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Long-term body composition changes in women following Roux-en-Y gastric bypass surgery

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Abstract

BACKGROUND—Although most individuals experience successful weight loss following Roux-en-Y gastric bypass (RYGB), weight regain is a concern, the composition of which is not well-documented. Our aim was to evaluate changes in body composition and handgrip strength as a measure of functional status in participants from a previous 1-year post-RYGB longitudinal study who had undergone RYGB approximately 9-years prior.

METHODS—Five women from an original larger cohort were monitored pre-RYGB and 1.5-months, 6-months, 1-year, and 9-years post-RYGB. Body composition was assessed at all time points using dual energy x-ray absorptiometry (DXA) and multiple dilution. Handgrip strength was measured using a digital isokinetic hand dynamometer (Takei Scientific Instruments, Ltd., Japan).

RESULTS—Mean time to final follow-up was 8.7-years. Lean soft tissue (LST) loss over the ~9-year period was on average 11.9 ± 5.6 kg. Compared to 1-year post-RYGB, 9-year LST was 4.4 ± 3.0 kg lower ($P=0.03$). Fat free mass (FFM) decreased over the 9-year period by 12.6 ± 5.8 kg. Mean FM decreased from 75.4 ± 22.6 kg pre-RYGB to 35.5 ± 21.5 kg 1-year post-RYGB, but then

trended towards an increase of 8.6 ± 7.0 kg between 1-year and 9-years post-RYGB ($P=0.053$). Loss of LST was correlated with loss of handgrip strength ($r = 0.64$, $P=0.0005$).

CONCLUSION—The continued loss of lean mass associated with decreased handgrip strength occurring with long-term trend towards FM regain post-RYGB is concerning. The loss of LST and functional strength carries particular implications for the aging bariatric population and should be investigated further.

Keywords

Lean tissue; lean body mass; fat free mass; dual-energy X-ray absorptiometry; obesity; RYGB; bariatric; handgrip strength

INTRODUCTION

The Roux-en-Y gastric bypass (RYGB) is a restrictive and malabsorptive procedure that reduces stomach capacity to approximately one ounce, bypasses part of the small intestine, and decreases nutrient absorption. Although overt macronutrient malabsorption is rarely reported, possible adverse outcomes of RYGB include protein deficiency, bone loss, abnormal fluid distribution, and excessive lean tissue loss.^{1–4} While body composition has been measured by many groups in the first year after surgery,^{5–12} few data exist regarding the impact of RYGB on body composition between 5 and 10 years after surgery. As might be expected, fat mass (FM)^{5,8,10–12} and percent body fat^{5,6,10,11} have been observed to substantially decrease in the first year after RYGB; however, fat-free mass (FFM) also decreases after surgery, albeit to a lesser extent. The degree to which FFM is lost in the first year after surgery varies among individuals undergoing RYGB and is influenced by factors including dietary protein intake, exercise and mobility, and inflammation.^{13–16} It is not well-studied what impact the changes in body composition, particularly FFM, may have on muscle strength and function over a 5 to 10 year period post-RYGB. Our aim was to evaluate changes in body composition and handgrip strength as a measure of functional status in participants from a previous 1-year post-RYGB longitudinal study who had undergone RYGB approximately 9-years prior.

METHODS

Subjects

As has been previously described,¹⁷ women with Class III obesity ($BMI \geq 40$ kg/m²) who planned to undergo RYGB surgery at the Weight Loss Management and Surgery Center at University of Minnesota Health, were recruited for the original 1-year longitudinal study between 2005 and 2007.¹⁷ The follow-up assessment of these original subjects was completed during 2014 and 2015. Both the original study and the follow-up protocol were approved by the University of Minnesota Institutional Review Board (IRB) and the Clinical and Translational Science Institute (CTSI). Returning subjects were compensated for their time. The 20 original subjects who attended at least three study visits as part of the original study were re-contacted through an IRB approved mailed letter and asked to return for one study visit. Individuals were excluded from the original study and follow-up if they (1) were on medications known to influence body composition (e.g. corticosteroids, anabolic

steroids), (2) had a pacemaker or other internally-placed biomedical device, (3) had conditions associated with significant hydration changes, and/or metabolic disturbances, such as pulmonary hypertension, congestive heart failure, abnormal thyroid function indices, neoplastic disease, liver failure, renal failure, type 1 diabetes, and poorly controlled type 2 diabetes, or (4) were pregnant. The original cohort was limited to women to maximize the homogeneity of the sample given the significant differences in body composition between men and women and because at the time of recruitment, only ~15% of the patients undergoing RYGB at our site were male.

Follow-Up Study Protocol

The day before testing, subjects were asked to avoid alcohol and vigorous exercise, and to maintain their usual fluid intake, limiting water consumption to no more than 250 ml water during the 2-hours just prior to testing. The study visit began in the morning after a 12-hour fast. Subjects remained fasted throughout all visit procedures.

Anthropometric Measurements—Each participant's height was measured to the nearest 0.1 cm using a wall-mounted stadiometer (model S100; AYRTON, Prior Lake, MN) and weight was measured to the nearest 0.1 kg using a stand-on digital scale (model 5002, SCALE-TRONIX, White Plains, NY). Waist and hip circumference were measured following standardized procedures as outlined in the Anthropometric Standardization Reference Manual.¹⁸

Total Body Water (TBW) and Extracellular Water (ECW)—To measure TBW, participants consumed 25 g of a 16% (wt/wt) solution of deuterium oxide, prepared following the method described in Trabulsi et al¹⁹ (supplying 4 g of 99.9% ²H₂O per pre-weighted dose, Sigma-Aldrich) in tap water, followed by 25 ml tap water rinse. To measure ECW, subjects consumed 1g/kg of a 3% (wt/vol) sodium bromide solution (Fisher) in tap water followed by a 25 ml tap water rinse. Serum samples were collected for analysis of bromide enrichment before dosing, and 4- and 5-hours post dose. In all cases, the 4-hour enrichment was lower than the 5-hour, thus, the 5-hour time point was used for data analysis. Urine samples were collected for analysis of deuterium enrichment before dosing, and 3-, 4-, and 5- hours post-dose. The average of 3-, 4- and 5-hour time points was used for data analysis. Subjects were asked to void their bladders hourly during the study visit, and they did not break their fast or consume any additional fluids throughout the 5-hour post-dose equilibration period. Urine samples were analyzed for deuterium enrichment by the laboratory of Dr. Dale Schoeller (University of Wisconsin, Madison, WI).^{19–21} TBW was determined from the deuterium space after reducing it by 4% to correct for exchange with the non-aqueous compartment.²¹

Serum samples were analyzed by high-performance liquid chromatography for bromide by the laboratory of Dr. Jennifer Rood (Pennington Biomedical Research Center, Baton Rouge, LA).^{22,23} The bromide dilution space was used to calculate ECW using the equation:

$$ECW = [dose / ([Br]_{5-hour} - [Br]_{Basal})] \times 0.95 \times 0.9; \quad (1)$$

where 0.95 is the Donnan equilibrium correction and 0.9 corrects for the intracellular distribution (including red blood cells).²¹

The original TBW and ECW data collected during the first year of weight loss following RYGB were used for comparison with the long-term follow-up data. For the first year of the study, we completed multiple dilution using a peripheral intravenous (IV) dosing protocol for deuterium and sodium bromide as has been previously reported.²⁴ For baseline (1-month pre-RYGB), 1.5-months, 6-months, and 1-year post-RYGB, TBW was calculated from the average deuterium enrichment of the 3-hour and 4-hour urine samples. For the same four time points, ECW was calculated from the 4-hour post-sodium bromide infusion serum sample. For all time points, ECW and TBW were converted to kg by multiplying by 0.993 (the density of water at 37°C). Oral dosing should result in slower equilibration time than IV dosing for both deuterium and bromide, thus we extended the equilibration time by one hour for the final follow-up visit.

Body Composition by Air Displacement Plethysmography (ADP)—Body composition was assessed by ADP using the BOD POD® (COSMED USA, Inc.; Concord, CA) only at the follow-up study visit and was not part of the original study protocol. The standard BOD POD® protocol was followed. The BOD POD® was calibrated each day before use. Body weight was measured using the device's electronic scale that was calibrated bi-weekly. Subjects wore tight fitting Lycra® or spandex® swimwear or lightweight sports bra and close fitting underwear and covered their hair with a tight fitting swim cap. Subjects were instructed to remove all metal and jewelry before entering the machine. The device reports the average of two raw body volume measurements. The Siri model was used to estimate body composition.²⁵ When the participant was capable of doing so, thoracic gas volume (TGV) was measured using the device. TGV measurement was repeated until a merit value (<1.0) was obtained to signify compliance with the TGV protocol. For the one participant who was unable to complete the TGV measurement, the device-predicted TGV result was used. Calculations were performed by the BOD POD®'s software (version 5.4.0). Repeat measurements of body volume using BOD POD® have been shown to result in an error equivalent to 0.8% body fat.²⁶

Body Composition by Dual Energy X-ray Absorptiometry—As described by Levitt et al.,²⁴ DXA scans from the original study were performed on the GE Lunar Prodigy (GE Healthcare, USA). By the time of the long-term follow-up visit, the CTSI had discontinued the use of the GE Lunar Prodigy. Therefore, follow-up scans were performed on the GE Lunar iDXA (GE Healthcare, USA). At baseline, study subjects were too heavy and/or large to obtain a whole body scan using the available standard sized DXA instrument; thus half-scans were performed,^{27,28} and for consistency, for all study visits up to 1-year post-RYGB. At the 9-year follow-up visit, both whole and half-body scans were obtained for four of the five individuals for whom it was possible, using the iDXA instrument. It has been reported that mirrored half-body scans are comparable to whole body scans using the iDXA.²⁸ Half-body scans from baseline, 1.5-months, 6-months, and 1-year post-RYGB were re-analyzed using the Lunar iDXA software. The right-side half-body scans were mirrored around the mid-line to create a “whole” individual for analysis. For each original (baseline, 1.5-months,

6-months, 1-year) scan, study subjects were scanned using an acrylic board to separate arm tissue from breast tissue as previously described.²⁴ Re-analysis of the isolated board using the new software indicated that it was interpreted by the iDXA as contributing the whole-body equivalent of 1.165 kg to fat mass (FM) and 0.365 kg fat free mass (FFM). Thus, these values were subtracted from the results for mirrored body FM, LST, and FFM from the original scans. No corrections were made to the mirrored half-body scans for the long-term follow-up visit because an acrylic board was not used. Precision of the iDXA instrument has been reported to be <1% for whole body bone mineral content (BMC)²⁹ and 1.5% for whole body FM and LST measures³⁰ in individuals with extreme obesity.

Resting Energy Expenditure (REE)—At the time of metabolic rate measurement, study subjects had been fasted for approximately 15-hours. After resting in a recumbent position for at least 30-minutes, measurement of REE was completed using a portable metabolic cart (TrueOne® 2400, Parvo Medics, East Sandy, UT). A trained technician completed the REE measurement following standard protocol. Briefly, after a 30-minute device calibration period during which time the subject rested in a quiet, thermoneutral environment, a ventilated canopy was placed over the participant and gas exchange was measured for at least 20-minutes. The room was kept at a comfortable temperature throughout the measurement and the participant was instructed to not talk or sleep during the measurement period. The first 5 minutes of data were discarded. For analysis purposes, results for each minute of testing for VCO_2 , VO_2 , and REE were averaged for the time period from 6–20 minutes, which for all individuals had coefficients of variation <10%, interpreted as steady-state. REE measurements were available for all subjects using the same protocol and device for the 1-year and 9-years post-RYGB visits. Pre-RYGB data were not available using the Parvo Medics device.

Handgrip Strength—Handgrip muscle strength was measured using a digital isokinetic hand dynamometer (Model T.K.K.5401, Grip D, Takei Scientific Instruments, Ltd., Japan). Handgrip strength was assessed with subjects in a standing position. Subjects were asked to keep their arm straight (elbow at full extension) and hanging by the side of their body. Subjects were asked to squeeze the dynamometer with as much force as possible without changing their body position or leaning to one side. Two measurements were taken from the right and the left hand consecutively (R, L, R, L) and the four measurements were averaged. Handgrip assessment was completed at all study visits following the same protocol.

Estimation of Fat Mass Using the 4-Component Model—At the follow-up visit ~9-years post-RYGB for which ADP was available to measure body volume, we calculated FM using the four-component model:^{31,32}

$$FM, kg = 2.7474 \times (\text{body volume}, l) - 0.7145 \times (TBW, l) + 1.4599 (BMC, kg) - 2.0503 \times (\text{body weight}, kg);$$

with body volume from ADP, TBW from deuterium dilution and BMC from DXA. FFM was calculated by subtracting FM from body weight.

Statistics

Statistical analyses were performed using SAS software, version 9.4 of the SAS system (SAS Institute Inc. Cary, NC, USA) and GraphPad Prism version 6.0 for Mac OS-X, (GraphPad Software, La Jolla California USA). Values are expressed as means $\pm$ standard deviations (SD), unless otherwise indicated. Non-parametric Friedman analysis of variance was used to assess overall differences in body composition measurements over the five time points for which data were available. Paired t-tests were used to evaluate weight, body composition and strength changes between 1-year and mean follow-up time of 9-years. A general linear model for repeated measures was used to determine the relationships between handgrip strength, LST, and age. For all tests, $P < 0.05$ was considered significant. Pearson's correlation (r) is reported for comparisons between methods.

RESULTS

Subject Characteristics

Of the 20 Caucasian, female subjects who completed the original study, 10 expressed interest in returning to the study when they were contacted between 8 and 9-years after the original study. Two of these 10 individuals declined to participate in the follow-up study, three were lost to follow-up after originally expressing interest, and five individuals completed the follow-up study visit. All women were seen for the final follow-up between 8 and 9 years after surgery. Mean time to final long-term follow-up visit was 8.7 ± 0.3 years after surgery (see Table 1). Mean age for these five women at time of surgery was 47.2 ± 10.9 years; at last follow-up visit, mean age was 56.2 ± 10.9 years. Most (four out of five) women were post-menopausal at the time of final follow-up. One individual had diabetes (most recent Hemoglobin A1C of 7.6 mg/dl) and was taking insulin; all other individuals were non-diabetic. Fasting blood glucose was within normal limits (defined as >70 mg/dl and <99 mg/dl) at the follow-up visit for all subjects. For the first three reported time points (baseline, 1.5-months, and 6-months) post-RYGB, the individual with diabetes exhibited elevated fasting blood glucose levels.

Changes in Body Composition and Handgrip Strength

Table 1 shows the body composition data for the 5 subjects at baseline, 1.5-months, 6-months, 1-year, and 9-years after surgery. Data were available for all five returning study subjects at each aforementioned time point. Average weight loss 1-year post-surgery was 46.2 ± 10.2 kg. Subjects regained 5.5 ± 6.7 kg of body weight between the 1-year and 9-year visits, although this was not significant ($P=0.15$).

DXA data for each time point are reported in Table 1 and individual data for each study participant are displayed in Figure 1. There was a trend toward decreased LST, FFM, and BMC (Table 1, Figure 1). Mean LST loss over the 9-year was 11.9 ± 5.6 kg. In addition, 9-year LST was 4.4 ± 3.0 kg lower than 1-year post-RYGB ($P=0.0327$). Unlike LST, mean FM decreased after surgery by 39.9 ± 8.32 kg, but then trended towards an increase of 8.6 ± 7.0 kg between 1-year and 9-years ($P=0.0527$).

Interestingly, mean handgrip strength decreased over the 9-year period from 31.9 ± 6.1 to 26.2 ± 4.5 kg of force (Table 1 and Figure 2A). Between 1-year and 9-years, mean handgrip strength decreased by 3.0 ± 2.2 kg of force ($P=0.0409$). When including all points in the data set, and not accounting for the effect of each visit, handgrip force was moderately correlated with DXA LST ($r=0.64$, $P=0.0005$, $r^2=0.41$, $n=25$ pairs) (Figure 2B). To control for the effect of visits and aging over the course of the study, handgrip strength was assessed as a function of DXA LST, age, and visit. Fitting a general linear model for handgrip strength with LST, age, visit, and time since surgery, we found that LST ($P<0.0001$) and age ($P<0.0001$) were significant contributors to the model. The model containing LST, age, and visit accounted for 84% of the variation in handgrip strength in this small cohort. LST was highly correlated with body weight ($r = 0.94$, $P<0.0001$). To account for the contribution of body weight to LST we also assessed a model containing the percent of body weight from LST (where percent of body weight from LST is expressed as $\%LST=LST/weight \times 100$), age, and visit. In this model both $\%LST$ and age were significant ($P=0.003$ and 0.0002 , respectively), and the model accounted for 62% of the variation in handgrip strength.

Figure 2C shows the handgrip measurements by age for each visit plotted in comparison to the manufacturer's normal values for each age between 33 and 68 years (T.K.K.5401, Grip D, manual). At the final follow-up visit, three out of five individuals demonstrated below normal functional status for their age, and two of these three individuals had previously been classified as having normal handgrip force for their age pre-RYGB.

Comparison of FM and FFM by Multiple Methods at 9-Years Post-RYGB

We calculated FM and FFM by the 4-component model, which utilizes body weight, BMC, TBW, and body volume and compared it to FM and FFM from ADP (calculated using the Siri model²⁵), and FM and FFM from DXA (Figure 3A and B); all three methods for FM and FFM were highly correlated ($r > 0.98$, $P<0.001$).

Long-Term Post-RYGB REE

Measurements of VCO_2 , VO_2 , and REE for each of the 5 individuals were available at 1-year and 9-years post-RYGB. There were no differences between 1-year and 9-years (VCO_2 : 0.182 v. 0.178 ml/min, $P=0.79$; VO_2 : 0.26 v. 0.25 ml/min, $P=0.31$; $P=0.58$; REE: 1769 v. 1661 kcal/day, $P=0.15$).

DISCUSSION

To the best of our knowledge, this is one of the first studies to comprehensively assess changes in body composition and strength beyond 5 years after RYGB. The most important finding from our study is the concerning trend of continued LST loss over the 9-year period accompanied by a trend towards weight regain, primarily as FM, beginning after 1-year. The importance of the LST loss was underscored by a strong association with diminished handgrip strength.

Our 1-year post-RYGB body composition data agree with other published reports.^{5–11,33,34} In our subjects, FM comprised ~84% of DXA total mass loss at 1-year post-RYGB. FM loss as a percent of weight loss has been reported to be between 73–80% at 6-months to 1-year

after RYGB.^{5-8,11,24,33,35} We also observed that LST loss was ~16% of DXA total mass loss at 1-year post-RYGB. FFM loss has been reported to be between 18–25% of weight loss 1-year after RYGB;^{5-8,35} and LST loss has been reported to be between 12–23% of weight loss 1-year after RYGB.^{11,33} On average, between 1-year and 9-years, our subjects lost 4.4 kg LST and gained 8.6 kg FM with weight regain of 5.5 kg (~14% of weight lost). While LST loss was significant in our sample, FM and weight regain could only be considered trends. One recent study (n=300) reported that mean weight regain as a percent of weight lost was 23% at 7 years after surgery.³⁶ At 1-year post-RYGB, our subjects had ~38% body fat and at 9-years that number had increased to ~45%. Although our sample size was small, this might suggest that important body composition changes could go unnoticed in a clinical setting where only body weight is monitored.

Individuals with obesity have been found to have abnormal fluid distribution characterized by a relative expansion of the ECW compartment compared to the intracellular water (ICW) compartment; this is typically assumed to be due to higher levels of adiposity.²⁴ Elevated ECW/ICW ratios ranging from 0.80 to 1.48 have been reported in individuals undergoing bariatric surgery,^{8,37-40} compared to 0.63 in lean individuals.^{37,38} The obesity-associated expansion of ECW does not appear to normalize after significant weight loss, with investigators reporting no change in the ECW compartment following weight stabilization over the first 1–2 years after various bariatric surgeries.^{24,37,39,40} Our data were in agreement with this; ECW/ICW values at all time points of our 9-year study period were higher than those reported for lean individuals.^{37,38}

Although the clinical relevance of the observed relative expansion of ECW before and after RYGB is not well understood, it does have ramifications for body composition assessment because changes in fluid distribution violate the underlying assumptions of two-compartment measurement methods such as densitometry (e.g. ADP) and deuterium dilution. Most notably, the assumptions that FFM is hydrated at 73.8%⁴¹ and that the body has a density of 1.1 g/ml²⁵ may not hold true in the obese and post-obese state, as observed by others.^{8,37-39} Our 4-component measurements appeared to agree well with ADP and DXA measures at 9 years, given that the mean hydration of FFM (defined as TBW/DXA FFM) was normal at 73%.

Our finding that handgrip strength had diminished significantly by 9 years is important in light of the observed association with loss of LST. In our study, three out of five individuals demonstrated below normal functional status for their age at the 9-year visit, and two of these three individuals had been classified as having normal handgrip force for their age before surgery. We cannot say definitively that the loss of LST accounted for the reduction in handgrip strength. It is possible that weight regain and continued loss of lean tissue were related to a lack of physical activity. Reid et al reported that in a cohort of 89 individuals with mean age of 50 years ~9 years post bariatric surgery, most do not meet current recommended step-per-day guidelines for physical activity.⁴² More work is needed to determine if a lack of physical activity, independent of aging and other factors, is contributing to the apparent decrease in LST and functional strength.

Limitations

We recognize that there were a number of limitations with our study. This long-term follow-up study had a small sample size. We found that ~9-years post-RYGB, only 25% of patients who completed our original study were willing to return. This underscores the difficulties for long-term follow-up studies in this population, particularly in geographical locations such as ours where individuals travel long distances to undergo bariatric surgery at a center for excellence.

Our study did not incorporate any male subjects because the original study was drawn from a clinic where only 15% of patients were male and all 20 original study participants were female. It is possible that changes in body composition for male subjects after RYGB are different from those seen in female subjects, although it has not been studied, given that the majority of studies focus on female subjects. There was also an inherent bias in our study sample. We do not know anything about the long-term weight loss success in the 15 women who did not return for follow-up, and it is possible that our return cohort was self-selected to include individuals who perceived that they had maintained their weight loss since the original study ended. Additionally, given the long time frame between the original study and the follow-up, several of the methodologies used were different as has been described in detail in the methods. For example, oral dosing was used in place of IV dosing for deuterium and bromide dilution, and the original DXA instrument had been replaced by a newer instrument. Finally, in any future assessments of the relationship between lean tissue and functional status it will be important to control for dietary protein intake and physical activity.

FUTURE DIRECTIONS

This study highlights the challenges inherent in completing long-term follow-up assessments of individuals after bariatric surgery. Studies in this population are clearly needed to identify contributors to deleterious changes in body composition, and to determine if behavioral and/or physical activity interventions can be protective of lean body mass. Following a large cohort over many years may not be feasible given low rates of return seen in our study, therefore a cross-sectional assessment including detailed body composition assessment (i.e. using DXA, multiple dilution, or other reference techniques) and utilizing robust epidemiological methods may prove to be the most effective way to assess body composition changes in the long-term after bariatric surgery.

CONCLUSIONS

The continued loss of lean mass during the first decade following RYGB surgery is a concerning trend in this population. This combined with the relationship between loss of handgrip strength and LST while controlling for age further indicates that in the long-term there may be physiologically important loss of muscle mass and function in this population. Our data highlight the need for closer monitoring of body composition, and suggest that clinical protocols to maintain LST and muscle strength may be warranted after bariatric surgery. Future work that controls for confounding variables in a larger post-bariatric cohort

is needed to confirm our finding of lean tissue loss, elucidate its impact on functional status, and demonstrate if it is preventable with exercise and nutritional intervention.

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FIGURE 1.

Changes in DXA measured tissue compartments after RYGB by individual including (A) lean soft tissue, (B) fat free mass, (C) total bone mass, and (D) DXA fat mass.

Abbreviations: RYGB, Roux-en-Y gastric bypass; DXA, dual energy X-ray absorptiometry; mo, month; LST, lean soft tissue; FFM, fat free mass; FM, fat mass; BMC, bone mineral content. Time points are baseline (pre-RYGB) and 1.5-months, 6-months, 1-year, and 9-years after RYGB surgery. See Table 1 for mean values and significance.

FIGURE 2.

Changes in handgrip strength after Roux-en-Y gastric bypass (RYGB) surgery are correlated with changes in lean soft tissue measured by DXA.

(A) Changes in handgrip force over time by individual, (B) correlation between lean soft tissue and handgrip force, (C) handgrip force by age compared to manufacturer normal values by age.

Abbreviations: DXA, dual energy X-ray absorptiometry; mo, month. Time points are baseline (pre-RYGB) and 1.5-months, 6-months, 1-year, and 9-years after RYGB surgery.

Normal handgrip strength values derived from handgrip device manufacturer (Model T.K.K., Grip D, Takei Scientific Instruments, Ltd. Japan).

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FIGURE 3.

Comparison between methods for assessment of (A) fat mass, and (B) fat free mass 9-years post-Roux-en-Y gastric bypass (RYGB) surgery.

Abbreviations: 4-comp, 4-component model calculated from density by air displacement plethysmography (ADP) using the BOD POD instrument, total body water (TBW) by deuterium dilution, and total bone mineral content (BMC) by dual-energy X-ray absorptiometry (DXA) using the following equation: Fat Mass, kg = $2.747 \times (\text{body volume, } l) - 0.7145 \times (\text{TBW, } l) + 1.4599$ (BMC, kg) - $2.0503 \times (\text{body weight, kg})$.

TABLE 1

Body Composition and Handgrip Strength after RYGB Surgery

Characteristics	Baseline	1.5 months	6 months	1 year	9 year	P-value
Time relative to surgery, years	-0.09 ± 0.07	0.12 ± 0.02	0.51 ± 0.01	1.0 ± 0.005	8.7 ± 0.3	—
Age, years	47.2 ± 10.9	47.6 ± 10.9	48.0 ± 10.9	48.6 ± 11.0	56.2 ± 10.9	0.001
Weight, kg	139.3 ± 35.9	125.4 ± 33.2	101.1 ± 32.2	93.2 ± 33.0	98.7 ± 30.2 ^{ns}	0.001
BMI, kg/m ²	48.8 ± 9.7	43.9 ± 9.0	35.3 ± 9.2	32.6 ± 9.7	34.9 ± 8.8	0.001
DXA						
Bone Mineral Content, kg	3.0 ± 0.7	2.9 ± 0.6	2.7 ± 0.5	2.7 ± 0.6	2.3 ± 0.6 ^{ns}	0.004
Lean Soft Tissue, kg	63.5 ± 13.2	57.7 ± 12.3	54.1 ± 10.6	56.0 ± 10.6	51.6 ± 8.7 [*]	0.004
Fat Free Mass, kg	66.4 ± 13.9	60.6 ± 12.9	56.8 ± 11.0	58.6 ± 11.0	53.9 ± 8.0 [*]	0.001
Fat Mass, kg	75.4 ± 22.6	66.7 ± 23.0	44.1 ± 20.6	35.5 ± 21.5	44.1 ± 19.5 ^{ns}	0.001
Handgrip strength, kg	31.9 ± 6.1	29.3 ± 5.8	29.1 ± 5.2	29.2 ± 5.5	26.2 ± 4.5 [*]	0.003
Multiple dilution						
TBW, kg	47.8 ± 10.9	44.2 ± 8.8	42.5 ± 8.3	44.3 ± 7.9	39.3 ± 7.5	0.001
ECW, kg	21.6 ± 6.5	21.7 ± 5.6	20.9 ± 4.6	22.3 ± 6.5	18.0 ± 4.4	0.058
ICW, kg	26.2 ± 4.4	22.5 ± 4.3	21.6 ± 5.0	22.0 ± 3.4	21.3 ± 3.6	0.034
ECW/ICW	0.82 ± 0.16	0.97 ± 0.20	1.00 ± 0.26	1.02 ± 0.28	0.85 ± 0.13	0.118
ECW/TBW	0.45 ± 0.05	0.49 ± 0.05	0.49 ± 0.07	0.50 ± 0.07	0.46 ± 0.04	0.118
FFM hydration coefficient						
TBW/DXAFFM	0.72 ± 0.03	0.73 ± 0.03	0.75 ± 0.01	0.76 ± 0.04	0.73 ± 0.03	0.098

Abbreviations: Roux-en-Y gastric bypass, RYGB; BMI, body mass index; DXA, dual energy X-ray absorptiometry; TBW, total body water from ²H₂O dilution; ECW, extracellular body water from bromide dilution; ICW, intracellular body water (ICW=TBW-ECW); FFM, fat free mass.

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Data are reported for n=5. All values are reported as mean $\pm$ SD. Time points are baseline (1 month pre-RYGB) and 1.5 months, 6 months, 1 year, and 9 years post-RYGB surgery.

Changes over the entire follow-up period post-RYGB were evaluated using non-parametric Friedman's test; P-value <0.05 considered significant.

Select comparisons between 1 year and 9 year values for weight, DXA tissue compartments, and handgrip strength were evaluated by paired t-test;

* indicates significant difference ($P < 0.05$), and ns indicates not significantly different.