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Review

# Obesity history, physical exam, laboratory, body composition, and energy expenditure: An Obesity Medicine Association (OMA) Clinical Practice Statement (CPS) 2022

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ABSTRACT

*Background:* This Obesity Medicine Association (OMA) Clinical Practice Statement (CPS) on History, Physical Exam, Body Composition and Energy Expenditure is intended to provide clinicians an overview of the clinical and diagnostic evaluation of patients with pre-obesity/obesity.
*Methods:* The scientific information for this CPS is based upon published scientific citations, clinical perspectives of OMA authors, and peer review by the Obesity Medicine Association leadership.
*Results:* This CPS outlines important components of medical, dietary, and physical activity history as well as physical exams, with a focus on specific aspects unique to managing patients with pre-obesity or obesity. Patients with pre-obesity/obesity benefit from the same preventive care and general laboratory testing as those without an increase in body fat. In addition, patients with pre-obesity/obesity may benefit from adiposity-specific diagnostic testing - both generally and individually - according to patient presentation and clinical judgment. Body composition testing, such as dual energy x-ray absorptiometry, bioelectrical impedance, and other measures, each have their own advantages and disadvantages. Some patients in clinical research, and perhaps even clinical practice, may benefit from an assessment of energy expenditure. This can be achieved by several methods including direct calorimetry, indirect calorimetry, doubly labeled water, or estimated by equations. Finally, a unifying theme regarding the etiology of pre-obesity/obesity and effectiveness of treatments of obesity centers on the role of biologic and behavior efficiencies and inefficiencies, with efficiencies more often associated with increases in fat mass and inefficiencies more often associated with decreases in fat mass.
*Conclusion:* The Obesity Medicine Association (OMA) Clinical Practice Statement (CPS) on History, Physical Exam, Body Composition and Energy Expenditure is one of a series of OMA CPSs designed to assist clinicians in the care of patients with the disease of pre-obesity/obesity.

## 1. Introduction

Beginning in 2013, the Obesity Medicine Association (OMA) created and maintained an online Adult "Obesity Algorithm" (i.e., educational slides and eBook) that underwent yearly updates by OMA authors and was reviewed and approved annually by the OMA Board of Trustees [1]. This was followed by a similar Pediatric "Obesity Algorithm" with updates approximately every two years by OMA authors. This OMA History, Physical Exam, Body Composition, and Energy Expenditure CPS is one of a series of OMA CPSs derived from

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the Obesity Algorithm, designed to assist clinicians in the care of patients with the disease of obesity.

## 2. Medical history

### 2.1. Body weight history

Body weight history in patients with pre-obesity/obesity may begin with an assessment of body weight increases or reductions over the patient's lifetime (e.g., slow and gradual, rapid and sudden, or a combination) and factors influencing weight change. Beyond nutrition, physical activity, and behavior, common factors that can influence body weight are physical health, mental health, medications, surgery, and life stressors or circumstances (e.g., family, marriage, newborn, work, moving, finances, and abuse). Another aspect of assessing body weight history is determining past strategies, behaviors, and interventions that proved to be either effective or ineffective in achieving a healthier body weight. Regarding body weight and potential body weight changes, patient assessment may include assessment of mental health, physical health, and mobility, as well as assessment of interaction with family and friends, work, instances of bias and discrimination, and existing or anticipated barriers to future weight reduction [2].

### 2.2. Baseline medical history

Baseline demographics may include [3]:

- Age, sex, gender identity, race, ethnicity
- Fat mass disease (i.e., increased adiposity-related osteoarthritis, sleep apnea)
- Sick fat disease clinical manifestations (i.e., adiposopathic type 2 diabetes mellitus, hypertension, dyslipidemia)
- Other medical and surgical conditions
- Eating disorder screening
- Mental health and stress screening
- Sleep pattern evaluation and sleep disorder screening

### 2.3. Medication history

Concurrent medication history may include [3]:

- Drug treatments with special attention to medications that may increase or decrease body weight
- Drug and food allergies
- Current or previous use of anti-obesity medications
- Use of supplements (i.e., especially weight loss supplements)

### 2.4. Review Of Systems (ROS)

A review of systems may include the following [3]:

- History of concurrent non-adiposity related conditions or situations potentially relevant to anti-obesity medications [e.g., glaucoma, pancreatitis, kidney stones, seizures, gastrointestinal abnormalities, cardiovascular disease, diabetes mellitus, hypertension, dyslipidemia, pregnancy status, pregnancy planning or prevention, breastfeeding, liver disease (including fatty liver), kidney disease, cancer, and planned forthcoming surgeries]
- Conditions having established drug treatment options that may promote weight change (e.g., migraine headaches, type II diabetes, hyperglycemia, insulin resistance, depression, psychiatric disease)
- Symptoms that may indicate obesity-related complications such as chest pain/angina, shortness of breath, edema, fatigue, snoring, insomnia, joint pain, urinary incontinence, erectile dysfunction, menstrual irregularity, infertility, gastrointestinal reflux, neuropathy, acne, intertrigo, and mood disorders

### 2.5. Family history

An assessment of family history includes [3]:

- Family members with obesity and/or metabolic diseases
- Family history of cardiovascular disease and/or cancer, including medullary thyroid cancer or multiple endocrine neoplasia type II (MEN II)
- Family history of psychological disorders

### 2.6. Social history and support systems

An evaluation of lifestyle factors and social history should include a record of the potential use of the following substances [3]:

- Tobacco history
- Alcohol intake
- Recreational drug use (e.g., marijuana, cocaine, heroin, methamphetamine, 3,4-methylenedioxymethamphetamine)

### 2.7. Socioeconomic and cultural history

Factors that may influence body weight include [2,3]:

- Socioeconomic status and cultural background
- Occupation and work schedule, including travel
- Family structure and social support for a healthful lifestyle
- Person who selects, purchases, and prepares food
- Marital or relationship status, including relationship stress/stressors
- Living situation, including other people living with the patient
- History of trauma, including abuse (e.g., physical, mental, or sexual)
- Geographic location (e.g., urban food desert)
- Access to healthful nutrition and physical activity information (e.g., current knowledge base, internet access, and knowledge centers)

### 2.8. Nutrition history

Nutrition history plays an important role in body weight and the treatment of obesity and includes the following [4–6]:

- Previous nutritional/dietary attempts to change weight and/or body composition. If unsuccessful or un-sustained, what were short- and long-term barriers to achieving or maintaining body weight reduction?
- Timing and frequency of meals, snacks, and beverage intake
  - 72-h recall of foods and beverages via questionnaire
  - Food and beverage diary, including types of food or beverages consumed and amount consumed for a week; return for evaluation
  - Electronic application tools for nutrition logging
- Nutritional content of food and beverages
- Location of home food consumption (e.g., eating area, television, computer)
- Location of away food consumption (e.g., workplace, restaurants, fast food)

### 2.9. Behavior history

Behavior plays an important role in the treatment of obesity and includes the following [6]:

- Readiness for change
- Triggers (e.g., hunger, appetite, lack of satiety, cravings, anxiety, boredom, reward) and emotional eating
- Nighttime eating
- History of disordered eating and/or eating disorders, such as binge eating disorder

- History of abuse or intimate partner violence
- Family/cultural/ethical/community influences

### 2.10. Physical activity history

Physical activity is one of the four pillars of the treatment of obesity (i.e., others being nutrition, medications, and behavior). Past and current physical activity history includes [6–9]:

- Previous physical activity/exercise
- If no longer engaged in a routine physical activity/exercise regimen:
  - o When? (Date of change)
  - o What? (Types of prior activity and cause for discontinuation)
  - o Why? (Identify barriers to re-engagement)
- Current physical activity (FITTE) [10].
  - o Frequency (number of bouts of physical exercise per week)
  - o Intensity (mild, moderate, vigorous)
  - o Time or duration (of each bout of activity)
  - o Type of physical activity/exercise
  - o Enjoyment (physical activity/exercise preferences)
- Current fitness level, endurance capacity, and mobility
- Availability and accessibility of exercise equipment
- Access to safe locations amenable to increased physical activity/exercise (e.g., gym, workplace, exercise facilities, bicycle paths and walkways, urban or rural home setting)
- Actual and perceived barriers to increased physical activity, including physical and mobility limitations, financial limitations, time limitations, and other barriers such as motivation challenges or fatigue.

#### 2.10.1. Evaluation prior to physical activity prescription

The following are examples of common medical conditions best evaluated before prescribing an exercise program [9]:

- Diseases of the heart, lung, neurologic, or musculoskeletal systems
- Metabolic diseases having potential risks with increased physical activity include:
  - o Atherosclerotic coronary heart disease (i.e., worsening ischemia)
  - o Diabetes mellitus (i.e., hypoglycemia, especially with weight loss in patients treated with insulin or sulfonylureas)
  - o Hypertension (i.e., increased blood pressure during strenuous exercise)

### 2.11. Routine preventive care

While targeted history and physical exams are appropriate for patients with obesity, it is also important to ensure patients with pre-obesity/obesity receive standards of medical care applicable to patients without obesity. Individuals with pre-obesity/obesity often do not receive the same preventive standards of care as those without obesity. Examples of standards of preventive medical care (depending upon gender and age) may include [11]:

- Breast cancer screening
- Pap smear (which may include assessment of human papilloma virus)
- Osteoporosis screening
- Prostate cancer screening
- Colorectal cancer screening
- Communicable disease screening
- Immunizations
- Other preventive screening based upon patient mental and physical health risk factors

## 3. Physical exam

### 3.1. Vital signs and anthropometric measurements

A physical exam may include the following measurements of vital signs and anthropometric quantities [12]:

- Height with bare or stockinged feet and measured with a stadiometer
- Weight using a calibrated scale and method consistent from visit to visit (i.e., wearing light indoor clothing or a gown)
- Body mass index
- Waist circumference
  - ○ Standing using superior iliac crest or at the midpoint between highest point of iliac crest and lowest rib
  - ○ Waist circumference may not provide additional diagnostic information when BMI $\geq$35 kg/m$^2$
- Blood pressure using appropriately sized cuff
- Pulse
- Neck circumference

### 3.2. Special considerations in the physical exam

Special emphasis may be placed on the physical examination of the following areas due to their relationships with risk and obesity [12]:

- Nose
- Throat
- Neck
- Lung
- Heart
- Abdomen
- Body shape
- Neurological system
- Musculoskeletal system
- Integument

## 4. Laboratory assessment

### 4.1. Laboratory and diagnostic testing

Table 1 describes takeaway messages for diagnostic management of patients with pre-obesity/obesity. In general, diagnostic tests include body fat (adiposity) specific testing, general laboratory testing, and individual diagnostic testing.

### 4.2. General laboratory testing

General testing includes the following [12]:

- Complete blood count
- Urinalysis

### 4.3. Adiposity-related blood testing

The following may be applicable to patients with pre-obesity/obesity [12–14]:

- Fasting blood glucose
- Hemoglobin A1c
- Fasting lipid levels
  - o Triglycerides
  - o Low-density lipoprotein (LDL) cholesterol

**Table 1**
**Ten Takeaway Messages: Obesity Evaluation.** Evaluation of the patient with pre-obesity/obesity involves record keeping and diagnostic and prognostic laboratory testing.

| | |
|---|---|
| 1 | Patients with obesity often do not receive standards of preventive medical care, and thus may not receive potential benefits of preventive medical care, when compared to patients without obesity. |
| 2 | Nutrition monitoring approaches include recording food and beverage diaries. |
| 3 | Body systems best evaluated before prescribing a physical activity program include cardiac, pulmonary, and neuromusculoskeletal systems as well as body metabolic processes (e.g., diabetes mellitus, hypertension). |
| 4 | Routine laboratory assessment may include measures of glycemia (fasting glucose levels, HbA1c), lipid levels, liver enzymes, electrolytes, creatinine and blood urea nitrogen, thyroid stimulating hormone, complete blood count, urine for microalbumin, and possibly vitamin D 25-OH. |
| 5 | Individual testing may include evaluation for insulin resistance, insulinoma or nesidioblastosis, hypercortisolism, oligomenorrhea/amenorrhea, hyperandrogenemia and polycystic ovary syndrome in women, and hypogonadism in men. |
| 6 | Other diagnostic tests in patients with pre-obesity or obesity might include magnetic-resonance imaging or computed tomography of the pituitary, resting electrocardiogram, cardiac stress testing, echocardiogram, coronary calcium scores, ankle-brachial index, sleep studies, and imaging studies of the liver (i.e., to evaluate for fatty liver). |
| 7 | Methods to measure body composition include dual-energy x-ray absorptiometry (DXA), bioelectrical impedance, whole body air displacement plethysmography, near-infrared interactance, body tape measure to assess muscle mass, calipers, or underwater weighing. |
| 8 | Prader-Willi syndrome is the most common non-inherited, non-polygenic genetic syndrome associated with obesity. |
| 9 | Melanocortin 4 receptor deficiency (autosomal dominant or recessive) is the most common inherited, non-polygenetic syndrome associated with obesity. |
| 10 | Medical conditions that may promote fat mass gain include hypothalamic damage, immobility, insulinoma and other causes of hyperinsulinemia, hypercortisolism, sleep disorders, some cases of untreated hypothyroidism, mental health disorders, and obesogenic effects of concurrent medications. |

  - o High-density lipoprotein (HDL) cholesterol
  - o Non-HDL cholesterol
- Liver enzymes and other liver blood tests
  - o Aspartate aminotransferase (AST)
  - o Alanine aminotransferase (ALT)
  - o Alkaline phosphatase
  - o Total bilirubin
- Electrolytes (i.e., potassium, sodium, calcium, phosphorous, others)
- Renal blood testing (e.g., creatinine, blood urea nitrogen, estimated glomerular filtration rate)
- Urine for protein and/or microalbumin to creatinine ratio
- Uric acid
- Thyroid stimulating hormone (TSH)
- 25-hydroxyvitamin levels, which may be decreased in patients with increased body fat and/or darker skin

### 4.4. *Individualized laboratory blood testing*

Individuals may benefit from other laboratory blood testing depending on their history and medical presentation:

- Glucose tolerance testing; fasting insulin with calculation of homeostatic model assessment for insulin resistance (HOMA IR) [15–18].
- Fasting proinsulin, C-peptide, and insulin if hyperinsulinemia is suspected as a secondary cause of obesity (e.g., insulinoma or nesidioblastosis) [19].
- One milligram (mg) overnight dexamethasone cortisol suppression test, 24-h urine collection for (free) cortisol, or repeated salivary cortisol collection at 11:00 p.m. if endogenous hypercortisolism is suspected as a secondary cause of obesity
- Prolactin, estradiol, follicle-stimulating hormone, luteinizing hormone, and pregnancy tests in females with unexplained oligomenorrhea or amenorrhea
- Testosterone and androgen levels are often increased in females with hirsutism or polycystic ovary syndrome. Dehydroepiandrosterone sulfate (DHEAS) is the sulfate ester derivative of DHEA, does not have diurnal variation (compared to DHEA), has blood concentrations ~100 times greater than DHEA, and is thus often used to assess adrenal androgens [20].
- Testosterone testing (and if low to a clinically significant degree, possibly prolactin, follicle-stimulating hormone, and luteinizing hormone) for males with impotence or signs/symptoms of hypogonadism [21].
- Apolipoprotein B and/or lipoprotein particle number, especially if triglyceride levels are elevated
- Iron studies (e.g., iron, total iron binding capacity, ferritin)
- Vitamin and mineral testing, especially in post-bariatric surgery patients and other patients at risk for vitamin and mineral deficiencies
- C-reactive protein (e.g., highly sensitive-CRP)

### 4.5. *Other individualized diagnostic testing*

The following diagnostic tests may be warranted depending on the individual patient [22–24]:

- Resting electrocardiogram (ECG)
- Cardiac stress testing
- Echocardiogram
- Coronary calcium scores
- Ankle-brachial index
- Sleep studies
- Pulmonary function testing
- Imaging studies of the liver
- Magnetic-resonance imaging or computed tomography of the pituitary

### 4.6. *Body composition*

Body composition analyses may assist in patient cross sectional assessment and longitudinal follow-up. The following are common methods for measuring body composition [25]:

- Dual-energy X-ray absorptiometry (DXA), ideally with android fat assessment (abdominal subcutaneous and visceral fat assessment) [26].
- Bioelectric impedance [27].
- Near-infrared interactance [28].
- Whole-body air displacement plethysmography (BOD POD) [29].
- Body tape measure to assess waist circumference and muscle mass, as well to measure wrist and neck circumference for use in some percent body fat equations [30].
- Caliper percent body fat measurements (i.e., three or more-site skinfold calculations) [31].
- Underwater weighing [32].
- Quantitative magnetic resonance (QMR) [33].
- Computerized tomography (i.e., single slice or volume method) [34].
- Deuterium dilution [35].

### 4.7. *Emerging science testing*

The following are emerging factors that may play a role in health and obesity [36]:

- Leptin
- Adiponectin
- Leptin-to-adiponectin ratio
- Free fatty acids
- Immune markers
  - o Tumor necrosis factor

- Interleukin 1 and 6
- Microbiota/infectious organism testing
  - Gut microbiota
  - Adenovirus assays
  - Evaluation for other microbes

## 5. Identify primary and secondary causes of obesity

### 5.1. Genetic syndromes

Certain genetic conditions can contribute to or cause obesity, including [37,38]:

- Isolated, not inherited genetic abnormalities (i.e., Prader Willi)
- Familial genetic abnormalities (i.e., melanocortin 4 receptor deficiency)

### 5.2. Medical conditions

Medical conditions may also contribute to or cause obesity, including [22,39–41]:

- Hypothalamic damage
- Immobility
- Insulinoma and other hyperinsulinemias
- Some cases of untreated hypothyroidism
- Hypercortisolism (Cushing's disease)
- Sleep disorders
- Obesogenic effect of some medications

### 5.3. Psychological and behavioral conditions

Behavior and psychological conditions can be primary or secondary causes of obesity, including [42]:

- Mental stress
- Depression
- Anxiety
- Post-traumatic stress disorder

**Table 2**
**Ten Takeaway Messages: Obesity and Body Composition Analyses.** Assessment of body composition can provide invaluable information regarding cross-sectional and longitudinal determination of body fat, often more accurate than body weight and body mass index alone.

| | |
|---|---|
| 1 | Lean body mass is total body mass less stored fat in adipose tissue (i.e., lean body mass = water, mineral, protein, glycogen, and essential organ fat). |
| 2 | In lean individuals, approximately 60% of body weight is water (i.e., water is 75% of the weight of muscle and body organs). In those with obesity, water weight can be as low as 40% of body weight due to the increased proportion of body fat that has relatively less water. |
| 3 | Ash weight of bone contributes a minor amount to total body weight (~3–10 pounds). |
| 4 | Percent body fat mass is highly variable and may range from <5% to >70%. |
| 5 | Percent body fat mass is dependent upon both fat and muscle mass. |
| 6 | Methods to measure body composition vary regarding accuracy, reproducibility, expense, and accessibility. |
| 7 | Some dual energy x-ray absorptiometry (DXA) scans can measure percent body fat, android fat (abdominal subcutaneous and visceral fat), lean body mass, and bone mineral density. |
| 8 | Calipers can estimate percent body fat, have variable accuracy (highly user dependent), are inexpensive, and may be most useful for frequent longitudinal assessments once body composition is determined by more accurate measures. |
| 9 | Bioelectrical impedance is a hydration-dependent body composition assessment procedure. Reasonable assessment of android fat may be achieved via a complementary tape-measured waist circumference. |
| 10 | Air displacement assessment of percent body fat is clothing and hydration dependent. Reasonable assessment of android fat may best be achieved via a complementary tape-measured waist circumference. |

- Binge-eating disorder
- Night-eating syndrome
- Eating disorders not otherwise specified
- Other psychiatric illness/mental health disorders

## 6. Body composition

Table 2 describes takeaway messages regarding obesity and body composition analysis.

### 6.1. Fat-free mass

Fat-free mass is total body mass (e.g., muscles, internal organs, water, bones, ligaments, and tendons) less any body fat and includes water, minerals, protein, and glycogen [43]. Dual x-ray absorptiometry (DXA) measures fat, soft tissue, and bone, and then reports fat free mass as total mass minus fat mass.

### 6.2. Lean body mass

Lean body mass is total body mass (e.g., muscles, internal organs, water, bones, ligaments, and tendons) less nonessential or storage adipose tissue. Lean body mass includes water, minerals, proteins, glycogen and small amounts of essential body fat found in bone marrow and internal organs. Using these definitions, lean body mass usually differs from fat-free mass by only ~5%; slightly less in men, slightly more in women. Reports of "lean mass" (e.g., some DXA reports) can differ from the definition above, with bone mineral content (BMC) sometimes excluded, as in [43]:

Total body mass = fat mass + lean mass + bone mass

Lean mass = total mass – fat mass – BMC

Percent body fat = fat mass / (total body mass – bone mass)

### 6.3. Body compartments

Body weight or body mass index are not measures of body composition. While not applicable to living beings, cadaver analysis is the only absolute "gold standard" for body composition assessment [44].

Body compartment models can be used to assess body composition measurements [45]. In clinical practice, the most utilized body compartment assessments include two-compartment and three-compartment body models. Compartment model definitions can vary; definitions here apply to common clinical body composition analyses applicable to obesity medicine.

#### 6.3.1. Two-compartment

The two-body compartment model includes fat mass and fat-free mass (i.e., water, protein, bone mineral, non-bone mineral). This can be assessed by: [45–47]:

- Dual-energy x-ray absorptiometry (DXA)
- Bioelectrical impedance (BIA)
- Underwater, or hydrostatic weighing
- Air displacement plethysmography (BOD POD)
- Skin fold thickness-derived calculations
- Deuterium dilution

#### 6.3.2. Three-compartment

The three-body compartment model includes fat mass, lean mass (water, protein), and bone mass. DXA measures two compartments at a time. But, by combining two different compartment analyses in an individual, DXA can quantitate fat mass, lean body mass, and bone mass [45,46].

#### 6.3.3. Other compartment models

More applicable models to research include the four-body compartment model that includes fat mass, total body water, protein, and bone mineral, and can be assessed by combinations of two compartment assessments, such as hydrostatic weighing plus DXA plus deuterium dilution, or hydrostatic weighing plus DXA plus bioimpedance spectroscopy [47]. The six-body compartment model includes fat mass, total body water, bone mineral, non-bone mineral, protein, and glycogen [25,45,46].

### 6.4. General principles of body composition assessment and measurement

Table 3 provides a general description of clinical methods to assess body composition, with most having the capability to assess percent body fat and others being able to measure lean body mass and measure or estimate, via calculation, fat location (i.e., android and visceral fat).

**Table 3**
**Body Composition Measurement Summary.** Shown are a variety of body composition measurement techniques as well as information about the accuracy, cost, and limitations of each method [48,49].

| Method | Accuracy[a] | Expense[b] | Limitations |
|---|---|---|---|
| Calipers | User dependent; may substantially vary from other measures of % BF | Inexpensive | Not an optimal measuring technique for patients with very high body mass index |
| Dual-energy x-ray absorptiometry (DXA) | Accurate | Relatively inexpensive to patient | Not all DXA measurements (1) distinguish visceral versus subcutaneous fat, or (2) accommodate patients with very high body mass index |
| Bioelectrical impedance analysis (BIA) | Accurate with some potential variability | Relatively inexpensive to patient | Hydration dependent |
| Air displacement plethysmography (BOD POD) | Accurate with some potential variability | Relatively inexpensive to patient | Clothing and hydration dependent; may not be able to accommodate individuals with very high body mass index |
| Underwater weighing densitometry | Accurate | Relatively inexpensive to patient | Time consuming, requires water submersion, and depends upon adequate lung exhalation |
| Computerized tomography/ magnetic resonance imaging | Accurate | Expensive | Not all CT and MRI scanners can accommodate individuals with very high body mass index. CT procedures expose patients to ionizing radiation |
| Deuterium dilution hydrometry | Accurate | Variable expense | Not readily available for routine commercial use |

**Abbreviations:** % BF: percent body fat; CT: computerized tomography; MRI: magnetic resonance imaging.

[a] The accuracy of all methods depends on the degree of training and quality of equipment.

[b] While expenses to the patient are variable, the cost of the machinery, setup, training, maintenance, certification, and staffing for many of these methods is expensive to the provider.

- Fat mass includes stored and essential lipids.
- Water is usually the largest single component of body mass (~60% of body weight).
  - ~55% intracellular
  - ~45% extracellular
- Minerals include calcium, phosphorous, magnesium, and others.
- Residual mass includes remaining proteins and glycogen.

#### 6.4.1. Skinfold calipers

Skinfold calipers are used to estimate proportion of body fat (see Table 3). However, skinfold caliper measurements are often associated with large user variability, making them generally less accurate than other measures. While caliper measurements may not be as accurate for a cross-sectional assessment, caliper measurements performed via a validated and consistent technique over time can be used as a longitudinal measure of changes in percent body fat.

#### 6.4.2. Hydrodensitometry

Underwater weighing is a two-compartment model that estimates proportion of body fat based upon the Archimedes principle, wherein the buoyant force (i.e., upward force opposite of gravity) of a body immersed in fluid is equal to the weight of the displaced fluid [49]. Hydrodensitometry compares measurement of body mass weight out of water versus body weight underwater, to estimate percent body fat. If the weight of the object is more than the weight of the water displaced, then the object will sink; if the object weighs less than water weight, then it will float. When air is exhaled from lungs, a person will sink and have underwater weight — which is why maximal exhalation is critical to hydrostatic weighing. Lean tissues are denser than water, and a person with more muscle will have more total body density and weigh relatively more underwater. Fat is less dense than water, and a person with more body fat will have less total body density and weigh relatively less underwater. In general, an important principle to remember is: "muscle sinks and fat floats." The knowledge of total body density can be used to estimate body composition (i.e., fat mass and fat-free mass).

#### 6.4.3. Dual X-Ray absorptiometry (DXA)

DXA is often considered a practical "gold standard" for body composition analysis due to accuracy, scope of measures, convenience, and safety [50]. Although MRI and CT may also be considered "gold standards," they are not as often clinically performed for body composition purposes in an obesity medicine practice [51].

- ***Metabolic disease and cardiovascular disease risk*** are increased with accumulation of android and visceral fat.
- ***Android fat*** is often defined as the fat contained between the pelvis and rib cage, or specifically, the area above the iliac crest with a height 20% of the distance from the iliac crest to the neck/skull base. Android fat includes visceral and abdominal subcutaneous fat.
- ***Visceral fat*** is the fat surrounding the internal abdominal visceral organs and equals android fat less abdominal subcutaneous fat.
- ***Lean body mass*** is total body mass less storage adipose tissue (i.e., includes water, mineral, protein, glycogen, and essential organ fat).

*6.4.3.1. DXA: definitions.* Depending on hardware and software, DXA measures body fat, lean mass, and bone-mineral density [52]. Fig. 1 describes the types of information that can be derived from DXA. DXA has low risk of radiation exposure, often approximately 5% of standard chest x-rays and approximately the same radiation as an intercontinental flight [53]. Greatest accuracy and consistency are achieved with appropriate patient preparation, appropriate user training, use of the same machine, employment of standard operating procedures, and routine DXA calibration [46]. Definitions for body composition may vary [52,53].

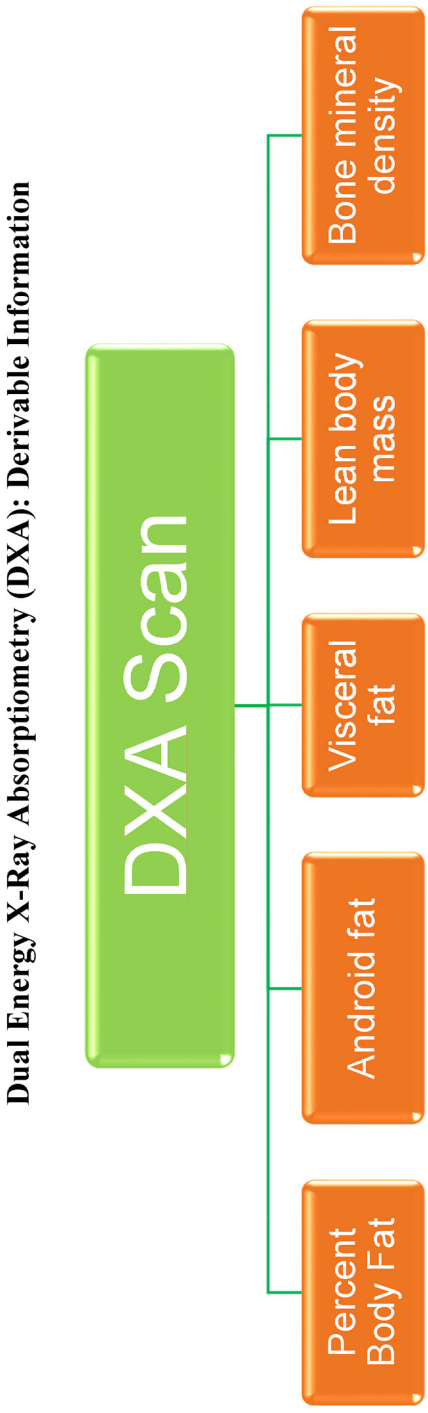


**Fig. 1. Dual Energy X-Ray Absorptiometry (DXA): Derivable Information.** DXA can provide information about patients including percent body fat, android fat, visceral fat, lean body mass, and bone mineral density [54]. Not all DXA scans measure and/or report android and visceral fat.

*6.4.3.2. DXA: percent body fat and abdominal adipose tissue.* Waist circumference (i.e., reflective of abdominal subcutaneous adipose tissue and intraperitoneal/visceral adipose tissue) correlates to the risk of metabolic and cardiovascular disease [55]. Some reported "centile" DXA assessments of percent body fat may be calculated from databases obtained decades prior (e.g., 1999–2004 National Health and Nutrition Examination Survey [56]), and thus centile assessments may not be an accurate comparison to the current-day population - especially given the increase in the obesity epidemic in the past decades. More recent (2015) reference standards can be found in the medical literature, with the upper 10th centile in adults representing [57]:

- > ~43–52% body fat among Caucasian women
- > ~32–41% body fat among Caucasian men

Some DXA machines can measure android fat and visceral fat [52,58]. As with body mass index, percent body fat alone does not provide information regarding android and visceral fat depots, which are most reflective of adiposopathy and increased cardiometabolic risk. DXA assessment of abdominal adipose tissue/android fat may often be 7 pounds or more, with ≥3 pounds often associated with increased cardiometabolic risk [59]. Visceral fat may often be 3 or more pounds in males and 2 or more pounds in women, with increased visceral fat associated with increased cardiometabolic risk [59]. Optimal visceral fat may be < 1 pound and optimal android fat may be < 3 pounds [58]. Table 4 describes the Obesity Medicine Association classifications of percent body fat and Table 5 describes the Obesity Medicine Association classifications of visceral and android fat. The cut-off points may change in the future, depending on accumulation of applicable data.

*6.4.3.3. DXA: compartments.* Monoenergetic x-rays measure a homogenous absorber component. For example, a characteristic monoenergetic chest x-ray provides a two-dimensional image. X-ray beams (photons) more easily pass through tissues such as lungs, creating a darker image. This contrasts to the attenuation of the X-ray beams by tissues such as bone, that creates a whiter image.

Dual-energy x-rays (e.g., dual x-ray absorptiometry or DXA) utilize two beams with different energy levels that quantitate densities of two absorber components. In body areas with no bone, DXA can measure the "two compartments" of fat mass and lean soft tissue mass. In body areas with bone, DXA can measure the "two compartments" of bone mineral mass and soft tissue mass [67,68]. By combining these two analyses, DXA can provide data regarding fat, lean tissue, and bone. Population-level analyses often suggest reasonable correlation between other percent body fat analysis methods and DXA [69]. However, at the individual level, other body fat analyses may not have concordance with DXA assessment. Other body fat analyses often utilize limited direct assessments that are used to calculate and estimate body composition, while DXA involves a more extensive assessment of body tissues to estimate body composition.

**Table 4**
**Obesity Medicine Association Classifications of Percent Body Fat.** The OMA classifications of percent body fat are based on a variety of scientific references as well as expert clinician opinions [55–57,60,61].

| Obesity Medicine Association Classifications of Percent Body Fat in Adults as Assessed by DXA | | |
|---|---|---|
| | Women | Men |
| Essential fat | <15% | <10% |
| Athlete | 15–19% | 10–14% |
| Fitness | 20–24% | 15–19% |
| Acceptable | 25–29% | 20–24% |
| Pre-obesity | 30–34% | 25–29% |
| Obesity | ≥35% | ≥30% |

**Table 5**
**Obesity Medicine Association Classifications of Visceral and Android Fat.** Levels of visceral and android fat are important risk factors for patients. Like the OMA classifications of percent body fat, the classifications of visceral and android fat are based on scientific references as well as expert opinions [59,62–66]. The pounds, grams, and kilograms listed represent approximate conversion values for the sake of simplicity.

| Obesity Medicine Association Classifications of Visceral and Android Fat in Adults | | |
|---|---|---|
| | Women | Men |
| Optimal visceral fat | <1 lb. (500 g/0.5 kg) | <1 lb. (500 g/0.5 kg) |
| Optimal android fat | <3 lbs. (1400 g/1.4 kg) | <3 lbs. (1400 g/1.4 kg) |
| Average total fat for adults | 70 lbs. (30 kg) | 80 lbs. (35 kg) |
| Average visceral fat for adults | 2 lbs. (1000 g/1 kg) | 3 lbs. (1400 g/1.4 kg) |
| Average android fat for adults | 7 lbs. (3000 g/3 kg) | 7 lbs. (3000 g/3 kg) |

**Abbreviations**: lbs: pounds; kg: kilograms.

*6.4.3.4. Dual Energy X-Ray Absorptiometry (DXA): bone mineral density.* When DXA is performed for body composition, bone mineral density measurements are often included. This is especially important for patients at risk for osteoporosis due to prior bariatric surgery or substantial weight loss via current and emerging anti-obesity drug treatments. DXA assessment of bone mineral density (BMD) reports ranges applicable to osteoporosis risk. T-scores are measures compared to a young healthy adult at peak bone mass (some T-scores are sex specific; other T-scores compare BMD of both males and females to the BMD of healthy 30-year-old White females). T-score ranges are as follows [70]:

- ***Normal*** = T-score of −1.0 or higher
- ***Osteopenia*** = T-score between −1.0 and −2.5
- ***Osteoporosis*** = T-score −2.5 or lower (2 ½ standard deviations below mean of a 30-year-old male/female)
- ***Z-score*** = Compared to matched controls (e.g., age, sex, weight, race/ethnicity)

Bone mineral density is more closely associated with lean mass than total body mass or fat mass [71]. If physical activity is maintained, then patients with pre-obesity or obesity often have an increase in lean mass and trend towards higher bone mineral density. If an increase in body fat is accompanied by physical inactivity, then this may increase the risk for lower bone mineral density [71]. Causes of osteopenia and osteoporosis include older age, genetic predisposition, physical inactivity or immobilization, prolonged lack of estrogen in women, prolonged lack of testosterone in men, calcium and/or vitamin D deficiency, cigarette smoking, excessive alcohol, hyperthyroidism, hyperparathyroidism, hypercortisolism, certain cancers and rheumatologic diseases, and large and rapid weight loss without adequate nutrient replacement (e.g., some bariatric surgeries). In the absence of calcium or vitamin D deficiency, the health benefits of calcium and vitamin D supplementation are unclear [72,73]. Gradual reduction in weight with maintenance of healthful nutrition, accompanied by resistance and higher impact physical exercise (when safe), may help maintain or possibly increase BMD.

*6.3.4.5. Dual Energy X-Ray Absorptiometry (DXA): Osteopenia treatment.* Patients with vitamin D deficiency may benefit from adequate dietary calcium, vitamin D, and physical exercise to avoid or treat osteopenia and/or prevent future bone loss [74]. Physical exercises with the greatest potential to increase BMD include weight-bearing resistance training (e.g., deadlifts, squats, military press, farmers walk) or high-impact exercises (e.g., running/jogging, jumping rope, stair running/climbing, racquet sports, basketball, dancing, plyometrics, lunges, and mountain cycling/biking) [75,76]. Physical activities that may not increase BMD but may prevent bone loss include low impact walking, yoga, and Pilates. Finally, physical activity that may not prevent bone loss and/or promote bone growth include swimming and road cycling/biking [77].

*6.3.4.6. Dual Energy X-Ray Absorptiometry (DXA): bone composition.* In lean individuals, about 60% of body weight is water. Among those with obesity, water weight can be as low as 40% of total body weight [78]. Water is found in fat-free mass, with approximately 75% of muscle and body organs being composed of water [79]. Conversely, about 30% of bone is water, and the other 70% is mineral salts and collagen. Regarding dry skeletal weight, 65% is hydroxyapatite (mainly calcium/phosphorous) and 35% is organic protein matrix (mostly type 1 collagen) [80]. DXA-reported bone mineral content (BMC) is the mineral content of bone (90% calcium and phosphorous) and is typically about 5–10 pounds [81]. Ash body weight (e.g., weight after cremation) is mainly bone mineral calcium and phosphate residual and is approximately 3–10 pounds. BMC and ash weight are typically higher in larger males compared to smaller females [82].

*6.4.3.7. DXA: reference body composition.* DXA assessments of muscle have values without "normal ranges." Lean body mass and fat composition are widely variable between individuals based upon genetics, sex, race, age, nutrition, and physical activity. Compared to Whites, percent body fat is generally lower among Blacks, and percent body fat is generally higher among Hispanic females compared to non-Hispanic Caucasian females [83]. For lean individuals, lean body mass (LBM) is often 75% of total body mass (40% muscle, 10% bone, and 25% organs), and highly trained athletes may have LBM >85% [84]. However, anthropometric measurements can vary, even among athletes in the same sport. Table 6 lists DXA body composition variance among professional football players (i.e., Green Bay Packers).

While muscle is only one component of lean body mass (LBM), in those with increases or decreases in physical activity, a longitudinal change in LBM is often considered a surrogate for a change in skeletal muscle mass. In some individuals, percent body fat may be <5% and in others >70%. While variable among individuals and not intended to represent absolute values, the following are approximate values of lean mass and body fat percentages for athletes [84]:

- Mean lean mass of male athletes may be approximately 130 pounds (football linemen may be ≥ 200 pounds)
- Mean lean mass of female athletes may be approximately 110 pounds; some have less/more
- Male athletes often have 10–14% body fat
- Female athletes often have 15–19% body fat

*6.4.4. Body compartments: Bioelectrical Impedance Analysis (BIA)*

Bioelectrical impedance analysis (BIA) measures impedance by body tissues to flow of electrical current (i.e., electrical resistance equals impedance) [86]. Three major groups of BIA devices include: hand-to-hand, foot-to-foot, and hand-to-foot [87]. Electrical current passes more easily through water and muscle, and less easily through fat. Many

**Table 6**
DXA Variance Among Football Players (Green Bay Packers). Anthropometric measurements can vary, even for athletes in the same sport. Shown are measurements of Green Bay Packers players from 2006 to 2011 [85]. Android fat >3 pounds may be associated with increased risk of cardiometabolic disease. Visceral fat <1 pound may be associated with reduced risk of cardiometabolic disease.

| Position | OL | DL | LB | TE | RB | WR | DB |
|---|---|---|---|---|---|---|---|
| BMI | 38 | 37 | 32 | 31 | 32 | 27 | 27 |
| Percent fat | 29% | 25% | 17% | 17% | 16% | 13% | 12% |
| Android fat | 4 | 3 | 1 | 1 | 1 | 0.6 | 0.6 |
| [kg (lbs)] | (9) | (6) | (2.6) | (2.6) | (2.4) | (1.3) | (1.3) |
| Visceral fat | 1 | 1 | 0.3 | 0.3 | 0.4 | 0.3 | 0.3 |
| [kg (lbs)] | (3) | (2) | (0.7) | (0.7) | (.9) | (0.7) | (0.7) |

**Abbreviations:** OL: offensive linemen; DL: defensive linemen; LB: linebacker; TE: tight end; RB: running back; WR: wide receiver; DB: defensive back; BMI: body mass index (kg/m$^2$).

BIA devices assume fat-free mass has a constant proportion of water. (~70%) [87].

The accuracy of BIA is hydration dependent; preparing for BIA requires the patient to remove all metal, eliminate body waste prior to the procedure, avoid exercise causing sweat for 8 h, and avoid large amounts of caffeine or alcohol for 12 hours before the procedure [87]. BIA can estimate total body water as well as fat-free and fat mass (two-compartment model). Less common "dual" BIA devices that utilize electrodes on the abdominal wall may allow evaluation of visceral fat, with variable correlation to dual-energy x-ray absorptiometry (DXA) [86, 88]. Some BIA devices with costs approximating DXA machines are reported to have accuracy that approximates body composition measured by DXA.

BIA devices may over- or under-estimate percent body fat compared to DXA (they often underestimate) [27]. Some BIA devices do not incorporate waist circumference (WC) and report android and visceral fat using population-based estimates/calculations [89]. Some of these BIA devices may correlate well to standardized measures for groups or populations, but less so for individuals [90]. For the individual, measuring waist circumference (WC) by measuring tape is a simple assessment tool that may complement BIA percent body fat and may correlate to the metabolic risk of DXA measured abdominal fat [91]. Waist circumference is sometimes included in BIA calculation and reports, increasing the accuracy of abdominal fat prediction. The percent body fat from different types of BIA devices may not correlate as well in individuals with increased waist or hip circumference [87]. Most BIA devices are less expensive than DXA machines, and, unlike DXA machines, BIA devices do not require trained technicians to operate [92]. Individuals with personal BIA devices (often accompanied by computer or smartphone applications) may initially correlate their initial reported values to a more standardized measure (e.g., DXA). Having the knowledge of a potentially more accurate baseline percent body fat (or at least knowledge of the known individual variance) may provide validated assurance of comparable values, which may then allow for greater confidence among those who want more frequent and convenient longitudinal measures of their body composition [93].

#### 6.4.5. Body composition: Whole Body Plethysmography (BOD POD)

*Plethysmo* is Greek for *enlargement*. Whole body plethysmography (BOD POD) is a two-compartment body composition assessment that measures body volume by air displacement, with principles similar to water displacement by hydrodensitometry weighing [29]. In preparing for whole body plethysmography, it is recommended patients not undergo strenuous exercise for 2 h before the procedure and not eat or drink for 1 h before the procedure. It is recommended that patients wear light clothing (a tight swimsuit is preferred) and a hair cap to avoid air trapping [94].

Body density (weight/volume) is used to estimate percent body fat, with weight measured via a scale before entering the closed chamber and volume determined by the air displaced upon entering the closed chamber. Whole body plethysmography employs the principles of Boyle's law, wherein at a constant temperature, volume and pressure are inversely related. Larger body volume decreases the air in the chamber and therefore increases air pressure in the chamber. By injecting air into the chamber, the air pressure can be measured and then used to calculate air volume. Once body density is measured (body weight/body volume), then, like underwater weighing, percent body fat can be calculated by using one of several equations, which are generally reflected by: *Percent Body Fat = (x/Body Density) – y*, wherein *x* and *y* are numbers that depend on the specific formula, which, in turn, often depends on race/gender. An important equation relevant to body composition analyses such as whole-body plethysmography (and underwater weighing) is the Siri equation [95], which is:

Percent Body Fat = (495 / Body Density) – 450

#### 6.4.6. Body composition: deuterium oxide dilution

Deuterium dilution is a two-compartment model assessment that assesses body fat composition by estimating total body water (TBW). TBW is found in fat-free mass, with less water in fat mass. Deuterium (heavy water) is a non-radioactive isotope of hydrogen ($^2H$), administered as deuterium oxide ($D_2O$ or $^2H_2O$); its hydrogen components contain a neutron and a proton. (An isotope is the same element with the same number of protons, but different neutrons; the hydrogen in $H_20$ or water has only one proton.) After mixing with body water (not fat), deuterium is eliminated from the body in saliva, sweat, human milk, and urine. The amount of TBW can be calculated by knowing the administration dose of $D_2O$ and the post-dose equilibrated concentration of $D_2O$ (in blood, saliva, or urine). In other words, the amount of known $D_2O$ administered into TBW will equilibrate into a concentration of D2O/TBW in measured blood, saliva, or urine. After collecting post $D_2O$ samples of blood, saliva, or urine, and after TBW is calculated by deuterium dilution, and if it is assumed that ~70% of fat free mass is water, then percent body fat can be estimated [96].

#### 6.4.7. Body composition: Computerized Tomography (CT) and Magnetic Resonance Imaging (MRI)

Both computerized tomography (CT) and magnetic resonance imaging (MRI) accurately measure adipose tissue and skeletal muscle [97]. CT increases exposure to ionizing radiation, a potential clinical concern with repeat CT testing [98]. MRI results in no radiation exposure, and both CT and MRI accurately assess visceral and hepatic fat [99].

## 7. Energy expenditure

Energy expenditure, or the total amount of energy humans use to maintain body function and perform physical activity, plays an important role in the genesis and treatment of obesity. Table 7 summarizes takeaway messages regarding energy expenditure and obesity.

### 7.1. Energy expenditure: calories

A calorie is the amount of heat energy required to raise the temperature of 1 g of water 1 °C. A Calorie (capital "C") is the same as a

**Table 7**
**Ten Takeaway Messages: Obesity and Energy Expenditure.** Energy expenditure is clinically applicable to pre-obesity/obesity management [100].

| | |
|---|---|
| 1 | For most individuals, resting metabolic rate (RMR) represents approximately 70% of total daily energy expenditure. |
| 2 | For most individuals without excess body fat, skeletal muscle, liver, brain, heart, and digestive system each individually account for approximately 10–20% of RMR for a total of about 75% of total RMR. Kidneys, adipose tissue, and remaining tissues account for ~25%. |
| 3 | Non-exercise activity thermogenesis (NEAT) varies among individuals, can range between 150 and 500 kcal/day (often greater than bouts of physical exercise), and can help account for the perception that some individuals more easily maintain a healthy body weight despite similar caloric intake and dedicated physical exercise. |
| 4 | Less than 5,000 steps per day is considered sedentary; ≥ 10,000 steps per day is considered active. |
| 5 | Direct calorimetry estimates energy expenditure via measurement of heat generated by an organism in an enclosed chamber. |
| 6 | Indirect calorimetry estimates energy expenditure via use of an electronic metabolic "cart" that measures carbon dioxide production and oxygen consumption. The respiratory quotient (RQ) equals $CO_2$ production divided by $O_2$ consumption and can be used to determine metabolic fuel or substrate utilization. The RQ for glucose utilization is 1.0; the RQ for fat utilization is 0.7. |
| 7 | Resting energy expenditure for healthy individuals can be estimated by calculations such as the Harris-Benedict or Mifflin St Jeor Equations. |
| 8 | Doubly labeled water estimates energy expenditure via oral administration of traceable hydrogen and oxygen isotope and the estimation of carbon dioxide production, reflecting energy expenditure due to tissue respiration. |
| 9 | Physical activity energy expenditure can be estimated by wearable technologies, such as pedometers and accelerometers. |
| 10 | Energy expenditure may be increased with greater inefficiency in physiologic and behavior processes. |

kilocalorie, which is the heat energy required to raise the temperature of 1 kg of water by 1 °C. One kcal equals 4.184 kJ. Kilocalories are used in food labels, usually expressed as Calories. When referring to food or physical exercise, it is common that the term "calories" (capitalized or not) actually refers to kilocalories (kcal) [101].

"3500 Calories per pound of fat" is commonly referenced as the approximate energy content for a pound of fat [102]. However, body weight homeostasis is dependent upon total energy expenditure, which includes RMR and physical activity (and diet-induced thermogenesis). The amount of physical activity required to "burn" the same pound of fat varies, depending on the underlying resting metabolic rate (RMR) and muscle efficiency. In turn, the RMR depends on body weight, including both muscle and fat mass. If a patient with pre-obesity or obesity loses body weight, then it is common that both fat and muscle mass are reduced, with less energy required to sustain these body tissues — hence a reduced resting metabolic rate. Other physiologic adaptations occur such as improved muscle efficiency. The reduced underlying RMR and physiologic adaptations with weight loss mean that greater physical activity will be required to "burn" future pounds of body fat. Furthermore, an important objective with weight reduction in patients with pre-obesity/obesity is to prioritize fat weight loss while avoiding excessive muscle weight loss. The preservation of muscle mass during weight loss is dependent upon physical activity and possibly protein intake during the weight loss, and it usually requires physical exercises involving resistance training [103]. In short, during negative caloric balance, dynamic adaptations in body energetics occur (changes in resting metabolic rate, skeletal muscle efficiencies) with greater energy expenditure and/or further reduction in energy intake required to achieve the same rate of (fat) weight reduction.

### 7.2. Energy expenditure: definitions

***Basal Metabolic Rate (BMR):*** BMR can be defined as the energy expended while fasting, rested, and supine in a thermoneutral environment [104]. BMR is increased with greater body weight, largely because of the increase in energy requirements for the increase in body tissues.

***Resting Metabolic Rate (RMR):*** RMR can be defined as the energy expended at rest and does not require overnight supine measurement [104]. It is increased with increased body weight. For most individuals without excess body fat, the components of RMR are [105]:

- ~20% skeletal muscle
- ~20% liver
- ~15% brain
- ~10% heart
- ~10% digestive system
- ~5% kidney
- ~5% fat
- ~15% remaining/residual

***Exercise Activity Thermogenesis (EAT):*** EAT is defined as planned, structured, and repetitive physical activity conducted with the objective of improving fitness (e.g., sports, gym activities) [106]. Like the fuel of gasoline for motor vehicles, available energy in muscle (the "fuel" of adenosine triphosphate or ATP) is used to facilitate motion (mechanical work), with some energy released as heat (thermogenesis). The efficiency in converting ATP to muscle mechanical work is around 30%; dynamic exercise efficiency can be increased with training and weight loss [107]. Muscle work efficiency may be decreased with resistance training [108]. An increase in body temperature with the "inefficient" release of heat (as opposed to fueling mechanical work) triggers the central nervous system (e.g., hypothalamus) to cool the body via increased dilation of skin smooth muscle blood vessels, increased heart rate, and increased sweat production — all helping to facilitate heat loss during physical exercise.

***Non-Exercise Activity Thermogenesis (NEAT):*** NEAT is defined as energy expenditure not typically considered physical exercise (e.g., maintaining posture, standing, stair climbing, fidgeting, cleaning, singing, and other activities of daily living) [106,109]. NEAT often represents the widest variance in total energy expenditure among individuals and can range from 150 to 500 kcal/day, which is often greater than bouts of physical exercise [106]. Along with genetic/epigenetic, biological (increased proportion of brown adipogenesis) [110], and environmental factors, NEAT is an example of a behavioral factor that may help explain perception that some individuals:

- Are "naturally lean"
- Can maintain a healthier body weight compared to others, even with the same caloric intake and same routine "exercise" activity

### 7.3. Energy expenditure: components

Fig. 2 demonstrates that body weight homeostasis is equal to energy intake (positive) balanced against energy expenditure (negative). In most individuals with moderate physical activity, components of total energy expenditure are approximately [111]:

- 70% resting metabolic rate
- 20% physical activity (EAT and NEAT)
- 10% diet-induced thermogenesis

The between-individual variance in energy expenditure is largely driven by RMR and NEAT. The variance in RMR is driven by differences in body mass. The variance in NEAT is dependent on individual behavior and may explain why some individuals more easily maintain a healthy body weight compared to others [112–114]. Regarding diet-induced thermogenesis, whole foods generally generate higher diet-induced thermogenesis than ultra-processed foods [115].

### 7.4. Energy expenditure: 2018 physical activity guidelines for Americans

Approximately 80% of U.S. adults and adolescents are insufficiently active [117]. General physical activity recommendations for adults include [117,118]:

- Engage in 150–300 minutes or more of moderate-intensity aerobic activity or 75–150 minutes or more of vigorous-intensity aerobic activity per week.
- Engage in muscle-strengthening activities on two or more days per week.

Walking may be considered either EAT or NEAT depending on the clinical context and patient's goals. Fig. 3 explicitly incorporates steps as an acceptable physical activity goal. Increasing the number of steps taken per day can be achieved by altering daily activity or by scheduled walking/running. Compared to being seated for hours (such as in the workplace), it is better to walk at least 10 minutes per hour. Small ways of increasing steps taken daily include activities such as taking the stairs instead of elevators or parking further from a destination. Patients benefit from monitoring the number of steps per day via a pedometer or other tracking device. The number of steps recorded by different pedometers can vary. In general [118]:

- < 5000 steps per day is sedentary (and the average number of steps for U.S. adults)
- 5000–7500 steps per day is low active
- 7500–10,000 steps per day is somewhat active
- >10,000 steps per day is active

Although variable, approximately one Calorie (kcal) is "burned" for every 20 steps (i.e., 4000 steps/20 = 200 Calories). 10,000 steps per day x 7 days per week x one calorie per 20 steps = 3500 calories burned per week.

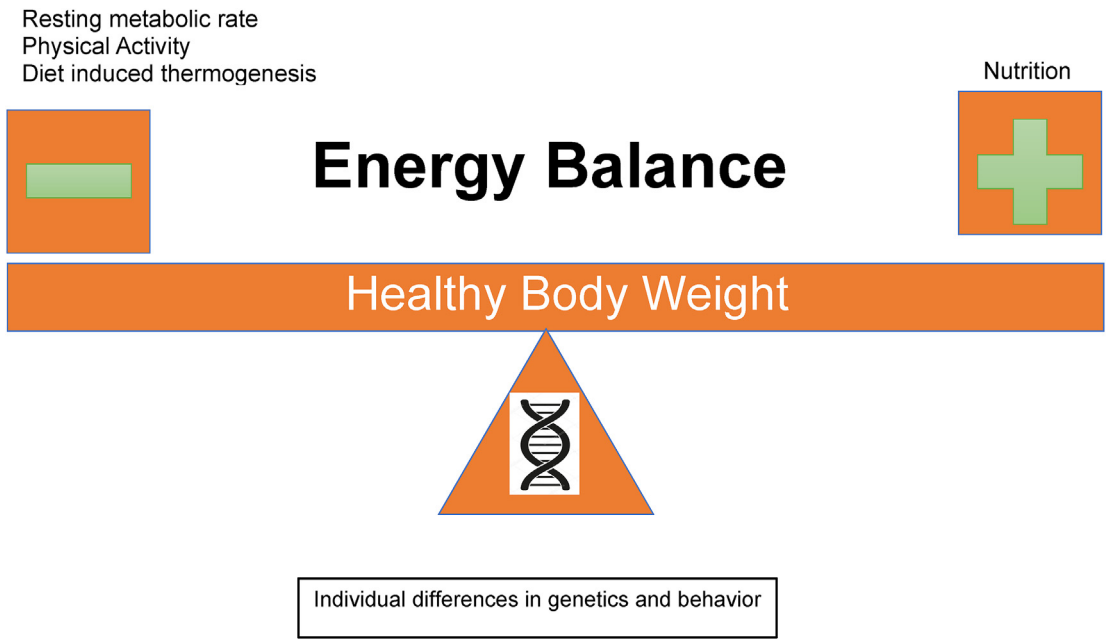


**Fig. 2. Body Weight Homeostasis.** The variance in resting metabolic rate (RMR) is dependent upon genetic influences on body mass-dependent energy expenditure (i.e., individuals of male sex, increased height, increased muscle, younger age, and with obesity typically have higher RMRs). An increase in fat free mass may not only increase RMR, but may also increase hunger, which influences the nutritional aspect of energy balance. Beyond RMR, other common contributors to variances in energy expenditure include non-exercise activity thermogenesis (NEAT), physical exercise activity, and diet-induced thermogenesis (DIT). Finally, RMR can be affected by climate. Hotter environments increase RMR to cool the body; colder environments increase RMR through non-shivering thermogenesis to warm the body [111–114,116].

**Energy Expenditure: Obesity Medicine Association Physical Activity Goals**

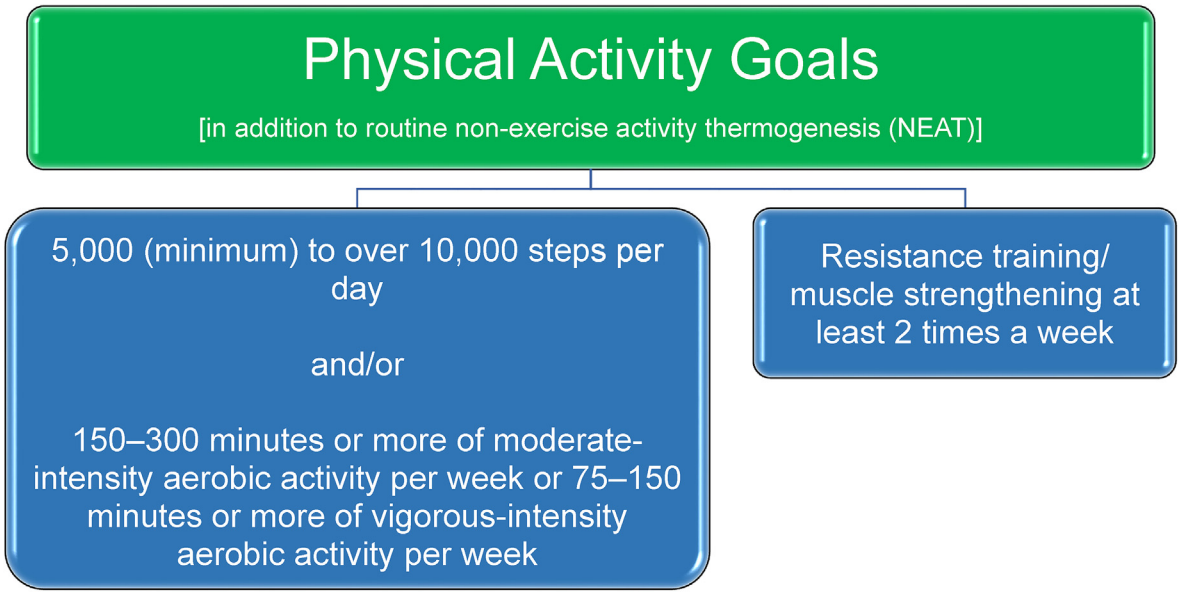


**Fig. 3. Energy Expenditure: Obesity Medicine Association Physical Activity Goals.** The OMA Physical Activity Goals include steps, which may be augmented by moderate intensity or vigorous intensity aerobic activity minutes per week, and resistance training sessions [106,117,118].

### 7.5. Measurement of energy expenditure via direct and indirect calorimetry

#### 7.5.1. Direct calorimetry

This method utilizes a closed chamber/calorimeter to assess the heat generated by an organism by measuring the differences in temperature of water entering and leaving the chamber via a heat exchanger. The value of generated heat can estimate total energy expenditure. The number of locations and facilities for direct calorimetry assessment is limited, and this technique is not often used in clinical practice [92].

#### 7.5.2. Indirect calorimetry

Indirect calorimetry estimates basal energy expenditure and resting energy expenditure via measuring oxygen consumption and carbon dioxide production. A metabolic cart is an electronic device, typically on a mobile push "cart" that measures $O_2$ consumption ($VO_2$) and $CO_2$ production ($VCO_2$). The cart typically contains a computer system, a monitor, and breathing tubes [92]. Energy expenditure is the use of cellular energy (ATP) to fuel muscle contraction, nerve impulse propagation, chemical synthesis, substrate phosphorylation, and ion transport [119].

- ATP + muscle = muscle contractions + heat
- ATP + biochemicals = metabolic reactions + heat
- ATP + membranes = transport across membranes + heat

#### 7.5.3. Cellular respiration

From an energetics perspective, "respiration" refers to the movement of oxygen and carbon dioxide in and out of cells and is a vital function not limited to breathing or the lungs. At the cellular level, respiration involves enzymatic reactions (i.e., citric acid cycle, electron transport chain, oxidative phosphorylation) that convert oxygen and chemical energy from food to biologic energy, which is required for the countless body physiologic processes required to sustain life and for muscular movements [120]. The overall formula describing cellular respiration is [119]:

Food + Oxygen = $C0_2$ + $H_20$ + Energy [~60% heat & ~40% adenosine triphosphate (ATP)]

Energy expenditure can be estimated by simplification of the Weir equation [121]:

Resting energy expenditure = $VO_2$ (oxygen consumption) + $VCO_2$ (carbon dioxide production)

[A more complete Weir equation is: *Energy expenditure* = $VO_2 + VCO_2$ – *Nitrogen (urine)]*.

#### 7.5.4. Indirect calorimetry formulas

Indirect calorimetry can measure energy expenditure by estimating oxidation rates of macronutrients (carbohydrates, fats, protein) via rates of respiratory exchange of $O_2$ and $CO_2$ and excretion of urine nitrogen. This assumes [122]:

- $FIO_2 + FIN_2 = 1$ [FI = Fraction of inspired (ambient) air]
- *Inhaled ambient air* = 21% $O_2$ + 79% $N_2$ + *less than 1%* $CO_2$

And requires knowledge of:

- Oxygen consumption ($VO_2$ *in* – $VO_2$ *out*)
- $CO_2$ production (expired $CO_2$)
- Nitrogen level (for full Weir equation)

Most indirect calorimetry devices measure $VO_2$ and $VCO_2$ through use of breathing tubes. Some devices only measure $VO_2$ [*metabolic rate* = $5(VO_2)$, where it is assumed that 5 Calories (kcal) are expended for each 1 L of oxygen consumed]. Some have proposed only measuring $VCO_2$ to estimate energy expenditure, but such an approach is not universally accepted [122].

#### 7.5.5. Respiratory quotient (RQ) = $CO_2$ production/$O_2$ consumption

The processes generating heat and stored energy (ATP) differ depending on the types of food [121]. For this reason, not only is indirect calorimetry used to assess energy expenditure, but it may also determine the oxidation rates of macronutrients. The respiratory exchange ratio (RER) is the proportion of $CO_2$ generated relative to the $O_2$ consumed. This can be done under non-steady-state conditions. Indirect calorimetry can utilize the RER to estimate the respiratory quotient (RQ) and assess the proportion of metabolized fuels at the cellular level [121,123].

- RQ for carbohydrates = 1.0 (carbohydrate molecules have one oxygen for every carbon and require less additional oxygen consumption per carbon for aerobic metabolism compared to fat)
- RQ for fats = 0.7 (fat molecules have less oxygen, and require more additional oxygen consumption per carbon for aerobic metabolism compared to carbohydrates)
- RQ for proteins = variable

In times of overfeeding, the RQ may be as high as 1.3 due to lipogenesis favored over lipolysis. Conversely, underfeeding and ketosis (starvation) decreases RQ due to lipolysis and disproportionate utilization of fatty acids as fuel. In treating severe chronic obstructive lung disease, increasing the proportion of dietary fats (relative to carbohydrates) decreases $CO_2$ production and decreases the amount of energy spent on respiration. Higher RQs may predict future increases in fat mass [123].

### 7.6. Energy expenditure: measurement by doubly labeled water

Deuterium is a nonradioactive tracer isotope of hydrogen ($^2H$), administered as deuterium oxide ($D_2O$ or $^2H_2O$). As noted previously, deuterium (heavy water) dilution can be used to estimate percent body fat. Deuterium can also be used to assess energy expenditure. Doubly labeled water contains a traceable hydrogen isotope (deuterium or $^2H$) and a traceable oxygen isotope ($^{18}O$). Thus, both hydrogen and oxygen are labeled ("doubly"). The oxygen component of doubly labeled water will decay quicker than the hydrogen component because oxygen is lost as both $CO_2$ (in expired air) and $H_2O$ (urine and sweat), whereas the hydrogen component is lost only as $H_2O$. The difference between the administered dose and the subsequent amount of doubly labeled water in urine, saliva, or blood over time is used to calculate the body's production of carbon dioxide over time. Similar to indirect calorimetry, the amount of carbon dioxide ($CO_2$) produced approximates energy expenditure [124].

### 7.7. Energy expenditure: measurement by non-calorimetric methods

Resting metabolic rate energy expenditure for healthy individuals can be estimated by calculations that include age, sex, weight, and height. Examples of resting metabolic rate equations include [121,125]:

- ***The Harris-Benedict and Mifflin St. Jeor Equations:*** Use age, gender, weight, and height to estimate basal metabolic rate and may be calculated and included in body composition analyses such as dual x-ray absorptiometry reports.
- ***Maintenance of Hemodialysis Energy (MHDE) Equation:*** Used for dialysis patients
- ***Measurement of energy expenditure from physical activity:*** Physical activity energy expenditure can be estimated by physical activity records as input data to validated energy-expenditure tables, calculations based on heart rate, motion sensors (e.g., pedometers), accelerometers (uniaxial, bi-axial, tri-axial), and wearable technologies such as watches or attachments to a belt around the waist or ankle [126].

### 7.8. Role of biologic and behavior efficiency/inefficiency in energy expenditure

Highly motivated individuals are often successful in many aspects of life due to a mindset of maximizing efficiency. By definition, efficiency mindset and efficient behaviors often conserve energy, potentially resulting in accumulation of body fat. Regarding body weight, breaking the efficiency and/or convenience mindset via promoting negative energy balance through implementing nutritional, physical activity, and behavior inefficiencies may help with chronic obesity management [127]:

- ***Food absorption inefficiency:*** Consuming unprocessed rather than ultra-processed fast food or convenience food may impair gastrointestinal energy absorption and/or decrease post-prandial fat store-promoting hormone secretion (e.g., insulin) [115].
- ***Microbiome-promoted inefficiency:*** Microbiota vary in gastrointestinal energy absorption efficiency [128].
- ***Fat storage inefficiency:*** Browning fat cells may increase non-shivering heat energy expenditure relative to fat storage.
- ***Skeletal muscle inefficiency:*** Weight reduction and routine dynamic training of the same muscles may reduce the energy cost of physical exercise through promoting biomechanical efficiency [108]. Growth of increased muscle mass through resistance training may help increase resting energy expenditure independent of physical activity. Varying the type of physical exercise and resistance training may increase energy expenditure and help mitigate biomechanical efficiency that occurs during weight loss.
- ***Exercise and sports inefficiency:*** Greater body demands during physical activity can increase energy expenditure. Simple, more "inefficient" measures include not holding the handles with treadmill exercise, and not holding handrails when walking up stairs.
- ***Sports location inefficiency:*** Engaging in sports at a park or gym instead of couch sports (i.e., video games)
- ***Transportation and ambulatory inefficiency:*** Increased non-exercise activity thermogenesis (NEAT) can increase energy expenditure (e.g., walking instead of automated travel; stairs instead of elevators/escalators) [106].
- ***Purchasing inefficiency:*** In-store shopping for food and merchandise rather than online or car delivery
- ***Workplace inefficiency:*** Taking frequent breaks from physical inactivity to increase daily steps and increase energy expenditure
- ***Mitochondrial inefficiency:***
  - o Cellular respiration involves metabolic processes that convert biochemical energy (e.g., food) into cellular fuel or ATP (i.e., molecules specialized for energy storage and transport).
  - o Carbohydrates, fats, and proteins can be used to generate ATP. For example, glucose (from food or glycolysis) > citric acid cycle > electron transport > oxidative phosphorylation.
  - o When mitochondrial respiration is "coupled" to generating stored energy, ATP synthesis takes place. When mitochondrial respiration is uncoupled to ATP synthesis, heat is released.
  - o Mitochondrial respiration and ATP synthesis are regulated by uncoupling proteins (UCP). UCP-1 is found in brown adipose tissue. UCP-2 is found in multiple body tissues. UCP-3 is predominantly found in skeletal muscle, brown adipose tissue, and heart [129]. White adipose tissue has more limited mitochondria compared to brown adipose tissue (with the "brown" color of brown adipose tissue due to iron-containing mitochondria).
  - o Compared to white adipose tissue, mitochondria and associated UCP are more concentrated in brown and beige adipocytes. Browning fat cells may increase non-shivering heat energy expenditure relative to fat storage. UCP activity and potential thermogenesis can also be increased with cold exposure and thyroid hormone [130].
  - o In some animals, increased UCP activity generates non-shivering thermogenesis (heat) during hibernation.
  - o After an acute bout of physical exercise, UCP activity may be increased in skeletal muscle, whereas chronic physical exercise training may not affect skeletal muscle UCP. Physical exercise may or may not increase browning of adipocytes [131].
  - o Capsaicin (from chili peppers) not only stimulates pain sensory receptors ("burning" sensation) but may also upregulate UCP-1 in brown adipose tissue and thus increase thermogenesis [132].
  - o One of the reasons the supplement 2,4 dinitrophenol (DNP) was banned was due to spikes in body temperature due to mitochondrial uncoupling [130], resulting in hyperthermia, and, in some cases, death.
  - o Some investigational anti-obesity therapeutic agents upregulate uncoupling proteins or increase brown or beige adipocytes, causing cellular inefficiency by "uncoupling" mitochondrial respiration towards ATP synthesis, and, instead, increasing the amount of energy released as heat [130].

## 8. Conclusions

This OMA Clinical Practice Statement on obesity history, physical exam, lab, body composition and energy expenditure discusses basic principles regarding history, physical exam, and diagnosis of patients with obesity, which may help clinicians better manage patients with obesity.

## Transparency [133]

This manuscript was largely derived and edited from the 2021 Obesity Medicine Association (OMA) Obesity Algorithm. Beginning in 2013, OMA created and maintained an online Adult "Obesity Algorithm" (i.e., educational slides and eBook) that underwent yearly updates by OMA authors and was reviewed and approved annually by the OMA Board of Trustees. This was followed by a similar Pediatric "Obesity Algorithm," with updates ~ every two years by OMA authors. Authors of prior years' version of the Obesity Algorithm are included in Supplement #1.

## Group composition

Over the years, the authors of the OMA Obesity Algorithm have represented a diverse range of clinicians, allied health professionals, clinical researchers, and academicians. (Supplement #1) The authors reflect a multidisciplinary and balanced group of experts in obesity science, patient evaluation, and clinical treatment.

## Author contributions

KB, SMC, AG, ABI, JT and HEB reviewed, edited, and approved the document.

## Managing disclosures and dualities of interest

Potential dualities or conflicts of interest of the authors are listed in the Individual Disclosure section. Assistance of a medical writer paid by the Obesity Medicine Association is noted in the Acknowledgements section. Neither the prior OMA Obesity Algorithms, nor the publishing of this Clinical Practice Statement received outside funding. The authors of prior OMA Obesity Algorithms never received payment for their writing, editing, and publishing work. Authors of this Clinical Practice Statement likewise received no payment for their writing, editing, and publishing work. While listed journal Editors received payment for their roles as Editors, they did not receive payment for their participation as authors.

## Individual Disclosures

KB reports being a consultant/advisor for Currax, Gelesis, Novo Nordisk, and Bariatric Advantage; speaker for Currax and Vivus; and

owner of Gaining Health. SC reports being an advisor for Gelesis and speaker for Novo Nordisk. AG reports advisor/consultant/speaker for Novo Nordisk, and advisor/consultant for Currax. Since his appointment in 2021 as Obesity Pillars Editor in Chief until time of publication, HEB has not served on any obesity-related promotional speakers' bureau. HEB is owner of Your Body Goal, and HEB's research site (L-MARC Research Center) has received research grants from the following potentially applicable obesity-research related companies: Alon Medtech/Epitomee, Amgen, Boehringer Ingelheim, Eli Lilly, NovoNordisk, and Pfizer. ABI and JT report no disclosures related to this project.

## Evidence

The content of the OMA Obesity Algorithm and this manuscript is supported by citations, which are listed in the References section.

## Ethics review

This OMA Clinical Practice Statement manuscript was peer-reviewed and approved by the OMA Board of Trustee members prior to publication. Edits were made in response to reviewer comments and the final revised manuscript was approved by all the authors prior to publication. This submission did not involve human test subjects or volunteers.

## Conclusions and recommendations

This Clinical Practice Statement is intended to be an educational tool that incorporates the current medical science and the clinical experiences of obesity specialists. The intent is to better facilitate and improve the clinical care and management of patients with pre-obesity and obesity. This Clinical Practice Statement should not be interpreted as “rules” and/or directives regarding the medical care of an individual patient. The decision regarding the optimal care of the patient with pre-obesity and obesity is best reliant upon a patient-centered approach, managed by the clinician tasked with directing an individual treatment plan that is in the best interest of the individual patient.

## Updating

It is anticipated that sections of this Clinical Practice Statement may require future updates. The timing of such an update will depend on decisions made by *Obesity Pillars* Editorial team, with input from the OMA members and OMA Board of Trustees.

## Disclaimer and limitations

Both the OMA Obesity Algorithms and this Clinical Practice Statement were developed to assist health care professionals in providing care for patients with pre-obesity and obesity based upon the best available evidence. In areas regarding inconclusive or insufficient scientific evidence, the authors used their professional judgment. This Clinical Practice Statement is intended to represent the state of obesity medicine at the time of publication. Thus, this Clinical Practice Statement is not a substitute for maintaining awareness of emerging new science. Finally, decisions by practitioners to apply the principles in this Clinical Practice Statement are best made by considering local resources, individual patient circumstances, patient agreement, and knowledge of federal, state, and local laws and guidance.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.obpill.2021.100007.

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