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Body Composition (Sarcopenia) in Obese Patients: Implications for Care in the Intensive Care Unit

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Abstract

The study of body composition is a rapidly evolving science. In today's environment, there is a great deal of interest in assessing body composition, especially in the obese subject, as a guide to clinical and nutrition interventions. There are some strikingly different compartments of body composition between the obese and the lean patient. We do have the ability to measure body composition accurately, although these techniques can be labor intensive and expensive. The recognition of patients with sarcopenic obesity has identified a potential high-risk patient population. These body composition abnormalities may have even greater importance in the intensive care patient.

Keywords

substrates; nutrients; adipose tissue; skeletal muscle

Introduction

The science of measuring body composition in humans is usually in response to the need to describe either deficiencies or excesses of a body component that is thought or known to be related to a health risk. Many of the conventional body composition measurement methods are based on assumptions that are violated in the very obese state. Accordingly, there is a significant lack of information on "normative" body composition in very obese persons with implications for formulating appropriate nutrition interventions.¹ Nutrition assessment based on body composition of the patient in the intensive care unit (ICU) can help identify at-risk patients and guide optimal nutrition management.

Body Composition in Obese Compared to Lean Individuals

The hallmark of obesity is excess adipose tissue mass, or fat mass, for a given body weight. In obesity, the increased body mass is due to both increased fat and fat-free mass (FFM). The relative contribution of these two components to the excess weight is influenced in part by age and an individual's proportion of fat and FFM prior to weight gain, assuming adequate protein intake occurs during the weight gain.^{2–4} Presented in Figure 1⁵ is a comparison of fat mass and fat-free mass components—namely, extracellular water (ECW),

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intercellular water (ICW), and solids in 3 situations: (1) the reference female (normal) (%fat from reference^{6,7}; ECW and ICW from reference⁸; solids were derived as 100% minus the sum of % body fat [BF] and % total body water [TBW]), (2) extreme obesity (before bariatric surgery), and (3) weight reduced (after bariatric surgery). Significant differences exist for all body compartments between the extreme obese and the reference (normal) states. When weight loss does occur in the extreme obese state resulting in a weight-reduced state (albeit, overweight state), there continues to be differences between this new weight-reduced state and the reference state. That is, weight loss following severe obesity does not produce a body composition comparable to a normal weight or lean state.

Adipose tissue (AT) or fat is located in site-specific depots in the body (Figure 2). An individual with lower body obesity (middle panel) has greater subcutaneous adipose tissue (SAT) deposits in the hip/thigh region (also known as femoral-gluteal adipose tissue) compared to upper body obesity (right panel), where there are greater abdominal fat stores that consist of visceral adipose tissue (VAT) and abdominal-subcutaneous adipose tissue. Throughout the body, there is intermuscular adipose tissue (IMAT) which is the adipose tissue located beneath the muscle fascia and surrounds the muscle bundles (ie, marbling within muscle). There are recognized age, sex, and race/ethnic influences on the mass of VAT and IMAT in adults. Obese individuals have greater absolute amounts of all adipose tissue depots. Greater abdominal adiposity, including increased VAT (Figure 3), is associated with insulin resistance, hyperglycemia, and the metabolic syndrome⁹ and is a risk factor for additional complications in the ICU.¹⁰

During negative energy balance, both fat and FFM are lost. The proportion of each depends on several factors, including the magnitude of the caloric deficit, the macronutrient content of the diet, and the proportion of fat and FFM at onset of weight loss.^{4,11,12} Weight loss in lean individuals results in a greater FFM loss compared to obese individuals.¹¹ A classical but largely untested hypothesis is that individuals with greater adiposity are less prone to protein, lean soft tissue, and body cell mass loss during periods of negative energy and nitrogen balance.

Water is an important constituent in the body. The hydration of FFM or the fraction of FFM as water is usually reported as ranging between 0.70 and 0.75 and, as such, is regarded constant (ie, $TBW/FFM = 0.73$ or 73% of the FFM compartment is water). A related assumption is that the fraction of FFM as bone mineral is also relatively stable.¹³ When bone is removed from the FFM compartment, the hydration of the remaining fat-free soft tissues is approximately 0.80.¹⁴ Changes in the body's TBW will affect body composition, especially when body composition estimates are acquired based on TBW assumptions. Much debate surrounds the validity of these assumptions in very obese individuals and in persons who have lost a significant amount of body weight where the extracellular water space may have expanded.¹⁵

Body Composition Measurements

Body composition measurement techniques do exist (Table 2). They vary in complexity, cost, and reliability. The validity of many commonly used body composition measurement techniques is brought into question in states where the hydration of FFM differs from the assumed constant of 73% (bioelectrical impedance analysis; dual-energy X-ray absorptiometry) or where the density of FFM differs from 1.100 g/cm³ (air displacement plethysmography; hydrostatic weighing). This is the case with the obese patient.

Deuterated (²H), tritiated (³H), or oxygen-labeled (¹⁸O) water can be used to determine actual TBW by dilution techniques.¹⁶ The tracer sodium bromide (NaBr) can be used for the measurement of ECW space.¹⁶ These isotope dilution techniques allow for the evaluation of

FM and FFM without making the assumption that the hydration of FFM is constant and therefore stable.

Perhaps the most valid method of body fat measurement in very obese individuals is a 3-compartment (3C) model that includes the actual measurement of TBW, body density, and body weight.¹⁷ There is no upper weight or size limit for the measurement of TBW or body weight. Body density is measurable in most persons using hydrostatic weighing, assuming that they are able to enter the hydrostatic weighing system. If a person is required to climb steps to enter the system, then the very obese patient may have difficulties with access. Body density is also measurable in persons with a high BMI (kg/m^2) using air displacement plethysmography, but the shape of a patient can be a limiting factor. In our laboratory, we have measured persons with BMIs up to $77 \text{ kg}/\text{m}^2$ using the Bod Pod (COSMED, Concord, CA). However, we have also had patients with lower BMIs who did not fit into the instrument because of their specific body shape. What is lacking, however, from a 3C model approach is information on the distribution of fat or lean tissue within the body. With weight loss, it is important to understand how different adipose tissue depots are changing given that specific adipose tissue depots are differentially related to metabolic risk. Similarly, there is growing interest in understanding the components of lean tissue, most specifically skeletal muscle. One important and as yet unanswered question is whether there is a disproportionate loss of skeletal muscle mass in ICU patients.

Sarcopenia in Obesity

Sarcopenic obesity is often defined in the literature as a body composition state that is a mixture of two different physiologic processes. These individuals demonstrate a relative increase in fat mass and a reduction in lean mass. How best to define *sarcopenic obesity* continues to be debated. The definitions for *sarcopenia* based on muscle mass^{18–20} alone and elevated fatness for *obesity* have produced conflicting results with regards to the relationship between “sarcopenic obesity” and impaired physical function.²¹ Reduced lean tissue mass, which is primarily reflecting reduced muscle mass, may only be clinically important if it is accompanied by reduced physical function (thereby impairing physical performance) and/or low muscle strength. Therefore, defining sarcopenia based on low muscle mass alone is likely sub-optimal. Few studies thus far have collected simultaneous measures of muscle mass, muscle strength, and physical performance to allow for a more definitive definition using these criteria.

Long-term obesity is associated with functional impairments.²² Obese individuals whose personal, unique muscle characteristics (eg, mass, composition, degree of adipose infiltration) are related to impaired functionality (mobility, strength), independent of the obese state, are undoubtedly at higher risk of negative health outcomes.²¹ In aging, there is not a clear and consistent relationship between changes in muscle mass and muscle strength; declines in muscle strength often exceed the observed losses observed in strength.^{23,24} An increasing emphasis is now being placed on monitoring indices of muscle quality other than muscle mass. Examples include muscle attenuation values determined by computed tomography²⁵ and intermuscular adipose tissue mass determined by magnetic resonance imaging.²⁶ Both of these techniques indicate the degree of marbling or fatty infiltration into muscle, lower extremity performance, and function.²⁷ In the ICU setting, body composition assessment in the obese patient may help identify the higher risk patients where nutrition intervention can change clinical outcomes. One of these populations may be obese patients with documented sarcopenic obesity.

Fuel Utilization in Obese vs Lean During Starvation

During periods of starvation, a greater proportion of energy is derived from protein oxidation in the lean vs the obese state. Moreover, despite the fact that an obese person has substantially more (up to 50% more) of both body protein and FFM than lean persons, obese persons lose these muscle (protein) components at a slower rate during prolonged starvation than do lean individuals.²⁸ Presented in Table 1 are the hypothetical values of body composition, fuel, availability, and survival time for 2 men weighing 70 kg (lean) and 140 kg (obese).²⁹ The information presented here serves to demonstrate how the greater fat and protein stores of the obese man should, in theory, allow him to survive for a substantially longer period of time as compared to a lean individual.

Obese patients have large fat stores from which free fatty acids and triglycerides should be available as energy sources during illness. Although well-controlled studies performed in critically ill patients are largely lacking, 1 study³⁰ did report that obese critically ill patients do not preferentially mobilize fat stores for energy compared to lean patients. This conclusion has subsequently been questioned by Breen.³¹

Within the ICU, critically ill patients with severe obesity (body mass index [BMI] >40 kg/m²) generally fare less well than mild to moderately obese patients with reported higher rates of mortality, nursing home admission, ICU complications, longer stays in the ICU, and longer time on mechanical ventilation.³² Obesity as a risk factor does have a paradox. This “obesity” paradox is noted where moderately elevated BMIs ($25 < \text{BMI} < 40$ kg/m²) are associated with lower mortality in the ICU. The benefits to these patients may come from characteristics of excess adiposity, including extra stores of energy, hormones, and anti-inflammatory mediators. This is in contrast to other body mass settings where low (<18.5 kg/m²) and very high BMIs (>40 kg/m²) are associated with higher morbidity and mortality.³³ Fuel utilization in the ICU patient is complex as several mediating factors or conditions have an influence: (1) underlying illness (eg, trauma, sepsis), which increases the catabolic response to injury, especially protein oxidation both in absolute terms and as a proportion of energy expenditure; (2) sedation/analgesics, which can reduce total energy expenditure and overall fuel utilization; (3) feeding regimes such as a prescription for a hypocaloric diet that increases fat oxidation as the energy deficit is largely made up by the breakdown of endogenous fat; (4) an increased tendency to use enteral tube feeding in the ICU, which is commonly associated with gastrointestinal intolerance and resultant underfeeding; (5) the use of high-fat feedings, which tend to reduce CO₂ production (and the energy equivalents of oxygen) relative to low-fat (high-carbohydrate) feeds; (6) the fact that many patients coming into the ICU are also already undernourished, in which case fat oxidation would again be favored and there may be prior adaptation to attenuated protein oxidation; and (7) the fact that most ICU patients receive insulin to control their blood glucose concentration. This means that the effects of insulin administration on fuel selection may need to be considered. When parenteral nutrition (PN) is administered in hypocaloric doses to overweight and obese ICU patients, it is recommended that they receive adequate nitrogen to promote wound healing and fight infection.³⁴ The protein dose can be administered in levels of up to 2 g/kg of ideal body weight in these patients. This could help preserve lean body mass and reduce adipose tissue.³⁵

Conclusion

There is a growing consensus that phenotyping obese patients in the ICU could aid in their treatment.

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Figure 1.

Body composition in extremely obese and weight-reduced states compared with reference female values.⁶⁻⁸ All body compartments (except solids) are significantly different in the extremely obese state compared with the weight-reduced state ($P < .05$), and body compartments in extreme obesity (except solids) and weight-reduced state (except solids and extracellular water [ECW]) are significantly different from reference female values ($P < .05$). ICW, intracellular water. Reprinted with permission from Macmillan Publishers Ltd: Elia M, Stubbs RJ, Henry CJ. Differences in fat, carbohydrate, and protein metabolism between lean and obese subjects undergoing total starvation. *Int J Obesity*. 1999;7:6.

Figure 2.

(a, b) Types of obesity in relation to fat distribution. Nonobese (left panel: BMI 22 kg/m², 22.7% fat), lower body obese (middle panel: BMI 36 kg/m², 33% fat), and upper body obese (right panel: BMI 37 kg/m², 47.3% fat). Images using a 3-dimensional photonic scanner (New York Obesity Nutrition Research Center, New York, New York). BMI, body mass index.

Figure 3.

Cross-sectional images through the abdomen (centered at L4–L5) showing distribution of adipose tissue, before (upper panel) and 1-year post (lower panel) bariatric surgery (woman, age 36 years). Visceral adipose tissue (VAT, blue), subcutaneous adipose tissue (green), intermuscular adipose tissue (IMAT, pink), and skeletal muscle (red). Total VAT mass before surgery was 4.47 kg (body weight 133.4 kg, BMI 52 kg/m²) and 1 year postsurgery was 0.77 kg (body weight 74.3 kg, BMI 29 kg/m²). BMI, body mass index.

Table 1

Hypothetical Values of Body Composition, Fuel Availability, and Survival Time in a Lean 70-kg Man and an Obese Man Twice Ideal Body Weight

	Lean Man	Obese Man
Initial		
Body weight, kg	70	140
Fat, kg	9.0	61.5
Protein, kg	12.2	15.7
Glycogen, kg	0.3	0.4
Loss during starvation		
Weight (% of initial)	38.0	69.0
Weight, kg	26.6	96.6
Fat, kg ^a	8.0	61.5
Protein, kg ^b	4.6	8.1
Glycogen, kg	0.3	0.4
Available energy during starvation, kcal (%)		
Fat	75,200 (77.6)	568,700 (93.8)
Protein	20,400 (21.1)	36,000 (5.9)
Glycogen	1260 (1.3)	1680 (0.3)
Total	98,860 (100.0)	606,380 (100.0)
Mean daily total energy expenditure, kcal/d ^c	1500	2260
Survival time, d	65	270

From Elia M, Stubbs RJ, Henry CJK. Differences in fat, carbohydrate, and protein metabolism between lean and obese subjects undergoing total starvation. *Obesity Res.* 1999;7:597–604. Reprinted by permission from Macmillan Publishers Ltd. Copyright 1999. The composition of the body in the lean man is based on reference man,¹⁴ and the excess weight in the obese individual is assumed to be 75% fat and 25% fat-free tissues.

^aFat accounts for 30% of the loss of body weight in the lean individual and 63% of the loss in the obese individual. Fat-free tissue accounts for 70% of the weight loss in the lean individual and 37% in the obese individual.

^b Assuming 1 gN = 6.25 g protein, there is a loss of 24.0 gN/kg loss of body weight in the lean individual and 12.4 gN/kg in the obese individual.

^c These are only approximate values partly because of the variable decrease in resting energy expenditure below that predicted for normal individuals of the same weight (~25% during long-term starvation in lean individuals²⁸ and partly because of the variable decrease in physical activity²⁸

Table 2

Advantages and Disadvantages of Available Noninvasive Methods for Measuring Body Composition in Obese Humans

Method	Primary Measurements	Advantages	Disadvantages
Bioelectrical impedance analysis/ bioimpedance spectroscopy	Total body water, extracellular and intracellular fluid spaces	Inexpensive Portable Simple, safe, quick	Population specific, poor accuracy in individuals and groups Questionable validity in very obese and following significant weight loss
DXA	Total body fat, lean mass and regional body fat and lean mass, bone mineral content and bone mineral density	Easy to use Low X-ray radiation exposure Accurate for limb lean and fat	Bias: body size, sex, fatness Many individuals with BMI >40 kg/m ² will not fit within the field-of-view for soft tissue. Expensive equipment and specialized radiology technician required to operate
Dilution techniques	Total body water and extracellular fluid	Acceptable in all age groups and body sizes Easy to administer isotopes	Inaccurate in some disease states Expensive equipment and labor for analyses
Air displacement plethysmography	Total body volume and total body fat	Relatively high accuracy Fast	Many individuals with BMI >60 kg/m ² will not fit within the instrument. Reduced accuracy in some disease states Expensive equipment
3-Dimensional photonic scanning	Total and regional body volume	Can accommodate extremely obese persons Easy to use Suitable for both research and clinical applications	Few scanners available thus far
Quantitative magnetic resonance	Total body water and total body fat	Easy to use Safe, fast	Upper weight limit of 400 lbs Expensive equipment Few systems available thus far
MRI/MRS	Total and regional adipose tissue (visceral, subcutaneous, intermuscular), skeletal muscle, organs (liver, heart, kidney, pancreas, spleen) Lipid content in liver and muscle	High accuracy and reproducibility for whole- body and regional adipose tissue and skeletal muscle	Many individuals with BMI >40 kg/m ² will not fit within the field-of-view for soft tissue. Expensive

BMI, body mass index; DXA, dual-energy X-ray absorptiometry; MRI, magnetic resonance imaging; MRS, magnetic resonance spectroscopy.