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SURGERY FOR OBESITY AND RELATED DISEASES

ASMBS guidelines

American Society for Metabolic and Bariatric Surgery Review of Body Composition

Jonathan Carter, M.D.[a,*], Farah Husain, M.D.[b], Pavlos Papasavas, M.D.[c], Salvatore Docimo, D.O.[d], Vance Albaugh, M.D.[e], Laura Aylward, Ph.D.[f], Cynthia Blalock, M.S.N.[g], Sue Benson-Davies, Ph.D.[h], for the Clinical Issues Committee of the American Society of Metabolic and Bariatric Surgeons

[a]*University of California, San Francisco, San Francisco, California*
[b]*Banner - University Medical Center Phoenix, Phoenix, Arizona*
[c]*Hartford Hospital, Hartford, Connecticut*
[d]*University of South Florida, Tampa, Florida*
[e]*Louisiana State University Health Sciences Center, New Orleans, Louisiana*
[f]*West Virginia University Health Sciences, Morgantown, West Virginia*
[g]*Vanderbilt University, Nashville, Tennessee*
[h]*University of South Dakota, Vermillion, South Dakota*

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Abstract Although the body mass index (BMI) has been used as a measure of obesity for decades, it is now possible to measure adiposity more directly with technologies that can quantitate body fat and other tissues. The purpose of this review is to understand body composition, describe the different ways to measure it, review changes in body composition after metabolic and bariatric surgery (MBS), and provide guidance on how providers can introduce measurements of body composition into their everyday practice. (Surg Obes Relat Dis 2024;■:1–8.) © 2024 American Society for Metabolic and Bariatric Surgery. Published by Elsevier Inc. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

Keywords: Body composition; Bariatric surgery; DXA; CT; MRI; Adiposity

Understanding body composition

Body composition refers to the relative masses of the various body tissue "compartments" shown in Figure 1. These compartments can be broadly divided into fat mass and fat-free (lean) mass. While most fat mass exists as stored triglyceride within defined adipose tissue [3], fat also exists within organs, and there it is referred to as ectopic adipose tissue. Fat-free mass includes skeletal muscle, organs, bones, and water. The largest component is skeletal muscle, which is critically important for overall energy requirements, fitness, and metabolic regulation [4]. The definitions of the various compartments are shown in Table 1.

Defined adipose tissue can be located either within the abdominal cavity (visceral) or outside it (subcutaneous). In general, subcutaneous fat composes approximately 80% of the total body fat, while visceral fat accounts for another 5%–10% [6]. Visceral fat is associated with increased cardiovascular and mortality risk [7,8], whereas subcutaneous fat has less of an effect, and indeed gluteofemoral fat (defined as subcutaneous fat below the inguinal ligament) has been shown to be metabolically beneficial and associated with cardiovascular risk protection [9].

* Correspondence: Jonathan Carter, M.D., University of California San Francisco, General Surgery, 400 Parnassus Ave, 2nd Floor, San Francisco, CA 94143.
E-mail address: jonathan.carter@ucsf.edu (J. Carter).

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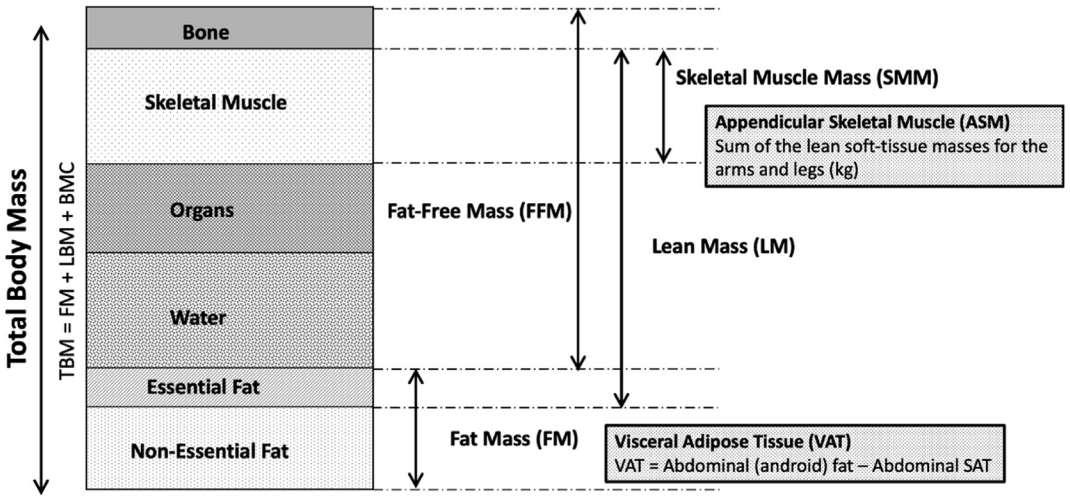


Fig. 1. Body composition components defined by dual-energy X-ray absorptiometry [1,2]. Exact proportions of the components vary by individual. TBM = total body mass; LBM = lean body mass; BMC = bone mineral content; SAT = subcutaneous adipose tissue.

Besides defined adipose tissue, fat exists ectopically within organs. The liver is one of the most easily recognizable and studied sites for ectopic fat. Historically, excess fat deposition within hepatocytes has been referred to as hepatosteatosis. Metabolic-associated fatty liver disease includes both steatohepatitis and cirrhosis. Skeletal muscle can also contain ectopic fat, referred to as myosteatosis. The functional significance myosteatosis less well understood [10]. Intramyocellular triglyceride is strongly associated with insulin resistance and is increased in patients with obesity and type 2 diabetes [11]. Interestingly, though, there is a phenomenon known as the 'athlete's paradox' in which endurance athletes also have elevated amounts of intramyocellular lipid, similar to those with obesity [12].

Once body composition is measured, predictions can be made on general health and all-cause mortality based upon the various components [13]. For instance, one meta-analysis reported that each 10% increment in body fat percentage was associated with a mortality hazard of 1.11 (95% confidence interval 1.02–1.20, 11 studies) in the general adult population and .92 (95% CI .79–1.06; 7 studies) for patients older than 60 years [13]. Similarly, each 5 kg increase in fat mass was associated with a mortality hazard ratio of 1.06 (95% CI 1.01–1.12; 10 studies). Each 2 kg/m^2 increase in fat mass index was associated with a mortality hazard ratio of 1.11 (95% CI 1.06–1.16; 7 studies). For each 1-standard deviation increase in visceral adipose tissue (VAT), the mortality hazard ratio was 1.17 (95% CI 1.03–1.33; 8 studies), whereas subcutaneous adipose tissue (SAT) had a protective effect—each 1-standard deviation increase in SAT reduced the hazard of death by .81 (95% CI .66–.99, 6 studies). There was a J-shaped association between body fat percentage and fat mass with all-cause mortality risk, with the lowest risk at body fat percentage of 25% and fat mass of 20 kg [13]. Lean body mass is also an important predictor of all-cause mortality [14]. For example, patients with low BMI are known to have increased all-cause mortality, and this effect is not from insufficient fat, but rather, insufficient lean muscle mass [13,15]. Hence, the literature has shown that body composition plays an important role in general health and mortality risk [13,15,16].

Technologies to measure body composition

Skinfold measurements

Skinfold measurement uses a direct assessment of several different body sites to estimate the percent total body fat. The assumption for this method is that the amount of subcutaneous fat is representative of the amount of total body fat [17]. A common method is a 7-site method which consists of chest, midaxillary, triceps, subscapular, abdomen, suprailiac, and thigh skinfolds [18]. The assessor pinches the skin and subcutaneous fat, pulls away from the body, and places the caliper around the skinfold to measure the width in millimeters [19]. Estimates of body fat are contingent on a number of factors, such as sex, age, and nutritional status, and predictive equations take these variables into account to optimize accuracy [19].

Advantages of skinfold measurements include that minimal involvement is needed by participants and assessment is portable, noninvasive, and inexpensive [19]. Skinfold measurements are also helpful for detecting trends in body fat over time. A primary disadvantage of skinfold measurements is measurement error [17]. The quality of the assessor's training impacts results, particularly inter- and intraobserver variability, and calipers must also be properly calibrated. Further, the accuracy is impacted by edema, dehydration, and muscle wasting [19].

Hydrostatic weighing (densitometry) and air displacement plethysmography

Hydrostatic weighing, often called underwater weighing, uses a 2-component model to estimate percent body fat. A

Table 1
Body composition measures by DXA [2,5]

Body composition component	DXA definitions
Total body mass (TBM)	TBM = FM + LBM + BMC Includes fat, muscles, internal organs, water, bones, ligaments, and tendons.
Fat mass (FM)	FM = TBM – LBM – BMC Includes stored adipose tissue and essential lipids
Lean body mass (LBM) or lean mass (LM)	LM = TBM – FM – BMC includes water, mineral, protein, glycogen, and small amounts of essential body fat in internal organs and bone marrow
Fat-free mass (FFM)	FFM = TBM – FM includes water, minerals, protein, and glycogen
Visceral adipose tissue (VAT)	VAT = abdominal (android) fat – abdominal subcutaneous adipose tissue (SAT) and is the fat surrounding the internal abdominal visceral organs
Gynoid region	Area includes the hips, upper thighs, and overlaps both the leg and trunk regions
Android region	Area between the ribs and the pelvis and is totally enclosed by the trunk region. Android fat includes visceral and abdominal subcutaneous fat.
Trunk region	Area between the hip joints and lower chin (i.e., neck, chest, abdomen, and pelvic area)
Bone mineral content (BMC)	Measurement of bone mineral found in a specific area (i.e., usually the lumbar spine and hips) and measured in grams (g)
Bone mineral density (BMD) (g/cm^2)	Amount of bone mineral in bone tissue derived by dividing the BMC (g) by the area (cm^2)

DXA = dual-energy X-ray absorptiometry.

participant sits on a suspended frame or chair, which is submerged into a tank of water [17]. This method calculates the difference between body weight in the air and body weight in water, correcting for the volume of air in the lungs, and determines body density [20]. Body fat is then estimated from body density with an equation [21]. Although hydrostatic weighing was once considered the gold standard for body composition, it was not advised for those with obesity because assumptions that must be met for valid testing are typically violated for patients with obesity [17]. Over time, hydrostatic weighing was replaced by air displacement plethysmography (ADP), which offered a faster assessment and was more accessible for those with mobility impairments [17].

ADP is used to assess body volume and estimate body composition. ADP is known commercially as the BOD POD [22]. During assessment, a patient sits in a fiberglass chamber and is instructed to breathe normally. After a series of measurements, the instrument's software subtracts body volume from the volume of the air in the test chamber. ADP is a valid measure of adiposity [23]. At its inception, ADP was seen as offering advantages over densitometry for those with overweight and obesity. Additionally, ADP requires less involvement by the participant and is easier to maneuver into and out of [23,24].

ADP has been validated as an accurate measure of body composition. A direct comparison of ADP with dual-energy X-ray absorptiometry (DXA) revealed that while ADP has good agreement for adults in the normal BMI category, ADP actually underestimated body fat percentage in those with overweight or obese BMI [24]. Advantages of ADP include fast assessment ($\leq$10 minutes), minimal training/expertise needed to run it, and minimal burden on the participant [19]. A major disadvantage of ADP is the cost of equipment and the physical space required to house the BOD POD [19]. Results are sensitive to hydration and body position [20]. Another disadvantage is that ADP, like hydrostatic weighing, cannot localize adiposity or measure visceral fat [20].

Bioelectrical impedance analysis

Bioelectrical impedance analysis (BIA) is based on the differential electrical conductance of fat and lean mass. Assessment involves standing on a conductive scale or placing several adhesive skin electrodes which in turn send a low-level alternating electrical current through the body. Electrically, the body is modeled as 5 cylinders of lean tissue consisting of the trunk and the 4 limbs [20]. BIA does not measure body composition directly; rather, it derives a quantity called a phase angle from measuring body resistance and capacitive reactance [25]. Those with more adiposity will have greater resistance and lower reactance, hence a different phase angle, compared to those with less adiposity [19]. BIA produces precise measurements; variability across repeated measures is estimated to be 1%–2% [26,27]. However, results are impacted by the placement of electrodes, skin temperature, menstruation status, blood chemistry, recency of food intake and exercise, and body position during the assessment [17]. Advantages of BIA are that it is noninvasive, portable, simple, and rapid [25]. However, hydration status highly impacts results, which is often considered the primary limitation of BIA [25–27]. Further, BIA is unable to estimate VAT specifically [20]. BIA is contraindicated for those with implanted electronic devices [19]. BIA has been studied as a predictor of all-cause mortality [7]. A U-shaped association between body fat percentage and mortality was found in both sexes, but the effect of high body fat percentage measured by bioimpedance was much greater for males than females. In fact, high body fat by bioimpedence showed little impact on mortality in females [7].

Dual-energy X-ray absorptiometry

DXA utilizes an x-rays at 2 different energy levels. One energy is best absorbed by denser tissue such as bones, and the other energy is best absorbed by soft tissue [28]. To perform the test, a patient lies supine on a table and the x-ray detector moves from head to foot. The amount of radiation used is very small—on par with a dental x-ray, and much less than a chest x-ray. DXA can be completed in 10–20 minutes [28]. DXA is considered the gold standard for the measurement of bone mineral density but also differentiates between lean tissue and fat [20]. An example DXA report is shown in Figure 2. DXA assesses fat mass and fat-free mass in all 4 extremities, as well as the head and the trunk. The patient's height and weight are measured at the time of the study, which then allows for various indices to be calculated, such as body fat mass, body fat percentage, fat mass index, adiposity indices, and lean indices (Fig. 2). Each measure is then reported as a percentile rank against both sex-specific young-normal controls and age-matched controls. DXA is a more accurate modality for estimating total body fat than density-based methods [20]. Overall, there is far less radiation exposure compared to computed tomography (CT), and it is less expensive than CT or magnetic resonance imaging (MRI) [29]. Typical costs for a DXA scan average $100–$200 [30].

The relationship between DXA-derived assessments of body composition and mortality in the general population has been studied. Padwal et al. studied 54,420 Canadians and demonstrated that high body fat assessed by DXA was associated with increased mortality [31]. The result persisted after adjustment by BMI [31]. Zong et al. examined the association of DXA-measured total and regional adiposity with mortality in 9471 Americans [32]. Higher total fat percent was significantly associated with increased risk of total mortality (hazard ratio of quartile 4 versus 2 = 1.48, 95% CI = 1.07–2.04) in multivariable adjusted models [32]. Regional adiposity (i.e., leg or trunk) and fat-free mass index were not significantly associated with total mortality [32]. Jayedi et al. characterized all-cause mortality as a function of body fat percentage and found J-shaped curves for both men and women [13]. For men, all-cause mortality was lowest at 22% body fat and for women, 35% body fat [13]. Additionally, fat index was associated with an increase in all-cause mortality after an inflection point of 8 kg/m^2 [13].

Limitations include the cost of the equipment, an inability to accommodate individuals with very high body weight, and exposure to very low doses of radiation (precluding its use in pregnant patients).

CT and MRI

CT body composition involves taking cross sectional images of the body, tracing the 2-dimensional boundaries of fat tissue, both SAT and VAT, and then finding the area of each [33]. This imaging technique is one of the more accurate methods for measuring fat mass, lean muscle mass, and bone [34]. Strengths of CT include accuracy of measurement of fat mass, shorter scan times, and its noninvasive nature. Limitations are cost, radiation exposure, and limitations in certain populations such as children and pregnant women. There can also be weight limits, and body mass/abdominal girth can limit access to this test [34].

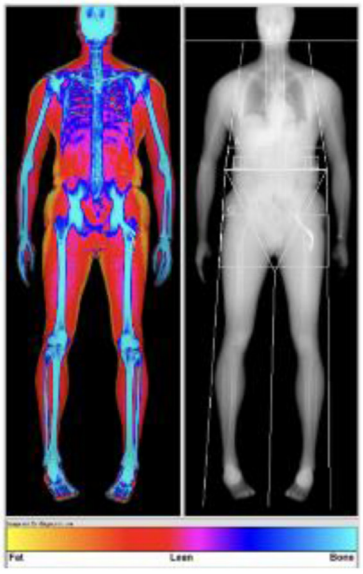
MRI uses magnetic properties of hydrogen nuclei to differentiate fat and lean tissue. MRI is used to estimate the volume of fat instead of the SAT and VAT [28]. A benefit of MRI is that it does not use ionizing radiation and provides accurate data. A limitation is that this test takes considerably longer to complete and has a high cost. It also may not be able to accommodate individuals with higher BMIs since the bore of the magnet may not accommodate large bodies.

Visual body composition

Advances in digital photography, the invention of 3-dimensional cameras, the widespread use of smartphones with high-resolution digital cameras, and the rise of machine-learning neural networks to replace classical statistical methods, have all given rise to a new way to assess body composition: visual body composition, also known as digital anthropometry [35–37]. Visual body composition has been developed to estimate both lean mass and fat mass [37]. Although most work to date has involved the use of commercially-available 3-dimensional camera systems to source the visual data, Majmudar et al. validated a smartphone-based algorithm in which the patient was photographed in tight fitting clothing in a standardized body position with photos taken from the front and the back [37]. A neural network algorithm was able to predict body fat percentage [37]. The prediction was compared against other predictions from several bioelectrical impedance systems and ADP, using DXA as the gold standard. Smartphone-based visual body composition outperformed bioimpedance and ADP: it had the lowest mean absolute error compared to all of the other evaluated methods [37]. Body fat percentage, as predicted by the algorithm, also had good concordance with DXA (Lin's concordance correlation coefficient was .93 in women and .94 in men, whereas BMI had very poor concordance of .40 in women .40 and .74 in men [37]. Although this technology is still in its infancy and has not been validated across different populations and settings, smartphone applications to perform visual body composition are already available on the market.

Changes in body composition after MBS

The changes that occur in body composition after MBS have been described in the literature. Carey et al. assessed basal metabolic rate and body composition by hydrostatic weighing to determine body composition changes at 4



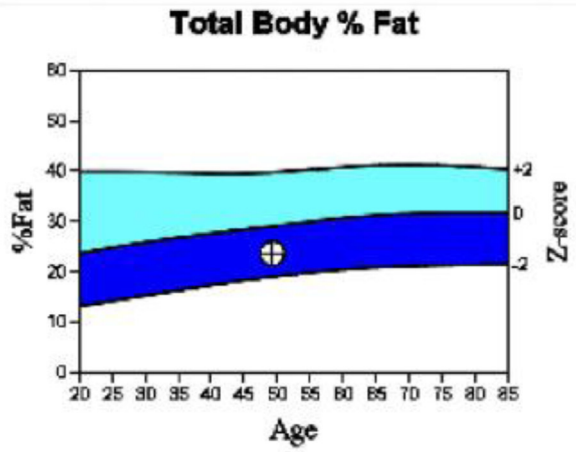
Results Summary:

Region	Fat[(g)]	Lean + BMC[(g)]	Total[(g)]	% Fat	% Fat YN %ile	% Fat AM %ile
L Arm	1145	4649	5793	19.8	35	12
R Arm	1193	4577	5770	20.7	39	14
Trunk	9554	31878	41432	23.1	41	12
L Leg	3822	11199	15021	25.4	45	35
R Leg	3891	11390	15281	25.5	44	33
Subtotal	19605	63692	83298	23.5	41	15
Head	1097	2906	4003	27.4		
Total	**20702**	**66598**	**87300**	**23.7**	**44**	**16**
Android (A)	1646	5147	6794	24.2		
Gynoid (G)	3975	10256	14230	27.9		

Total BMD CV 1.0%, ACF = 1.031, BCF = 1.024
TBAR1209 - NHANES BCA calibration

Adipose Indices:

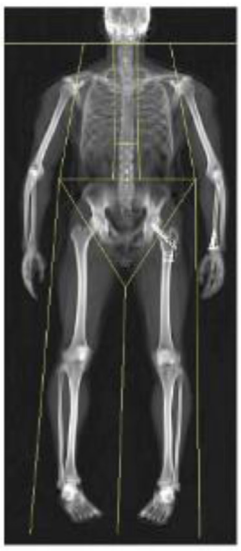
Measure	Result	YN %ile	AM %ile
Total Body % Fat	**23.7**	**44**	**16**
Fat Mass/Height² (kg/m²)	5.90	43	18
Android/Gynoid Ratio	0.87		
% Fat Trunk/% Fat Legs	0.91	43	12
Trunk/Limb Fat Mass Ratio	0.95	40	9
Est. VAT Mass (g)	378		
Est. VAT Volume (cm³)	409		
Est. VAT Area (cm²)	78.5		



Lean Indices:

Measure	Result	YN %ile	AM %ile
Lean/Height² (kg/m²)	18.2	44	32
Appen. Lean/Height² (kg/m²)	8.54	53	49

YN = Young Normal
AM = Age Matched
Est. VAT = Estimated Visceral Adipose Tissue



DXA Results Summary:

Region	Area (cm²)	BMC (g)	BMD (g/cm²)	T - score	Z - score
L Arm	281.53	314.22	1.116		
R Arm	251.33	260.93	1.038		
L Ribs	116.40	97.06	0.834		
R Ribs	126.47	89.03	0.704		
T Spine	171.98	152.55	0.887		
L Spine	54.78	58.09	1.061		
Pelvis	238.03	315.54	1.326		
L Leg	451.90	613.00	1.356		
R Leg	474.05	652.54	1.377		
Subtotal	2166.47	2552.97	1.178		
Head	174.80	371.13	2.123		
Total	**2341.27**	**2924.10**	**1.249**	**0.5**	**0.6**

Total BMD CV 1.0%, ACF = 1.031, BCF = 1.024

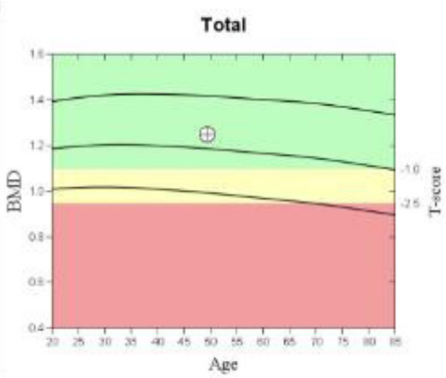


Fig. 2. Example of a body composition report from dual-energy X-ray absorptiometry (DXA) from a 50-year-old male. Measures of fat mass and fat-free mass (lean + bone mineral content) are shown for each body part, from which body fat percentage, body fat index, and other indices are calculated. DXA also measures bone density and calculates a T-score. BMC = bone mineral content; YN = young normal; AM = age matched; BMD = bone mineral density; Est. VAT = Estimated visceral adipose tissue; CV = coefficient of variation; ACF = autocorrelation function; BCA = bias correction factor; NHANES BCA = National Health and Nutrition Examination Survey Body Composition Analysis; ACF = autocorrelation function.

time points within the first year following gastric bypass and found that in the first 6 months, both fat mass and lean mass decreased, whereas afterward, lean mass stabilized while fat mass continued to decrease [38]. On average, 25% of the total weight lost in the first year was lean mass, which is consistent with a range of 20%–35% demonstrated in other studies that used DXA to measure body composition after gastric bypass [39].

Because both lean mass and fat mass are lost early after MBS, clinicians should exercise caution in using body fat percentage as their primary measure of body composition after MBS. For example, Schneider et al. showed that 17 months after Roux-en-Y gastric bypass (RYGB), patient BMI decreased from 44–31 kg/m^2, total body fat decreased by 37%, yet body fat percentage only decreased from 45%–39% [40]. Other measures of body composition, such as fat index and lean index, may prove to be better measures to follow after MBS than body fat percentage.

Several studies have compared body composition between RYGB and sleeve gastrectomy (SG) in patients with similar starting weights, body composition, and BMI. Schnieder et al. studied a subset of patients randomized to ether SG or RYGB in the Swiss Multicenter Bypass or Sleeve Study trial and assessed body composition by DXA before surgery and again after 17 months [40]. After MBS, patients experienced a ∼30% reduction in BMI and a ∼35% reduction in fat mass without a significant difference observed between SG and RYGB [40]. Additionally, the distribution of fat loss (truncal versus leg) did not differ between procedures, nor did the decline in resting energy expenditure [40]. Long-term, Buhler et al. studied body composition changes after 5 years in 72 patients who underwent SG and compared them to 70 contemporaneous patients who underwent RYGB at the same center [41]. Baseline characteristics were similar, except there were more patients with diabetes in the RYGB group and a slightly higher BMI in the SG group. Total body percent weight loss was 26% after RYGB and 24% after SG, P = .243. Fat mass decreased from 49–35 kg after RYGB and from 51–39 kg after SG, with no statistically significant difference between the 2 at 5 years. Similarly, lean mass decreased from 63–45 kg after RYGB and 62–48 kg after SG, with no statistically significant difference between the 2 at 5 years. In summary, the literature has not shown clinically significant differences in body composition changes between SG and RYGB in the short- or long-term.

How to introduce alternative measures of obesity into clinical practice

Measuring body composition in everyday practice can improve upon an individual assessment of obesity, help patient education, allow clinicians to trend fat and muscle loss over time, identify patients with sarcopenic obesity, and can diagnose osteopenia or osteoporosis in MBS patients before or after surgery. For MBS programs interested in adding body composition to the care of their patients, a simple place to start would be to add DXA as part of the preoperative evaluation and then repeat 1 year after MBS.

Body composition in the initial assessment of the MBS patient

Body composition measurements can provide a more accurate and detailed evaluation of an individual's body composition, which can be especially helpful for individuals with class 1 obesity (BMI 30–35 kg/m$^{2)}$. In this population, body composition and metabolic assessment can be used to identify a patient's individual phenotype, as defined in Table 2 [42–44]. Those with a metabolically unhealthy phenotype are at higher risk of cardiovascular events and, therefore, likely benefit from more aggressive interventions such as MBS.

Another benefit of body composition assessment in the preoperative evaluation of the MBS patient is to identify patients with sarcopenia and sarcopenic obesity [1,45]. Sarcopenia is diagnosed with low muscle mass and low strength. Different strength tests that define muscle quality (e.g., hand grip strength, chair stand, gait speed) are often combined with DXA to define sarcopenia [1]. Although sarcopenic obesity tends to be more prevalent among older patients, middle-aged and younger patients may benefit from screening for sarcopenic obesity prior to MBS [45]. Evidence shows that patients with sarcopenia have a higher

Table 2
Summary of phenotype characteristics associated with a BMI 30–35 kg/m^2 [42]

Phenotype	Characteristics
Metabolically healthy obesity	•Healthy metabolic profile •Absence of type 2 diabetes mellitus, dyslipidemia, or hypertension •Excessive body fat •High insulin sensitivity •Low VAT •Low VAT/total body fat mass index
Metabolically unhealthy obesity	•Abnormal metabolic profile •High VAT •3 or more points from the NCEP-ATP III
Sarcopenic obesity	•Loss of skeletal muscle mass and function •Increased risk of metabolic alterations •High VAT •Low muscle mass and weak muscle strength •Lack physical exercise

BMI = body mass index; VAT = visceral adipose tissue; NCEP-ATP III = National Cholesterol Education Program Expert Panel and Adult Treatment Panel.

risk of complications (e.g., mobility disorders, increased risk of falls and fractures) and postoperative mortality [45]. One study found that individuals diagnosed with sarcopenic obesity prior to MBS may be at an increased risk for gastric leak after SG [46].

Monitoring fat loss, lean muscle loss, and bone health after MBS

MBS induces loss of both fat and lean body mass. Nuijten et al. found that MBS was associated with an average of 8.2 kg loss of skeletal muscle mass, half of which was lost in the first 3 months [2]. Additionally, lean body mass accounted for 23% of the total weight lost at 12 months [2]. Monitoring and protecting against lean body mass loss is important after MBS because such loss is associated with long-term weight regain from decreased energy expenditure and an increased appetite [2]. With early detection of significant lean body mass loss postoperatively, recommendations for increased protein intake and exercise may prevent further reduction in lean mass and physical function [47].

Another concern after MBS is fracture risk due to bone loss and changes in bone density [5,48–50]. MBS has a negative impact on bone health, which in turn increases the risk of bone fractures [48–50]. Saad et al. estimated that at 2.2 years postsurgery, the risk of any bone fracture was 40% higher following MBS procedures compared to controls with obesity [48]. Additional evidence shows that fracture risk tends to increase well beyond 5 years post-MBS [50]. Screening patients for bone health, including objective measures of bone mineral content and bone density by DXA as part of a routine MBS evaluation, may reduce the onset of osteopenia, osteoporosis, or fracture risk in patients.

Conclusions

Body composition measurement provides a direct assessment of adiposity that can supplement the BMI in the assessment of the MBS patient. A number of technologies exist to measure body composition, each with advantages and disadvantages. Some technologies, like DXA, can also provide measures of lean muscle mass and bone density that may be useful in the longitudinal care of MBS patients. Measuring body composition in everyday practice may improve upon an individual assessment of obesity, help patient education, allow clinicians to trend fat and muscle loss over time, identify patients with sarcopenic obesity, and diagnose osteopenia or osteoporosis in MBS patients before or after surgery.

Disclosures

No conflicts of interest to report for any of the authors.

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