate in less PA than the general population. Studies which have tried to promote increased participation in PA among bariatric surgery participants are limited. Recent clinical intervention studies have shown that postoperative exercise training stimulates multiple health benefits including but not limited to whole body insulin sensitivity, muscle mitochondrial dysfunction, and glucose tolerance.[58–60] Additionally, exercise training can maintain skeletal muscle mass, leading to the fact that weight loss could positively be affected by regular exercise. Thus, PA could be a potential additional therapy for surgery induced caloric restriction and produce tissue specific metabolic benefits in addition to surgery.[61]

PA is very important for long-term weight management, however different patients have different needs and/or abilities, with that in mind the patient's team may have specific recommendations in order to stage PA for the patient. As previously mentioned, there are no PA recommendations in place for bariatric surgery patients. The recommendations for activity are to engage in moderate activity for 150 minutes weekly, and to safely exercise as it is different from person to person. These recommendations come from the CDC's recommendations for PA set in place for the general population.

The direct timeline depends on the type of exercise. Patients are encouraged to begin walking while in the hospital. As the healing process begins patients may ramp up exercise time and intensity, another reason why protein intake is essential post-surgery. Post-surgery, exercises requiring weights, sit-ups, pull-ups, or any abdominal straining should wait until the patient's team gives the go-ahead.[62]

Weight Loss Maintenance Post Bariatric Surgery

Bariatric surgery is not an unerring treatment option, although it does produce momentous improvements in metabolic health. A huge problem is that there is a lack of studies reporting long term follow up ($\geq$1 year) in cohorts with sufficient retention rates.[16] The extensive number of visits that patients must encounter when meeting with healthcare providers may contribute to retention rates. Weight loss success may also contribute to retention rates. Participants who have lost their desired weight might feel less inclined to continue visiting with their nutritionist, primary care provider, etc. only to continue self-reporting diet, PA and medications. However, for participants who experience suboptimal weight loss, exercise may provide the necessary supplemental therapy needed for weight loss. Exercise alone is not viewed to cause a substantial body weight reduction.[63] According to the Physical Activity Guidelines Committee Report, exercise alone is described to result in weight loss of <3% of initial body weight.[64] In individuals with severe obesity, exercise in combination with diet induced caloric restriction yield an additive reduction in body weight.[65,66] However, there is limited research on the topic of bariatric surgery, and as mentioned there are no Physical Activity Guidelines for the bariatric surgery population. According to Shah et al. a randomized controlled trial conducted in 2011 showed that a high-volume exercise prescription post bariatric surgery had no impact on body weight and waist circumference when compared to the control group.[66] Another report suggested that attending a structured exercise education classes showed excess weight loss at 12 months postoperatively, but not 36 months postoperatively.[58] The data does not completely rule out the probability that a higher dose of exercise may elicit additional weight loss in a favorable way following weight loss surgery.[67]

According to Chaston et al. loss of fat free mass (bone, organ, and skeletal muscle accounted for roughly around 31.3% of weight loss following RYGB surgery.[68] In addition, fat free mass (FFM) accounts for a meaningful portion of resting energy expenditure and has been hypothesized that the loss of FFM may predispose individuals to weight regain in the long term.[69,70] This does come at a bit of a price, especially in regard to older bariatric surgery patients. The loss of skeletal muscle and bone density may have a negative impact on physical function and may onset the progression of sarcopenia (relative deficiency of skeletal muscle mass and strength) as well as hinder the individual's quality of life.[71] Indices of obesity such as BMI in an elderly population do not relate as strongly with adverse health outcomes such as diabetes or cardiovascular disease as compared to younger individuals. Resistance exercise has been postulated as an excellent way to maintain muscle mass in older adults[72], and this may be an effective tool for older bariatric surgery patients. It is important to note that the duration of resistance-type exercise training is an imperative factor determining an individual's response to exercise training (i.e. weight loss). Caloric restriction in combination with supervised exercise assuaged the loss of FFM according to a number of randomized studies.[73–75] Randomized controlled exercise trials with comprehensive information regarding body composition of participants are needed to provide the level of evidence that suggest that exercise is a feasible therapy for bariatric surgery participants.

It is evident that there is a relationship between protein intake, PA, and weight maintenance for this population. In addition to weight maintenance, there are other reasons why PA is important for this population. Functional abilities such as muscular fitness and cardiovascular endurance are important for participants to return to daily activities such as work, childcare, and carrying heavy objects. Given the paucity of literature in this area, I aim to assess whether PA is associated with WL maintenance in post bariatric surgery patients. The specific aim of this project is to determine whether PA is effective in weight maintenance after twelve months of follow up in a population of

169 participants (Males = 31, Females = 138). In combination with dietary guidelines for bariatric surgery patients, an adequate consumption of protein will preserve and/or increase lean body mass with PA and will show a decrease in weight regain post bariatric surgery.

METHODS

Study Design and Population

Our study included a total of 368 patients who underwent bariatric surgery at Boston Medical Center (BMC), an urban academic medical center, from 06/01/2016-05/31/2017. We extracted baseline clinical data from electronic medical records (EMR), including gender, self-identified race, weight, height, date of birth, date of enrollment in the bariatric surgery program, and surgery date. Additionally, we requested the visit dates, clinician's names (including referrals) and text from visits. We also collected self-reported PA and 24-hour dietary recall information from patients who had this data available in their EMR at least 1-year post surgery (n=121, 80.2% female), and assessed weight status through 06/01/2019.

We conducted a retrospective analysis to observe the association of lifestyle factors with weight maintenance post-bariatric surgery. A weight was not always collected at the date of nutritionist visit. The average time difference between date of last weight and date of nutritionist data (which included diet, PA, weight, height, and medications) was 51 days. The average difference between nadir weight and final weight was 5.81 pounds.

In the current investigation, participants who had follow up data for at least one-year post surgery, and at one-year pre surgery visits were included (n=169) (Figure 1). Participants were excluded with incomplete data (n=39), for example they did not have a dietary recall (n=13) or PA (n=26) recorded post ≥ 365 days. Patients were also excluded for which the surgery conducted was a secondary bariatric surgery (e.g. conversion procedure or an Apollo overstitch) (n=8), as shown in Figure 1. The final exclusion criteria was if any female patients were pregnant post operatively (n=1). All participants had a weight recorded ≥365 days after surgery. Based off of our data and previous findings, having visits ≥365 days was important as this time frame allowed us to analyze when maximal weight loss occurred for patients.[76,77] At BMC, all surgeries were performed by two experienced surgeons using the same surgical technique, in addition follow-up care was provided by the same team during the observational phase of this study. Data from a total of 121 patients were included in our final analyses. This study was approved by the Boston Medical Center Institutional Review Board.

Figure 1. Study Flow Diagram:

N=368 with Surgery Conducted Between
06/01/2016- 05/31/2017

Exclude if no nutrition visit
≥365 days (N=199)

N=169 with Nutrition Visits

Exclude if surgery was a
conversion procedure or an
Apollo overstitch (N=8)

N=161 with Laparoscopic Revision Gastric Bypass, Gastric Bypass, Apollo Endo-
surgery Overstitch or Gastrectomy Sleeve Single

Exclude if no dietary recall
(N=13)

N=148 with Complete Dietary Recalls

Exclude if no PA recorded
(N=26)

N=122 with PA Data

Exclude if pregnant (N=1)

N=121 with PA Data, Complete
Dietary Recalls and Not Pregnant

Clinical Data

We extracted clinical data from the EMR, including gender, self-identified race, weight, height, date of birth, date of enrollment in the bariatric surgery program, and surgery date. BMI was calculated using the patient's height and weight using the formula kg/m2. Races included in the study were Caucasian/white, African American/black, Asian, American Indian, Hawaiian, and other. Asian, American Indian, and Hawaiian were categorized to other. If participants did not report race or it was missing, then the parameter was set to undefined.

Dietary and Physical Activity Data Extraction

In addition to baseline clinical data and follow-up weights, the bariatric surgery dietitian assessed dietary adherence to the program criteria which included: 1) adherence to the postoperative vitamin/mineral supplementation 2) intake of at least 60 g of quality protein/day 3) sufficient hydration of water of at least 1.5-2.0 L/d 4) avoidance of concentrated sweets and fried foods 5) intake of low glycemic load foods and a 6) 24-hour dietary recall. Exercise compliance was assessed by the following 1) cardiovascular exercise 2) resistance exercise 1-2 times/week. All measurements, including PA and dietary recalls were taken at each nutritionist visit before surgery as well post operatively. Diet and exercise data included in the analyses was collected by 9 dietitians.

Two research assistants extracted PA text and dietary recall data from dietitian notes. Data was extracted from five sample dietary and PA recalls, using records of patients excluded from the study. Following this, research assistants discussed techniques that worked, and how to minimize any discrepancies, such as by individually inputting ingredients in homemade dishes after looking up the recipe (i.e. traditional home dishes like Jamaican stew). For traditional home dishes, the research assistants looked up the main three ingredients of the dish and individually included the ingredients in the dietary recall. If the dish was more complex, the research assistants included the main five ingredients. In addition, the two research assistants discussed how to code for “walking to work,” when no time frame or distance was given, by inputting the time frame for 15 minutes. This time frame was by no means negligible, but not large enough to skew the active METs-hour. Once this was completed the two research assistants each coded the same 10 dietary and PA recalls from the population to ensure the caloric intake was within ± 5% of total caloric intake, and ± 1.5 METs. From there the remaining dietary and PA recalls were split in half and each of the research assistants coded half of the dietary and PA recalls. Each patient's PA data was coded using the Activities Completed over Time in 24-hours (ACT24), a validated web-based tool which generates a summary score for each participant.[78,79] The ACT24 system was designed by the National Cancer Institute investigators in the Division of Cancer Epidemiology and Genetics and the Division of Cancer Control and Population Sciences.

A 24-hour dietary recall was used to assess food intake as this information was collected during the dietitian visit and is a validated short-term dietary assessment in clinical interventions. Dietary data extracted from the EMR was entered into The Automated Self-Administered Dietary Assessment Tool (ASA24).[80–82]

Procedure for Assigning METs

Metabolic equivalents (METs) are a simple and easily understood procedure to calculate the energy cost of activities.[79] Simply put, a MET is a numerical value that represents a multiple of the resting metabolic rate for a given activity. We calculated estimated METs from the dietitian record using ASA24 software system. One MET equates to a rate of oxygen consumption of 3.5 milliliters per kilogram of body weight per minute (ml/kg/min) in adults.[83] Sedentary behaviors are behaviors defined as behaviors that require little energy expenditure, whereas active behaviors were those involving an upright posture or that had higher MET levels,[84,85] such as light (<3 METs), moderate (3-5.9 METs), and vigorous-intensity activity (≥6 METs). Active METs-hours were calculated as the self-reported sum of light, moderate, and vigorous activity across the duration of all captured PA. In order to ensure patients were distributed accordingly, we looked at a histogram plot to determine cutoff values for lower active METS-hour and higher active METs-hours. Active METS-hours was then dichotomized such that patients were either in the lower active METS-hour (METs-hours ≤1.5) group or higher active METS-hour (METs-hours >1.5) group. For example, a patient who fell into the higher active METS-hour category went to the gym and walked on the treadmill for 60 minutes, the sum duration for this patient would be 60 minutes. In contrast, a patient who fell into the lower active METS-hour category went to gym and walked on the treadmill for 15 minutes. There were some patients who were active at their work site, which we coded for moderate activity multiplied the duration of the patient's workday. For occupation based PA, we used a previous report which estimated the median and range of METs per occupation.[86] ACT24 has been found to be reasonably precise in estimating MET-hours/day (plus or minus 10% of doubly labeled water (DLW)), and lower active METs-hour time (plus or minus 3% of active physical activity level), and correlated with light (r =0.34), and moderate–vigorous activity (r =0.47) vs. an accelerometer.[87]

Protein Intake Calculation

We calculated protein intake from the dietitian record using ASA24 software system. The ASA24 dietary recall gave an output for each patient and presents an estimation of macronutrients, food group, vitamins & minerals, and energy.[88] Based off of this estimation we were then able to calculate the percentage of protein in the diet. We calculated the percentage of protein in diet by taking the value of protein that was found in the diet and then multiplied that value by 4 and divided the product by the total kcal found in the patient's diet.[89] According to Johns Hopkins the goal post bariatric surgery is to ingest 60-80 grams of protein per day.[90] In accordance to these standards, the dietitians assessed dietary adherence by ensuring patients were ingesting at least 60 grams/day which equates to 25% protein intake. In order to ensure patients were meeting this cutoff we looked at a histogram plot and a tertiles table to determine cutoff values for low and moderate-high protein intake. Based off of the distribution and lowest tertile, we determined the cutoff values for percent protein intake was <27.6% (low protein intake) and ≥27.6% (moderate-high protein intake).

Post-Surgery Weight Nadir and Follow-Up for Weight Regain

The lowest weight among participants whose weight was measured at 10 or more assessment was classified as nadir weight. Patients with a nadir weight that occurred

<365 days were excluded from the study. We calculated total weight loss (WL) as the difference between the presurgical weight and the weight for each subject at the final recorded clinical appointment in the EMR, an important note is that the final recorded weight did not always align with the dietitian appointment. In addition, we calculated the difference between nadir weight and final recorded appointment weight as weight regain (WR). This calculation allowed us to analyze percent weight regain by looking at WR divided by nadir weight. If the lowest weight was measured during the final recorded assessment, then that weight fits the criteria as the participants nadir weight for the purposes of our investigation, and they would have 0% weight regain. A total of 61 participants had 0% weight regain. The maximum weight gained back was 69 pounds or 32 kg. Based off of this distribution the cutoff was weight gain <2 % and ≥2% (on average <4 pounds and ≥4 pounds, respectively). In other words, % weight regain is the gain in weight after patients reach their lowest weight (nadir) during our follow-up period which occurred ≥365 days post-surgery, represented as a percentage of nadir weight.

Statistical Analyses

The primary objective for this study was to estimate the effects of PA and protein intake on weight loss and weight regain of at least 1 year after RYGB and Laparoscopic Gastrectomy Single Sleeve. We ran t-tests to observe the differences in mean (± standard deviation) demographic characteristics in our population by weight regain (< or ≥2% weight regain from nadir weight), by < or ≥26.7% protein intake, and by PA level (< or ≥1.5 active MET-hours). A logistic mixed model was used to examine race, age, sex, number of visits, surgery, active METS-hour, and percent of protein in diet. A total of six logistic mixed models were run. Our primary outcome was to determine if patients had <2% of weight regain from nadir weight or ≥2% weight regain from nadir weight. We first performed a logistic model to see the effect of low weight regain <2% or high weight regain ≥2% and how that may affect protein consumption. This model was adjusted for age, sex, and race. We further adjusted our model by including time to nadir weight. Then we performed a linear model to see how % weight regain affected active METS-hour. We performed a chi-square test to see if there was a correlation between active METS-hour and percent protein intake. We found that percent protein intake was correlated with METS-hour ($r=0.07$, $p=0.003$), so rather than trying to model in same model we performed a separate factorial analysis which included active METS-hour and percent protein intake, separately.

In order to see how patients who regained <2% or ≥2% of their nadir weight we combined the protein intake (low vs. moderate-high) and activity (lower active METs-hour vs higher active METs-hour). This allowed us to compare four variables and how the synergy of protein intake and active METS-hour affected patient weight regain. We found that one of our four groups, low protein intake & active, had a total of 6 patients. In order to get a more evenly distributed comparison we combined low protein intake & lower active METs-hour with low protein & active. Finally, we performed a logistic model to see how protein intake and activity affected % weight regain. Our final model was adjusted for age, sex, and race. Since time to nadir minimally changed our effect size, we opted to not include it in this final model. Multivariable logistic regression was used to determine unadjusted and adjusted association between 1) the percentage of protein found in diet and percentage weight regain from nadir weight 2) percentage weight regain from nadir weight and active METS-hour and 3) active METS-hour & percent of protein found in diet and percentage weight regain from nadir weight. All models were built using a combination of confounders based on parameters previously deemed a priori to be of relevance and found to be significantly associated. We included patients who were postoperative RYGB for ≥12 months.

All statistical analyses were performed using the SAS studio 3.71 (SAS Institute, Inc., Cary, North Carolina).

Sensitivity Analyses

In order to see if our model was affected by changes in variables such as race and sex, we performed a series of analyses to see whether the results changed when something about the way we approached the data analysis changes. This was necessary to do to ensure the consistency between the results of the primary analysis and the results of the sensitivity analysis, which strengthened the credibility of our findings.

Table 1. Variables used in this study.	
AGE	Age at time of final visit
BASELINE_WEIGHT	Weight at first visit with a medical provider (prior to surgery)
START_BMI	Initial Body Mass Index (kg/m^2)
DATE_OF_SURGERY	Date of Surgery
DATE_DIFFERENCE	Date of surgery to date of nadir weight
DIETARY_PRO	Dietary protein in grams
ETHNICITY	Self-identified race or ethnicity
FINAL_WEIGHT	Weight at the final recorded visit with a medical provider
FINAL_BMI	Final recorded Body Mass Index (kg/m^2)
METS	Metabolic equivalents
NADIR_WEIGHT	Lowest recorded weight with a medical provider
NUMBER_VISITS	Number of visits with a medical provider (pre-surgery and post-surgery)
SURGERY	Type of surgery (Laparoscopic Gastric Bypass or Laparoscopic Gastric Sleeve Single)
WEIGHT_CHANGE	Amount of weight regain from nadir weight to final weight
WEIGHT_LOSS	Total weight loss from baseline weight to final weight
NADIR_FINAL_WEIGHT	Categorized into 2 groups: 1. Nadir weight is not final weight 2. Nadir weight is final weight
PROACTIVE (Protein Intake and Activity)	Categorized into 4 groups: 1. Low Protein & Sedentary 2. Low Protein & Active 3. Moderate-High Protein & Sedentary 4. Moderate-High Protein & Active
PROACTIVITY (Protein Intake and Activity)	Categorized into 3 groups: 1. Low Protein & Sedentary/Active 2. Moderate-High Protein & Sedentary 3. Moderate-High Protein & Active

ACTIVITY (METS-hour)	Categorized into 2 groups: 1. Lower Active METs-hour 2. Higher Active METs-hour
SEX (Sex)	Categorized into: Male or Female
DEMO (Race)	Categorized into 2 groups: 1. African American/Black & Hispanic American 2. Non-Hispanic White & Other Race/Multi-Racial
PERCENT_PRODI (Percent of Diet That is Protein)	Categorized into 2 groups: 1. <26.7% Percent Protein (Low Protein) 2. ≥26.7% Percent Protein (Moderate-High Protein)
PERCENT_WC (Percent Weight Regain)	Categorized into 2 groups: 1. Low Weight Regain <15% of Total Weight 2. High Weight Regain ≥15% of Total Weight
AGE_Q	Categorized into 4 groups: 1. 20-34 Years Old 2. 35-49 Years Old 3. 50-64 Years Old 4. 65+
VISTS_TERT (Number of Visits)	Categorized into 3 groups: 1. Low Number of Visits 2. Average Number of Visits 3. High Number of Visits
DATES	Categorized into 2 groups: 1. <2 years 2. ≥2 years

RESULTS

Descriptive Data Explaining the Association of Socio-Demographic Factors with High Weight Regain Occurring One Year After Bariatric Surgery

The majority of the participants were 43 years old, were female (80.2%), and had an initial BMI of 47.6 kg/m^2 (Table 2). Patients on average visited a health care provider in the BMC Weight Management group on 41 separate occasions. Of the 121 patients, individual race/ethnicities were reported as White/Caucasian (37.2%), Black/African America (24.8%), Hispanic (33.1%), and Other (5%). During our follow-up period, starting 1-year post surgery, 75 patients (62.0%) regained some weight back after reaching their nadir weight. Out of the total population, 59.5% of patients gained <2% of their nadir weight back, while 40.8% of patients gaining ≥2% of their nadir body weight (Table 2). We found that 75.2% of patients reached their nadir weight within the first 2 years post operatively. 86.11% of patients who reached nadir weight within the first 2 years post-surgery had a low weight regain compared to 40.82% of patients who reached nadir weight ≥2 years and gained ≥2% of their nadir weight back. We observed that 73.6% of patients consuming a moderate-high protein (>26.7% dietary protein) intake either maintained their nadir weight or regained <2% back, compared to 42.9% of those who consumed a lower protein diet and regained ≥2% of their nadir weight back. Participants who gained at least 2% of their weight back ate a diet containing lower percent of protein (29% ± 6% vs. 31% ± 8%; $p<0.0001$). Those who gained more weight back also tended to be older, have lower initial weight, and lose less total weight after surgery.

Table 2. Demographics and Comparisons Between those with Low Weight Regain (<2%) and High Weight Regain (≥2%)				
Characteristic	**All (n=121) (weighted Col %)**	**Percent Weight Regain**		**P-Value**
		Low Weight Regain (<2%)	**High Weight Regain (≥2%)**	
		(n=72) (% of Column total)	**(n=49) (% of Column total)**	
Age				
20-34	35 (28.9%)	27 (37.5%)	8 (16.3%)	
35-49	54 (44.6%)	32 (44.4%)	22 (44.9%)	**.003**
50-64	27 (22.3%)	11 (40.7%)	16 (32.7%)	
65+	5 (4.1%)	2 (2.8%)	3 (6.1%)	
Age, years**	42.62 ± 11.4	40.04 ± 10.64	46.41± 11.5	**<0.0001*****
Race				
White/Caucasian	45 (37.2%)	26 (36.1%)	19 (38.8%)	.58
Black/African American	30 (24.8%)	15 (20.8%)	15 (30.6%)	
Hispanic	40 (33.1%)	29 (40.3%)	11 (22.5%)	
Other	6 (5.0%)	2 (2.8%)	4 (8.2%)	
Sex				
Female	97 (80.2%)	56 (77.8%)	41 (83.7%)	.43
Male	24 (19.8%)	16 (22.2%)	8 (16.3%)	
Baseline Weight (pounds)	**273.6 ± 61.5**	278.1 ± 62.7	266.9 ± 59.8	**<0.0001*****
Weight Loss (pounds)******	**84.4 ± 36.7**	85.0 ± 37.3	83.6 ± 35.9	**<0.0001*****
Nadir Weight (pounds)******	**179.1 ± 40.8**	185.6 ± 44.6	169.6 ± 32.7	**<0.0001*****
Initial BMI (kg/m$_2$) ******	**47.6 ± 8.5**	48.0 ± 8.4	46.9 ± 8.8	**<0.0001*****
Final BMI (kg/m$_2$) ******	**32.7 ± 5.82**	32.5 + 5.9	33.2 ± 5.7	**<0.0001*****
Weight Regain (pounds)******	**5.82 ± 9.51**	0.7 ± 1.1	13.4 ± 11.2	**<0.0001*****
Is Nadir Weight the Final Weight?				
Nadir is Not Final Weight	75 (61.9%)	26 (36.1%)	49 (100.0%)	**.0001**
Nadir is Final Weight	46 (38.1%)	46 (63.9%)	0 (0.0%)	
Time to Nadir Weight				
<2 Years	91 (75.2%)	62 (86.1%)	29 (59.2%)	**.0008**
≥2 Years	30 (24.8%)	10 (13.9%)	20 (40.8%)	
Active METs-Hour				
Lower Active METs-hour (<1.5 METs-Hour)	78 (64.5%)	49 (68.1%)	29 (59.2%)	.31
Higher Active METs-hour (≥1.5 METs-Hour)	43 (35.5%)	23 (31.9%)	20 (40.9%)	
METs-Hour	1.3 ± 0.4	1.2 ± 0.4	1.3 ± 0.5	**<0.0001*****
Percent Protein in Diet				
Low Intake	40 (33.1%)	19 (26.4%)	21 (42.9%)	**.05**
Moderate-High Intake	81 (66.9%)	53 (73.6%)	28 (57.4%)	
Percent Protein in Diet	0.3 ± 0.1	0.3 ± 0.1	0.3 ± 0.1	**<0.0001*****
Protein Intake and Activity				
Low Protein & Sedentary/Active	40 (33.1%)	19 (26.4%)	21 (42.9%)	
Moderate-High Protein & Sedentary	60 (49.6%)	36 (50.0%)	24 (48.9%)	**0.005**
Moderate-High Protein & Active	21 (17.4%)	17 (23.6%)	4 (8.2%)	

Number of Visits				
Low	38 (31.4%)	30 (41.7%)	8 (16.3%)	
Average	43 (35.5%)	24 (33.3%)	19 (38.8%)	**.002**
High	40 (33.1%)	18 (25.0%)	22 (44.9%)	
Surgery				
Laparoscopic Gastric Bypass	72 (59.5%)	48 (66.7%)	32 (65.3%)	.87
Laparoscopic Gastrectomy Sleeve	49 (40.5%)	24 (33.3%)	17 (34.7%)	

P-value indicates varying proportions of METS-hour based on sex, age, race, surgery type, and percent protein in diet
Analysis conducted: Chi-square
*Boldface indicates significance at the $p<0.05$ level
**Continuous variables presented as mean ± SD, categorical presented as frequency (%)
*** Analysis conducted: Student's t Test
Percent Weight Regain measured as difference between nadir and final weight calculated as percentage:
Low Weight Regain: less than 0.02%
High Weight Regain: greater than or equal to 0.02%
Percent Protein in Diet measured as protein in kcal divided by total kcal in diet:
Low Intake: less than 26.7%
Moderate-High Intake: greater than or equal to 26.7%
Sex, Surgery, Race, Percent Protein in Diet, and Age: No Values Missing (sample size=121)

Weight Loss and Regain Differs by Protein Intake

Patients who consumed ≥26.7% (moderate-high) protein in their diet lost 7.4 more pounds compared to patients who consumed <26.7% (low) protein in their diet (p-value <0.0001; Table 3). Those who consumed a moderate-high protein diet also regained 3.3 pounds more of their nadir weight compared to those consuming a low protein diet (p-value <0.0001; Table 3). Middle aged participants (aged 35-65) had a greater tendency to eat a high protein diet (p-value <0.02; Table 3). There appeared to be no racial differences in adherence to protein intake recommendations.

We next explored how adjusting for age, sex, race, and time to nadir weight impacted our observed association between protein intake and percent weight regain (Table 5). A patient consuming a low protein diet had 2.71 (CI 1.16 – 5.29) times the odds gaining ≥ 2% of their weight back from nadir compared to patients who consumed a moderate-high protein diet, after adjusting for age, sex, and race (p-value <0.05; Table 4). After further adjusting for time to nadir weight, consuming a low protein diet was associated with 2.42 (CI 1.01-5.79) times the odds gaining ≥ 2% of weight back (p-value <0.05; Table 5).

Table 3. Demographics and Comparisons Between those with Low Protein Intake and those with Moderate-High Protein Intake			
Characteristic	**Percent Protein Intake Low Intake (<26.7% Protein) Moderate-High Intake (≥26.7% Protein)**		**P-Value**
	Low Intake	**Moderate-High Intake**	
	(n=40) (% of Column total)	**(n=81) (% of Column total)**	
Age			
20-34	17 (42.5%)	18 (22.2%)	**.02**
35-49	11 (27.5%)	43 (53.1%)	
50-64	10 (25.0%)	17 (30.0%)	
65+	2 (5.0%)	3 (3.7%)	
Age**	40.8 ± 12.3	43.5 ± 10.7	**<0.0001*****
Race			
White/Caucasian	14 (35.0%)	31 (38.3%)	.97
Black/African American	11 (27.5%)	19 (23.5%)	
Hispanic	13 (32.5%)	27 (33.3%)	
Other	2 (0.5%)	4 (4.9%)	
Sex			
Male	7 (17.5%)	17 (20.9%)	.65
Female	33 (82.5%)	64 (79.1%)	
Baseline Weight (pounds)	**267.8 ± 56.7**	**278.9 ± 63.4**	**<0.0001*****
Weight Loss (pounds)******	**79.42 ± 23.7**	**86.90 ± 41.5**	**<0.0001*****
Nadir Weight (pounds)******	**170.23 ± 39.9**	**183.44 ± 40.8**	**<0.0001*****
Initial BMI (kg/m$_2$) ******	**45.7 ± 7.0**	**48.51 ± 9.2**	**<0.0001*****
Final BMI (kg/m$_2$) ******	**32.10 ± 6.4**	**33.0 ± 5.5**	**<0.0001*****
Weight Regain (pounds)******	**8.03 ± 12.4**	**4.72 ± 7.4**	**<0.0001*****
Time to Nadir Weight			
<2 Years	27 (67.5%)	64 (79.01%)	.17
≥2 Years	13 (32.5%)	17 (21%)	
Active METs-Hour			
Lower Active METs-hour (<1.5 METs-Hour)	33 (82.5%)	45 (55.6%)	**.0036**
Higher Active METs-hour (≥1.5 METs-Hour)	7 (17.5%)	36 (44.4%)	
Percent Weight Regain			
Low Weight Regain (<0.02)	19 (47.5%)	53 (65.4%)	**.05**
High Weight Regain (≥0.02)	21 (52.5%)	28 (34.6%)	
Number of Visits			
Low	14 (35.0%)	24 (29.6%)	**.05**
Average	11 (27.5%)	32 (38.5%)	
High	15 (37.5%)	25 (30.9%)	
Surgery			
Laparoscopic Gastric Bypass	26 (65.0%)	54 (66.7%)	.86
Laparoscopic Gastrectomy Sleeve Single	14 (35.0%)	27 (33.3%)	

P-value indicates varying proportions of percent protein intake based on sex, age, race, surgery type, and METS-hour
Analysis conducted: Chi-square
*Boldface indicates significance at the p<0.05 level
**Continuous variables presented as mean ± SD, categorical presented as frequency (%)
*** Analysis conducted: Student's t Test
Percent Weight Regain measured as difference between nadir and final weight calculated as percentage:

Low Weight Regain: less than 0.02%

High Weight Regain: greater than or equal to 0.02%

Activity definitions measured in METs then converted to METS-hour:

Lower Active METS-hour: less than 1.5

Higher Active METs-hour: greater than or equal to 1.5

Sex, Surgery, Race, METS-hour, and Age: No Values Missing (sample size=121)

Table 4. Factors Associated with ≥2% Weight Regain

Characteristic	Univariate Odds Ratio (95% CI)	Adjusted Odds Ratio (OR) **
Age	1.022 (0.99-1.06)	**0.94 (0.91-0.98)**
Race		
African American/Hispanic	1.14 (0.53-2.5)	0.78 (0.36-1.73)
White/Other	1 (Ref)	1 (Ref)
Sex		
Female	1.25 (0.47-3.32)	1.64 (0.58-4.62)
Male	1 (Ref)	1 (Ref)
Percent Protein in Diet		
Low Protein (<26.7%)	0.50 (0.19-1.4)	**2.71 (1.16-6.29)**
Moderate-High Protein (≥26.7%)	1 (Ref)	**1 (Ref)**

*Boldface indicates significance at the $p<0.05$ level
**Adjusted OR included covariates: age, sex, race, percent weight regain, and percent protein in diet.
Percent Weight Regain measured as difference between nadir and final weight calculated as percentage of nadir weight:

Low Weight Regain: less than 0.02%
High Weight Regain: greater than or equal to 0.02%

Table 5. Factors Associated with ≥2% Weight Regain Including Time to Nadir Weight		
Characteristic	**Univariate Odds Ratio (95% CI)**	**Adjusted Odds Ratio (OR) ** **
Age	1.022 (0.99-1.06)	**0.95 (0.91-0.98)**
Race		
African American/Hispanic	1.14 (0.53-2.5)	0.81 (0.36-1.84)
White/Other	1 (Ref)	1 (Ref)
Sex		
Female	1.25 (0.47-3.32)	1.66 (0.38-4.70)
Male	1 (Ref)	1 (Ref)
Time to Nadir Weight		
<2 Years	0.55 (0.24-1.30)	**0.28 (0.11-0.72)**
≥2 Years	1 (Ref)	**1 (Ref)**
Percent Protein in Diet		
Low Protein (<26.7%)	0.50 (0.19-1.4)	**2.42 (1.01-5.79)**
Moderate-High Protein (≥26.7%)	1 (Ref)	**1 (Ref)**

*Boldface indicates significance at the p<0.05 level
**Adjusted OR included covariates: age, sex, race, time to nadir weight, percent weight regain, and percent protein in diet.
Percent Weight Regain measured as difference between nadir and final weight calculated as percentage of nadir weight:
Low Weight Regain: less than 0.02%
High Weight Regain: greater than or equal to 0.02%

Weight Regain Differs by Physical Activity Level

Patients who had active METs-hour ≥1.5 lost 10.28 more pounds compared to patients who had lower active METs-hour (p-value <0.0001; Table 6). However, patients who were more active regained more weight back on average. To further analyze we assessed whether patients regained <2% of their weight back from nadir weight compared to those who regained ≥2% of their weight back from nadir to examine the effect. We found that a larger proportion of patients who were less active (<1.5 MET-hours per day) (62.8%) maintained their weight; whereas for patients who were more active, only 53.5% maintained their weight, but these results were not significantly different from one another (p-value <0.32; Table 6). But on average, those in the active group gained more weight back (5.89 vs. 5.77 pounds; p<0.0001). The discrepancy between these two results means that there were likely a few of the active participants who regained a substantial amount of weight back, but as a whole, active participants may be more likely to maintain their weight.

We then explored how adjusting for age, sex, race, and time to nadir weight impacted the association between PA and percent weight regain. Given that time to nadir weight did not impact the effect size, we did not include it in the final model. We found that patients with lower active METs-hour had 0.71 (CI 0.32 – 1.60) times the odds of regaining more nadir weight back. Although not statistically significant, the relationship between PA and weight regain mat be important to study further.

Table 6. Demographics and Comparisons Between Those with Lower Physical Activity Level and Higher Physical Activity Level			
Characteristic	**Physical Activity Level**		**P-Value**
	Lower Active METs-Hour <1.5	**Higher METs-Hour ≥1.5**	
	(n=78) (% of Column total)	**(n=43) (% of Column total)**	
Age			
20-34	24 (30.8%)	11 (25.6%)	
35-49	34 (43.6%)	20 (46.5%)	.94
50-64	17 (21.8%)	10 (23.3%)	
65+	3 (3.9%)	2 (4.7%)	
Age**	41.98 ± 11.83	44.85 ± 9.51	**<0.0001*****
Race			
White/Caucasian	27 (34.6%)	18 (41.9%)	.18
Black/African American	16 (20.5%)	14 (32.6%)	
Hispanic	30 (38.5%)	10 (23.3%)	
Other	5 (6.4%)	1 (2.3%)	
Sex			
Female	62 (79.5%)	35 (81.4%)	.8
Male	16 (20.5%)	8 (18.6%)	
Baseline Weight (pounds)	**273.24 ± 65.7**	**274.21 ± 53.8**	**<0.0001*****
Weight Loss (pounds)******	**88.08 ± 35.6**	**77.80 ± 37.9**	**<0.0001*****
Nadir Weight (pounds)******	**175.38 ± 41.0**	**185.78 ± 39.9**	**<0.0001*****
Initial BMI (kg/m_2) ******	**47.33 ± 8.7**	**48.03 ± 8.19**	**<0.0001*****
Final BMI (kg/m_2) ******	**31.99 ± 5.6**	**33.99 ± 5.9**	**<0.0001*****
Weight Regain (pounds)******	5.77 ± 10.6	5.89 ± **7.2**	**<0.0001*****
Time to Nadir Weight			
<2 Years	42 (53.8%)	33 (76.7%)	**.01**
≥2 Years	36 (46.2%)	10 (23.3%)	
Percent Protein in Diet			
Low Intake	33 (42.3%)	7 (16.3%)	**.004**
Moderate-High Intake	45 (57.7%)	36 (83.7%)	
Percent Weight Regain			
Low Weight Regain (<0.02)	49 (62.8%)	23 (53.5%)	.32
High Weight Regain (≥0.02)	29 (37.2%)	20 (46.5%)	
Surgery			
Laparoscopic Gastric Bypass	52 (66.7%)	28 (65.1%)	.86
Laparoscopic Gastrectomy Sleeve Single	26 (33.3%)	15 (34.9%)	
Number of Visits			
Low	30 (38.5%)	8 (18.6%)	**.03**
Average	28(35.9%)	15 (34.9%)	
High	20 (25.6%)	20 (46.5%)	

P-value indicates varying proportions of METS-hour based on sex, age, race, surgery type, and percent protein in diet
Analysis conducted: Chi-square
*Boldface indicates significance at the p<0.05 level
**Continuous variables presented as mean ± SD, categorical presented as frequency (%)
*** Analysis conducted: Student's t Test
Percent Weight Regain measured as difference between nadir and final weight calculated as percentage:
Low Weight Regain: less than 0.02%

High Weight Regain: greater than or equal to 0.02%

Percent Protein in Diet measured as protein in kcal divided by total kcal in diet:

Low Intake: less than 26.7%

Moderate-High Intake: greater than or equal to 26.7%

Sex, Surgery, Race, Percent Protein in Diet, and Age: No Values Missing (sample size=121)

Table 7. Factors Associated with ≥2% Weight Regain		
Characteristic	**Univariate Odds Ratio (95% CI)**	**Adjusted Odds Ratio (OR) ** **
Age	**0.95 (0.92-0.98)**	**0.95 (0.92-0.99)**
Race		
African American/Hispanic	0.72 (0.35-1.49)	0.83 (0.38-1.89)
White/Other	1 (Ref)	1 (Ref)
Sex		
Female	1.46 (0.57-3.75)	1.60 (0.59-4.30)
Male	1 (Ref)	1 (Ref)
Active METs-Hour		
Lower Active METs-hour (<1.5 METs-Hour)	0.68 (0.32-1.45)	0.71 (0.32-1.60)
Higher Active METs-hour (≥1.5 METs-Hour)	1 (Ref)	1 (Ref)

*Boldface indicates significance at the p<0.05 level
**Adjusted OR included covariates: age, sex, race, percent weight regain, and METS-hour.
Percent Weight Regain measured as difference between nadir and final weight calculated as percentage:
Low Weight Regain: less than 0.02%
High Weight Regain: greater than or equal to 0.02%
Percent Protein in Diet measured as protein in kcal divided by total kcal in diet:
Low Intake: less than 26.7%
Moderate-High Intake: greater than or equal to 26.7%

Table 8. Factors Associated with ≥2% Weight Regain Including Time to Nadir Weight		
Characteristic	**Univariate Odds Ratio (95% CI)**	**Adjusted Odds Ratio (OR) ****
Age	**0.95 (0.92-0.98)**	**0.95 (0.92-0.99)**
Race		
African American/Hispanic	0.72 (0.35-1.49)	0.84 (0.38-1.89)
White/Other	1 (Ref)	1 (Ref)
Sex		
Female	1.46 (0.57-3.75)	1.61 (0.58-4.45)
Male	1 (Ref)	1 (Ref)
Time to Nadir Weight		
<2 Years	**0.23 (0.09-0.56)**	**0.26 (0.10-0.65)**
≥2 Years	**1 (Ref)**	**1 (Ref)**
Active METs-Hour		
Lower Active METs-hour (<1.5 METs-Hour)	0.68 (0.32-1.45)	0.73 (0.32-1.67)
Higher Active METs-hour (≥1.5 METs-Hour)	1 (Ref)	1 (Ref)

*Boldface indicates significance at the p<0.05 level
**Adjusted OR included covariates: age, sex, race, time to nadir weight, percent weight regain, and METS-hour.
Percent Weight Regain measured as difference between nadir and final weight calculated as percentage:
Low Weight Regain: less than 0.02%
High Weight Regain: greater than or equal to 0.02%
Percent Protein in Diet measured as protein in kcal divided by total kcal in diet:
Low Intake: less than 26.7%
Moderate-High Intake: greater than or equal to 26.7%

The Combined Association of Protein Intake and Physical Activity Level with Weight Regain

In our final model, we combined protein intake and PA level to see the combined association with weight regain. For individuals that achieved a moderate-high protein intake (≥26.7% protein diet), having a lower active METs-hour compared to having a higher active METs-hour (active METs-hour < 1.5 vs. active METS-hour ≥1.5) was associated with 1.84 (CI 0.69 – 4.94) times the odds of patients gaining ≥ 2% of their weight back from nadir weight p-value <0.05; Table 9). Individuals with low protein intake, a percent of dietary protein <26.7% (with any activity level), had 3.72 (CI 1.41 – 9.81) times the odds of having high weight regain compared to those who were active and had moderate-high protein intake (p-value <0.05; Table 9).

Table 9. Factors Associated with Patient's Gaining ≥ 2% of Weight Back from Nadir Weight

Characteristic	Univariate Odds Ratio (95% CI)	Adjusted Odds Ratio (OR)**
Age	**0.95 (0.92-0.98)**	**0.94 (0.91-0.98)**
Race		
African American/Hispanic	0.72 (0.35-1.50)	0.82 (0.37-1.83)
White/Other	1 (Ref)	1 (Ref)
Sex		
Female	1.46 (0.57-3.75)	1.61 (0.57-4.52)
Male	1 (Ref)	1 (Ref)
Protein Intake and Physical Activity Level		
Low Protein (<26.7%) & Sedentary/Active	**3.039 (1.23-7.5)**	**3.72 (1.41-9.81)**
Moderate-High Protein (≥26.7%) & Sedentary	1.382 (0.56-3.41)	1.84 (0.69-4.94)
Moderate-High Protein (≥26.7%) & Active	**1 (Ref)**	**1 (Ref)**

*Boldface indicates significance at the p<0.05 level
**Adjusted OR included covariates: age, sex, race, and protein intake & METS-hour combined.
Percent Weight Regain measured as difference between nadir and final weight calculated as percentage:
Low Weight Regain: less than 0.02%
High Weight Regain: greater than or equal to 0.02%

DISCUSSION

Bariatric surgery is the recommended treatment option for patients with severe obesity and/or comorbid conditions.[91] In addition, there is rising evidence that increasing PA pre- to postoperatively and higher PA levels are associated with greater weight loss and improved fitness following bariatric surgery.[50] Our study implemented two novel ways to examine PA and dietary recalls in the context of bariatric surgery patients, and how they influenced percent weight regain after reaching nadir weight. Participants in our study regained an average of 5.8 pounds (Table 2), which is typical for patients in the 1-4 year period post-surgery after reaching nadir weight.[12] We reported that maintaining weight status after reaching nadir weight was related to protein intake, and that an individual's PA level may further modify weight status. After adjustments, those with moderate-high protein and low activity had 1.84 (CI 0.69-4.94) times the odds of ≥2% weight regain of nadir weight compared to patients who were moderate-high protein and higher activity, however, individuals with low protein intake (and any activity level) had 3.72 (CI 1.41 – 9.81) times the odds of gaining back ≥2% of nadir weight compared to active individuals consuming a moderate-high protein level (p-value <0.05; Table 9). Previous research suggests that increased involvement in PA is associated with increased weight loss.[20]

The Physical Activity Guidelines Committee Report described exercise alone in weight loss of <3% of initial body weight[64], which led to the possible synergistic effects that protein intake may have with PA. Our study found that percent protein intake and time of achieving nadir weight are important factors in determining how much nadir weight is regained. The recommendation of protein intake is around 60-80g/d or 25% of total caloric intake, the average intake of protein in our population was 30% (Table 2). Kanerva and colleagues examined carbohydrate and protein intake in men and women following bariatric surgery and how it affected initial weight loss. They found that patients who consumed more protein and a relatively lower proportion of carbohydrates had lost more weight in comparison to a higher carbohydrate consumption and lower consumption of protein.[92] Schollenberg et al. observed that protein supplementation positively affected body weight loss and composition, the intake of 30-35g of protein powder resulted in a decrease in body weight of 25.4%.[93] Schiavo et al. found that a protein-enriched diet that provided 2 g of protein per kg ideal body weight led to a significant higher fat mass loss in 30 men compared with an isocaloric diet at 3, 6, and 12 months after bariatric surgery.[94] A review by Mahawar and Sharples found that there is little impairment of protein digestion and absorption after RYGB[95], these results are in contrast with the possible impairment of protein digestion and absorption after RYGB suggesting there are other mechanisms that are involved after bariatric surgery. While this study did not measure glucose tolerance, insulin sensitivity, and muscle mitochondrial dysfunction in regard to PA and protein intake[58–60], future studies can explore the potential improvements that may arise from PA and protein intake post-operatively. Furthermore, there is a scarcity of (long-term) data in regard to protein intake.

Other Factors Related to Weight Regain Post-Bariatric Surgery

Consistent with previous findings we found that other factors were involved in weight regain post bariatric surgery.[27] We found that younger individuals were more likely to regain weight after bariatric surgery in our study. Our findings are consistent with previous reports that age and sex are important factors for weight loss post bariatric surgery.[96] Previous studies have indicated that older adults had greater initial weight loss and less weight regain after weight loss intervention, with the added benefit that exercise is an excellent way to maintain muscle mass in older adults.[71,97,98] It is interesting to note that patients who achieved a nadir weight within the first 2 years post-surgery had 0.26 (CI 0.12 – 0.76) times the odds of gaining ≥2% of their nadir weight back ($p < 0.05$, Table 7). Future studies can explore whether prescribing a structured, supervised regimen program to ensure nadir weight is met within the first two years influences a lower weight regain.

Patients who regained more nadir weight back visited the medical team more compared to patients who maintained their weight (25% vs. 44.9%; p-value <0.05; Table 2). This may suggest that patients who are content with their weight loss are less inclined to continue visiting the medical team, whereas those who are regaining nadir weight would like to seek the advice of their medical team.

African Americans and Hispanics had more percent weight regain of nadir weight compared to Caucasians (53.1% vs. 38.8%; Table 2), however on average had 14% higher PA when compared to Caucasians (Table 5). These results are similar to those found by Anderson[99], Sugerman[100], and Latner et al.[101] The exact etiology of this racial disparity in weight loss between ethnic backgrounds has not been explained, and is likely due to a number of factors. The literature is sparse and there is much we do know about which individuals will have successful sustained weight loss and which individuals will gain back their weight. In regard to outcomes involving weight loss surgery, race is an important factor to consider. Existing literature suggests that African American patients lose less weight than Caucasian patients.[99,102,103] There are a combination of factors, including but not limited to differences in energy intake, energy expenditure, and income levels. Previous studies have reported lower daily energy expenditure in African Americans compared to Caucasian patients after bariatric surgery.[104,105] Differences in weight outcomes following bariatric surgery may also stem from metabolic differences in insulin and glucose metabolism between African American and Caucasian patients.[96] In a non-bariatric population, African Americans are significantly more insulin resistant than Caucasian counterparts with similar obesity levels.[106–109] Studies also suggest differences in β-cell physiology, African Americans compared to Caucasian patients have higher basal plasma insulin secretion.[110–112] RYGB may also affect appetite control via the hormone ghrelin, African Americans have slightly reduced suppression after meal consumption.[113] These previous findings may suggest that the modulatory effects of RYGB on insulin secretion via GLP-1 and appetite control via ghrelin might differ by race. [96] While it is not explored in this paper, it is important to keep in mind these changes in regard to dietary factors and factors that may influence weight regain.

Strengths and Limitations

The main strength of this report was its novel use of the rich data captured by the EMR, including previous day dietary and PA recall, an instrument that has been shown to reasonably accurate and valid for estimating dietary protein total PA and sedentary time.[80,82,87,88] The ability to examine active and sedentary behaviors by type, duration, and intensity allowed examination in differences in energy expenditure in response to exercise and work days in a population of bariatric surgery patients.

Although this type of long-term follow-up of dietary and PA data in this population is more novel, the type of instrument used is a limitation. Previous research indicates under-reporting or over-reporting how often they participate in PA, sedentary time, and the quantity of food during nutritionist visits.[114,115] Patients are asked to self-report consumed food at their appointments with nutritionist. However, self-reporting data has some consequences. For example, energy intake in weight regain may be greater than observed because subjects tend to over adhere to their dietary recommendations on the day that the diet is being recalled.[116] ACT24 has been validated for total active and sedentary time and METs-hour/day[87], however less is known about the validity of MVPA or for specific activities. The bariatric surgery population is a large database of adults living in the Greater Boston, Massachusetts area, which may limit the generalizability of the findings. Another potential limitation in the study is that of its retrospective nature. As noted previously, a significant number of subjects missed data points after 12 months. Also noted was that PA data and dietary recalls were extracted from dietician notes, which contributed to the difficulty to fully utilize the capabilities of ACT24 because it requires amount of time slept to calculate METs for sedentary time. There was a total of nine dieticians' part of the bariatric surgical team, which may contribute to a limitation of how data was collected due to variability in how the dietary recall was performed and recorded in the EMR.

Prevalence data is influenced by recall. Low PA is associated with other unhealthy habits aside from weight regain. Based off of this we were unable to disentangle the true driver of observed associations due to multiple correlated variables. Also, this study was observational, and causal relationships between protein intake and duration of PA and their effects on weight maintenance cannot be inferred. Finally, the analysis relied on estimations calculated to deduce active METS-hour and percent of protein intake, so the results are subject to the limitations of active METs and macronutrient composition in the diet. Future studies may also want to assess how exercise over the long term may affect factors that influence energy intake, body composition, and metabolic rate.[58] Additional research may also be required to examine whether PA and protein intake impact the location of weight regain (i.e. subcutaneous or visceral fat depots). Combining the use of EMR followed by metabolic analysis can be the next steps in a more catered approach to achieving maintenance of nadir weight post bariatric surgery.

Conclusion

In summary, our data suggest that patients who consumed a moderate-high protein diet tend to gain less weight after bariatric surgery in comparison to those who consumed less protein. For those achieving a moderate-high protein diet, we provide some evidence that there may be an additional benefit to also being physically active, although our results were not statistically significant. Future prospective longitudinal studies and strategies are needed to investigate implications further and define the magnitude of the association between protein intake, PA and bariatric surgery, as well as targeting various demographic subpopulations who might stand to benefit more from certain lifestyle interventions post-bariatric surgery.

LIST OF JOURNAL ABBREVIATIONS

Adv Nutr An Int Rev J	Advances in Nutrition
Aliment Pharmacol Ther	Alimentary Pharmacology & Therapeutics
Am J Clin Nutr	American Journal of Clinical Nutrition
Am J Epidemiol	American Journal of Epidemiology
Am J Physiol – Endocrinol Metab	American Journal of Physiology. Endocrinology and Metabolism
Ann Intern Med	Annals of Internal Medicine
Ann Surg	Annals of Surgery
BMJ	BMJ: British Medical Journal
Br Obes Metab Surg Soc	British Obesity and Metabolic Surgery Society
Clin Cardiol	Clinical Cardiology
Clin Nutr	Clinical Nutrition
Diabetes Obes Metab	Diabetes, Obesity & Metabolism
Endocrinol Metab Clin North Am	Endocrinology and Metabolism Clinics of North America
Eur J Epidemiol	European Journal of Epidemiology
Exerc Sport Sci Rev	Exercise and Sports Sciences Reviews
Int J Behav Nutr Phys Act	International Journal of Behavioral Nutrition and Physical Activity
Int J Obes	International Journal of Obesity
J Acad Nutr Diet	Journal of the Academy of Nutrition and Dietetics
J Am Diet Assoc	Journal of the American Dietetic Association
J Am Med Dir Assoc	Journal of the American Medical Directors Association

J Assoc Acad Minor Phys	Journal of the Association for Academic Minority Physicians
J Clin Endocrinol Metab	Journal of Clinical Endocrinology and Metabolism
J Clin Invest	Journal of Clinical Investigation
J Clin Psychiatry	Journal of Clinical Psychiatry
J Gastrointest Surg	Journal of Gastrointestinal Surgery
J Nutr Heal Aging	Journal of Nutrition, Health & Aging
J Sci Med Sport	Journal of Science and Medicine in Sport
JAMA – J Am Med Assoc	JAMA: The Journal of the American Medical Association
Journals Gerontol – Ser A Biol Sci Med Sci	Journals of Gerontology. Series A, Biological Sciences and Medical Sciences
Mayo Clin Proc	Mayo Clinic Proceedings
Med Sci Sports Exerc	Medicine and Science in Sport and Exercise
N Engl J Med	New England Journal of Medicine
Nutr Clin Pract	Nutrition in Clinical Practice
Obes Res Clin Pract	Obesity Research & Clinical Practice
Obes Rev	Obesity Reviews
Obes Surg	Obesity Surgery
Prev Chronic Dis	Preventing Chronic Disease
Psychosom Med	Psychsomatic Medicine
Rocz Państwowego Zakładu Hig	Roczniki Państwowego Zakładu Higieny
Surg Obes Relat Dis	Surgery for Obesity and Related Diseases

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CURRICULUM VITAE

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