RECOGNITION
RECONNAISSANCE

New Insights into Body Composition and Health
Through Imaging Analysis

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Abstract

From calipers to magnetic resonance imaging (MRI), we have come a long way in our ability to analyze body composition. Some historical milestones are a reminder that many concepts in muscle and fat metabolism, and their measurement, have stood the test of time. However, newer imaging technology has improved our understanding of population heterogeneity in body composition, and the potential health problems associated with certain body composition phenotypes. Imaging analyses, such as dual energy X-ray absorptiometry, computed tomography, and MRI, have provided detailed characterization of the type and amount of fat deposited centrally (abdominal adipose tissue), the trajectory of losses in muscle tissue (sarcopenia), and the combination of low muscle mass/high fat mass (sarcopenic obesity). The last is a new emerging health concern because the presence of these two disproportionate tissue depots may have an additive effect on increasing morbidity. Ongoing measurement of body composition is needed, and preliminary research suggests this may have important nutritional implications.
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Résumé

Des pinces pour mesurer le pli cutané à l'imagerie par résonance magnétique (IRM), nous avons accompli de grands progrès dans notre capacité à analyser la composition corporelle. Certains repères historiques nous rappellent que de nombreux concepts relatifs au métabolisme et à la mesure de la masse musculaire et adipeuse ont résisté au passage du temps. Cependant, de nouvelles techniques d'imagerie ont amélioré notre compréhension de l'hétérogénéité de la population quant à la composition corporelle et des problèmes de santé potentiels associés à certains phénotypes de composition corporelle. L'absorptiométrie biphotonique à rayons X, la tomodensitométrie et l'IRM, par exemple, permettent de caractériser en détail le type et la quantité de tissu adipeux déposée au centre du corps (tissu adipeux abdominal), la trajectoire des pertes de tissu musculaire (sarcopénie) et la combinaison d'une perte de masse musculaire et d'une forte masse adipeuse (obésité sarcopénique). Cette dernière condition est apparue récemment comme objet de préoccupation en santé publique, car ces deux dépôts de tissus disproportionnés peuvent conjuguer leurs effets pour accroître la morbidité. Il est nécessaire de poursuivre les mesures de la composition corporelle, et les recherches préliminaires portent à croire qu'elles pourraient avoir d'importantes répercussions en nutrition.
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INTRODUCTION

For decades, measurement of body composition has been an important component of nutritional assessment. Various techniques have been used to obtain information beyond height and weight. Height and weight can give measures of mass, surface area, and a body mass index (BMI), but these do not provide differential information on the absolute or relative amounts of bone, lean tissue, and fat tissue. With newer imaging techniques for body composition measurement, fat and lean tissue type, amount, distribution, and change over time can be accurately quantified.

Methods of body composition measurement have developed over the years. Research studies in which imaging methodologies have been used highlight important associations between body composition and health and demonstrate the need for body composition to be measured routinely.

HOW HAS MEASUREMENT CHANGED?
Early approaches

Shen et al. (1) and Wang et al. (2) have written detailed chronological accounts of the history of body composition knowledge. Fundamental discoveries that have informed present-day measurement can be tracked back to the mid-1800s. In 1906, Magnus-Levy described the concept of fat-free mass (FFM) for the first time (1). This led to early representation of the human body as a two-compartment model of fat mass and FFM. In 1921, Matiegka developed an anthropometric model to estimate total body muscle mass (1).

Many of these early models were based on skinfold and circumference measurements. Skinfold calipers and tape measures are still very useful tools. For certain types of field studies or patient populations, they are often the only option for indirect body composition assessment. If they are used carefully, they can provide useful and reliable data.

Bioimpedance analysis

In 1943, Nyboer pioneered the use of tetrapolar bioimpedance analysis (BIA) (1). Bioimpedance analysis relies on the relationship between body composition and body water content. A very low electrical current is passed through the body, and estimates of fat and FFM are derived from

the resistance (or impedance) to this current. This method of analysis is now widely used throughout the world, particularly for field studies or multicentre patient studies in which an easily transportable, noninvasive method is required. Bioimpedance analysis has been validated in healthy adults and in some clinical populations, including patients with Crohn's disease, human immunodeficiency virus infection, or renal disease (3,4).

Hydrodensitometry

In the 1950s, hydrodensitometry was used in human research studies (1,5). Hydrodensitometry, or underwater weighing, provides an estimate of body composition from body density (body density = mass/volume). Thus, body volume must first be determined. This is calculated from the amount of fluid displaced by the body when a person is immersed in a tank of water. Body volume is equal to the "apparent loss of weight," corrected for by the density of the water at a given temperature.

More recently, air displacement plethysmography (ADP) has become commercially available in the form of the BOD POD® (Life Measurement, Inc., Concord, CA) (6). Air displacement plethysmography depends on the same measurement principles as hydrodensitometry: body density is equivalent to the ratio of its mass and volume (7). The term "plethysmography" refers to the measurement of size, in this case volume (8), which is determined by the air displaced by the body when a person sits inside the pod or chamber at a standard temperature.

Recent methods

An earlier version of dual energy X-ray absorptiometry (DXA), dual photon absorptiometry, was first described in 1963 and was used to measure whole-body composition in 1970 (1,9). Present-day DXA machines provide a simple and rapid method of quantifying bone mineral content, bone mineral density, and body composition (lean and fat mass) (Figure 1).

Figure 1
Dual energy X-ray absorptiometry machine

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Dual energy X-ray absorptiometry is rapidly becoming the method of choice for body composition research because it is precise and overcomes some disadvantages of other commonly used methods (10,11). The very low dose X-ray source produces two photon energies with different attenuation profiles to detect bone and soft tissue. The soft tissue can be further differentiated and quantified into lean and fat tissue, including both whole body and regional measurements. This method is noninvasive and safe, and the test takes approximately five minutes.

In 1973, Hounsfield reported the potential usefulness of computed tomography (CT) imaging in determining body composition (1,12); by 1979 CT was being used in research for this purpose (1,13). These events began a new era in our understanding of fat and muscle metabolism. Scanned cross-sectional images from CT can be specifically analyzed for muscle and fat tissue at specific body sites (Figure 2). The sum of serial cross-sectional scans can be used to calculate the volume and surface. Computer software such as sliceOmatic (TomoVision, Montreal, QC) allows the user to visualize and compute the anatomical volumes and surface of different tissues in CT, thereby permitting secondary analysis of electronically stored images. Computed tomography scans may also be available as part of the medical record.

Because of the higher radiation dosage of CT, research using this methodology is often done retrospectively, through patient files, or prospectively, when patients require a CT scan as part of standard treatment and monitoring. Similarly, imaging software can be used to assess body composition from stored MRI images. Today, CT and MRI are increasingly used in body composition research. Thus, significant changes have occurred over the past century, which have increased our capacity to measure and understand body composition, structure and function.

WHAT HAVE WE LEARNED?

One key factor that has become apparent through the use of these imaging measurement tools is that the population is heterogeneous in terms of body composition. The increasing prevalence of obesity has led to a much greater range in body fat, but we also cannot ignore what may be happening to muscle mass. The sedentary nature of our population has implications for muscle strength and function. A longer lifespan and the high prevalence of chronic disease are potential additive influences, which can lead to body composition abnormalities. Three situations or syndromes, discussed below, demonstrate these abnormalities, which include increased abdominal adipose tissue, sarcopenia, and sarcopenic obesity.
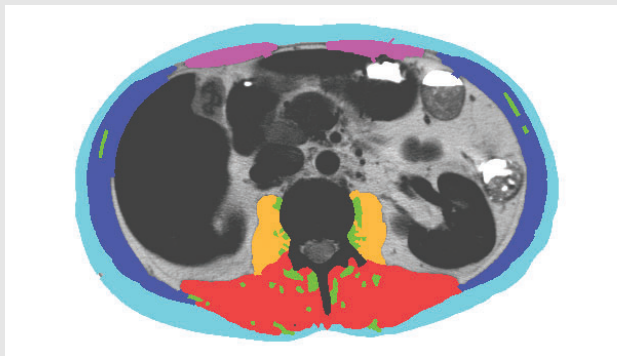
Abdominal adipose tissue

Fat distribution is widely accepted as a key measure of health risk. Health risks increase with increased waist circumference (WC) values specified as risk cut points for both males and females (14). Fat deposited more centrally (i.e., in an android distribution) is associated with increased risk of chronic disease. Imaging technology has shown that not all fat tissue is the same, and it is not distributed uniformly.

In earlier work from our research group (15), body

Figure 2
### Schematic of secondary analysis of a CT image to quantify abdominal adipose and muscle tissue

Light blue: subcutaneous AT   Red: paraspinal muscles
Green: intramuscular AT   Orange: psoas muscles
Light grey: visceral AT   Purple: rectus abdominus
Dark blue: transverse/oblique abdominal
AT = adipose tissue; CT = computed tomography
Four consecutive slices (6.5 mm thick x 4) starting from lumbar vertebra 3 (L3) were selected to measure muscle and AT. A single slice (6.5 mm thick) at L4-L5 was chosen to assess visceral adipose tissue (22).

Figure 3
### Abdominal MRI image in a female child (Case 1)
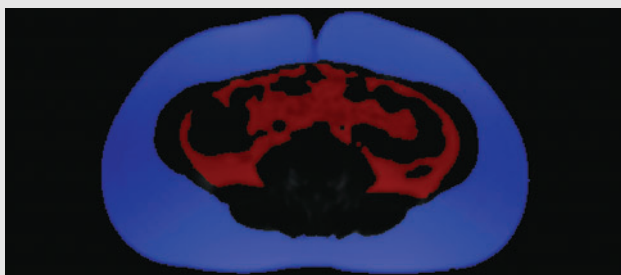
Blue: umbilical subcutaneous abdominal adipose tissue
Red: umbilical visceral adipose tissue
Figure reproduced by permission of G.D.C. Ball, University of Alberta (unpublished observations)

Figure 4
Abdominal MRI image in a female child (Case 2)

Blue: umbilical subcutaneous abdominal adipose tissue
Red: umbilical visceral adipose tissue
Figure reproduced by permission of G.D.C. Ball, University of Alberta (unpublished observations)

Figure 5
Abdominal CT image in a woman (BMI = 40.4), illustrating sarcopenic obesity (low muscle/high fat)*
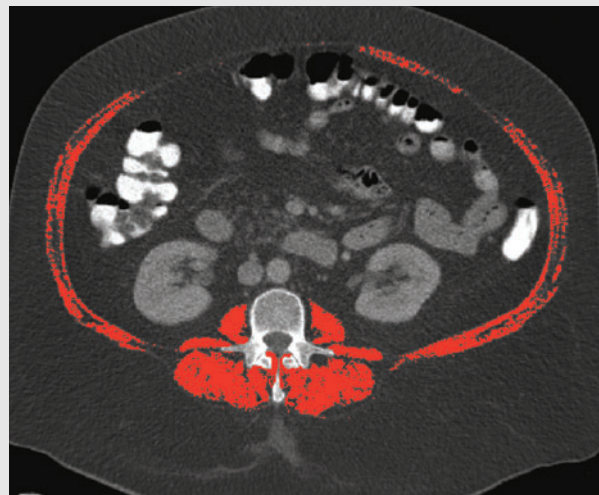
BMI = body mass index; CT = computed tomography

*Muscle (shown in red) at CT-L3 site cm^2/m^2 = 29.46

Data and figure reproduced by permission of V.E. Baracos, University of Alberta (unpublished observations)

Figure 6
Abdominal CT image in a man (BMI = 44), illustrating relatively normal musculature and fat for age*

BMI = body mass index; CT = computed tomography

*Muscle (shown in red) at CT-L3 site cm^2/m^2 = 89.78

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Table 1
Age and BMI characteristics in two preadolescent girls*

	Case 1	Case 2
Age (years)	10.4	10.1
BMI (kg/m²)	25.58	25.58
BMI percentile	97.38	97.31
BMI z-score	1.94	2.00

*Both girls were Caucasian and in the Tanner I stage of development.

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composition changes were investigated during the renourishment period of treatment for people with anorexia nervosa. Patients were concerned that the weight gain, in particular the fat gain, would be deposited centrally in the stomach area. Dual energy X-ray absorptiometry demonstrated that weight gain was widely distributed, and the gynoid-type fat distribution was maintained.

The use of CT and MRI has established that two types of fat tissue, visceral adipose tissue (VAT) and subcutaneous abdominal adipose tissue (SAAT), are deposited centrally in adults (16,17). Higher amounts of VAT are associated with features of the metabolic syndrome, such as insulin resistance, dyslipidemia, and high blood pressure (17,18).

Abdominal body fat has also become a significant concern in children (19,20). In Table 1, characteristics of two children are presented (G.D.C. Ball, University of Alberta, unpublished observations). Both were female and of similar ages, BMI, BMI percentile, BMI z-score, ethnicity, and stage of development. However, despite these similarities, Figures 3 and 4 and Table 2 show that they possess very dissimilar patterns of abdominal fat deposition. The child in Case 1 has more total VAT (by 25%; shown in red) and less total SAAT (by 20.6%; shown in blue) than the child in Case 2. As such, the first child is at greater risk of health problems related to the metabolic syndrome. Even at the young age of ten, differences in abdominal fat deposition are present.

Sarcopenia

Sarcopenia (sarco = muscle, penia = lack of) is a term that represents loss of muscle mass and strength. It is primarily studied in the elderly because of the muscle atrophy of aging; however, it is also being seen more frequently in younger people. Measurement of mid-arm circumference and calculation of arm muscle area may suggest muscle wasting; imaging technology can quantify it. Sarcopenia is associated with functional disability and frailty, and it has a negative impact on quality of life (21).

A retrospective study of patients with non-small-cell lung cancer was completed to investigate tissue change during the trajectory of cancer progression, treatment, and follow-up care (22). Electronically stored repeat CT scans (as required by standard care) of 45 patients were obtained for secondary imaging analysis of muscle and fat tissue at the lumbar vertebrae 3-5 site (L3-L5). The total sample comprised 23 men and 22 women, with a mean age (± standard deviation) of 60.9 ± 8.7 and a mean BMI of 26.5 ± 4.8. Most of the patients (73.3%) lost muscle tissue and some were in the sarcopenic range. However, some patients maintained or gained muscle mass. At the same time, approximately 50% of the group lost fat, while the other 50% maintained or gained fat mass (22). The notable results were that the tissue change was highly variable and that body composition was extremely heterogeneous in the group. Of particular concern was the group that lost muscle and gained fat. This body composition phenotype has been described as sarcopenic obesity.

Sarcopenic obesity

Sarcopenic obesity is an emerging health problem characterized by low muscle mass and high body fat. Body mass index and arm muscle area may act as screening measures for this syndrome, but DXA can quantify the muscle and fat tissue more accurately. Baumgartner et al. (23,24) used a specific index called appendicular skeletal mass (lean mass of arms and legs measured by DXA)/(height²) to develop cut points for sarcopenia (males: < 7.26 kg/m²; females: < 5.45 kg/m²). Obesity has been defined as being above the 60th percentile for the reference population (males: 28% body fat; females: 40% body fat). In this case, the reference population comprises people older than 60 (23,24).

Sarcopenic obesity and the elderly: The prevalence of sarcopenic obesity was estimated at 5% in the New Mexico Elder Health Survey (23), and at 5.8% in elderly subjects in the New Mexico Aging Process Study (24). Those with

Table 2
Comparative abdominal MRI results in two preadolescent girls with similar BMIs but different fat deposition patterns*

Result	Case 1	Case 2	Difference
UVAT (mL)	46.5	26.2	77.5% (1>2)
TVAT (L)	2.0	1.6	25.0% (1>2)
USAAT (mL)	117.1	224.6	91.8% (2>1)
TSAAT (L)	6.8	8.2	20.6% (2>1)

BMI = body mass index; MRI = magnetic resonance imaging; TSAAT= total subcutaneous abdominal adipose tissue); TVAT = total visceral adipose tissue; USAAT = umbilical subcutaneous abdominal adipose tissue (outlined in blue in Figures 3 and 4); UVAT = umbilical visceral adipose tissue (outlined in red in Figures 3 and 4)

*Case 1 in Figure 3 and Case 2 in Figure 4

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sarcopenic obesity were more likely to be male and more likely to have a decline in the instrumental activities of daily living (ADLs) score (hazard ratio 2.63) than were non-sarcopenic obese, non-sarcopenic non-obese, and sarcopenic non-obese people (24).

Sarcopenic obesity and breast cancer: Sarcopenic obesity has also been identified as a concern for breast cancer patients (25). Previously we investigated body composition changes during treatment for people with breast cancer. Weight gain during and after treatment was consistently reported in this population. Dual energy X-ray absorptiometry demonstrated that, even though weight was maintained, lean tissue decreased significantly (26). More recent studies have confirmed a unique pattern of weight gain often observed in breast cancer patients: usually fat gain with a loss or no change in lean tissue. A healthy diet and a combination of resistance and aerobic exercise have shown promise in preventing these body composition changes (25).

Sarcopenic obesity and colon cancer: The health impact of abnormal body composition was investigated further in patients with colon cancer (n=62) (27). Chemotherapy dosage is often based on the patient's body surface area (BSA). For example, the Mosteller formula for BSA $(m^2) = [height (cm) \times weight (kg)]/3,600]^{1/2}$. Thus, it is plausible that people with the same body mass, but very different levels of body fat and muscle, could metabolize drugs quite differently.

In this study, body composition was determined by retrospective CT image analysis of patients who had been previously monitored for chemotherapy toxicity symptoms. Lean body mass (LBM) was determined to be a significant predictor of toxicity symptoms, and the sex differences observed were likely partly due to women's lower LBM (27).

In a subsequent clinical study, Prado defined patients with sarcopenic obesity according to cut points from Baumgartner et al. (23,24). She found preliminary evidence that those with sarcopenic obesity have a greater risk of being partially or totally bedridden (according to a functional status question from the Patient-Generated Subjective Global Assessment) (28), and they have lower resting energy expenditure and lower protein intake than patients with the other body composition phenotypes (C. Prado, unpublished results).

Unknown factors: Many unknown factors remain about the etiology, health costs, and potential treatments for sarcopenic obesity. In Figures 5 and 6 (V.E. Baracos, University of Alberta, unpublished observations), both patients have a BMI above 40. The patient in Figure 5 demonstrates musculature that is approximately two standard deviations below the average for a person of the same age. The patient in Figure 6 has relatively normal musculature for his age. The impact of these differences is yet to be determined. Low muscle mass and high body fat may have a synergistic negative effect (insulin resistance, inflammatory cytokines) on physical health (29) and on functional capacity for ADLs (24). The role of nutritional factors requires further investigation.

RELEVANCE TO PRACTICE

Body composition can now be measured accurately with various tools and techniques. This is important because the population is heterogeneous in terms of fat deposition and muscle mass. The distribution, amount, and type of body fat are known to be key health indicators. In addition, the level of muscle mass is a key health indicator, and sarcopenic obesity is an emerging syndrome with significant health consequences.

Not only routine measures of height, weight, BMI, and WC, but also a measure of body composition should be included for nutritional assessment of individuals and groups. Skinfold and circumference measures and/or BIA are the most expedient forms of measurement for daily practice. For clinics, hospitals, or community health centres, ADP or DXA may be options. At present, secondary analysis of electronically stored CT/MRI images is primarily a method used for body composition research in academic settings. However, this methodology also offers an exciting new tool for practice-based research.

Recent discussions have been held within the dietetic profession about our preferred future. I would like to suggest a preferred future for body composition measurement. It would include:
- specialist body composition assessment training for students and dietitians.
- state-of-the-art equipment in dietetic work settings.
- increased capacity for research on body composition and health.
- enhanced partnerships with other disciplines interested in body composition.

In fact, this preferred future does not seem that far away!

Acknowledgements

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