Current body composition measurement techniques

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Purpose of review
The current article reviews the most innovative and precise, available methods for quantification of in-vivo human body composition.

Recent findings
Body composition measurement methods are continuously being perfected. Ongoing efforts involve multisegmental and multifrequency bioelectrical impedance analysis, quantitative magnetic resonance for total body water, fat, and lean tissue measurements, imaging to further define ectopic fat depots. Available techniques allow for the measurement of fat, fat-free mass, bone mineral content, total body water, extracellular water, total adipose tissue and its subdepots (visceral, subcutaneous, and intermuscular), skeletal muscle, select organs, and ectopic fat depots.

Summary
There is an ongoing need for methods that yield information on metabolic and biological functions. Based on the wide range of measurable properties, analytical methods and known body composition models, clinicians, and scientists can quantify a number of body components and with longitudinal assessment, can track changes in health and disease with implications for understanding efficacy of nutritional and clinical interventions, diagnosis, prevention, and treatment in clinical settings. With the greater need to understand precursors of health risk beginning prior to conception, a gap exists in appropriate in-vivo measurement methods with application beginning during gestation, that is, fetal development.

Keywords
assessment method, human, human phenotyping, *in vivo*

INTRODUCTION

Clinicians and researchers have long reported that individuals of the same age, height, and weight [thus, same BMI (kg/m^2)], can have different body shapes, body composition, energy requirements, and metabolic profiles. It is widely accepted that body composition can independently influence health. Body composition in aging is characterized by an increase in fat mass and decrease in lean tissues, including skeletal muscle mass which in older adults is related to reduced muscle strength and functional capability, as well as greater morbidity and mortality [1,2▪]. Increased fat mass, including in which the fat is distributed are considered important contributors to obesity-related health risk, including type 2 diabetes, cardiovascular disease, and mortality [3]. Elevated maternal glycemia during pregnancy is associated with increased offspring birth weight and risk of obesity in childhood [4]. However, influences of maternal body composition on offspring fat mass and fat-free mass (FFM) are still unclear, with some studies finding positive association with fat mass [5] and others with FFM [6]. There is a need for feasible and reliable body composition measurement methods applicable across the lifespan, for use at the individual level, in clinical research, and in epidemiologic studies. The relative importance of knowing the composition of the body greatly depends on the question of interest. The need to assess body composition commonly arises in investigations of obesity and malnutrition, weight loss composition following bariatric surgery, muscle wasting, sarcopenia, lipodystrophy, altered states of hydration, and osteopenia/osteoporosis. This review focuses on the latest and evolving technologies.

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KEY POINTS

- There are several available accurate techniques for the assessment of body composition both at the clinical and research level.
- There is no single technique that can be safely and widely used across the lifespan.
- A new technique that can be safely assess body composition across the lifespan and that can be easily reproduced at the clinical and research level needs to be developed.

BODY COMPOSITION MEASUREMENT METHODS

Bioimpedance

Bioimpedance (BIA) is a commonly used method for body composition assessments in clinical practice and research studies. Recent developments in BIA technologies involve systems that incorporate multiple frequencies (MF-BIA) and multiple body segments. It is a quick and simple to use technology, that measures total body water (TBW) (MF-BIA measures intracellular and extracellular water independently). FFM is estimated assuming a constant hydration of FFM of 73%.

A number of segmental MF-BIA devices are proposed for use in upright and supine positions, extending use to nonambulatory or bed-bound persons. BIA equations developed in a specific population are generalizable to similar populations only and caution is warranted when applying to a population different to the validation sample, to avoid misclassification of important conditions such as sarcopenia and cachexia [7]. The 8-electrode segmental system allows for independent assessment of limbs and trunk and has been reported to be more accurate than traditional wrist–ankle measurement [8].

One output from segmental MF-BIA devices is the resistive index, which can be used for estimation of limb lean mass as reported on in elderly participants [9]. A second output is the phase angle. Phase angle provides information on hydration status and cell mass. Phase angle is calculated from arctangent of the reactance-to-resistance ratio, with the advantage of being independent of equations and assumptions, unlike all other BIA output [10]. Phase angle is known to decrease with age and height and increase with greater FFM in men and women [11▪]. A low phase angle is associated with worse overall health outcomes, and it is associated with increased mortality risk in persons older than 65 years [10]. Low phase angle is associated with lower excess weight loss and less total weight loss at 12 months after surgery ($r = 0.3$ and 0.24, respectively, $P < 0.001$ for both) [12]. In a study involving older women (69 ± 6 years), resistance training for 12 weeks was associated with a 3.5% increase in phase angle and a 5.3% increase in appendicular soft lean tissue (ASLT), measured by dual-energy X-ray absorptiometry (DXA). After 12 weeks of 'detraining', there was no significant change in ASLT by DXA yet phase angle decreased by 7.6% (compared with posttraining values), suggesting that reduced levels of physical activity are associated with less favorable body composition outcomes, detectable before changes in body composition are detected by available assessment techniques [13].

Limitations of BIA include assumptions involving a fixed hydration. In clinical paradigms where hydration is altered, the use of BIA for body composition estimates is inaccurate. For instance, during pregnancy TBW increases by about 6 l, violating the 73% hydration standard [14]. One study reported that TBW estimates from BIA showed that women with uncomplicated pregnancies have a different hydration profile from women with early and late onset of preeclampsia [15]. Ellegard *et al.* [16] reported that MF-BIA overestimated TBW [compared with deuterium dilution (D_2O)] in women with overweight and obesity at 8–12 weeks postpartum, although accurately estimated changes in TBW after a 12-week lifestyle intervention.

In summary, although there is increased functionality of the most recently developed BIA technologies, BIA is not as yet a reference method due to reliance on specific assumptions, the most important being a constant hydration. The introduction of segmental and MF-BIA has greatly improved limitations related to differences across individuals in the length of limbs and trunk and differences in body shape.

Quantitative magnetic resonance

The quantitative magnetic resonance (QMR) EchoMRI system (Echo Medical, Houston, Texas, USA) ranks among the newer body composition techniques. The EchoMRI has been validated in adults (<250 kg) [17,18▪▪], the EchoMRI/Small, developed for small animals up to 50 kg, was validated in children 3–50 kg (2 weeks to 16 years old) [19], and the EchoMRI infants has been validated in infants from birth to 12 kg [20▪▪]. The measurement is acquired with the participant in a supine position and the measurement acquisition time is 2–4 min. This technique does not require the participant to be absolutely still, a significant advantage when

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assessing infants and children. The QMR output includes fat mass, lean mass, and TBW. Reported precision is high, with test–retest coefficient of variation for fat mass (0.5%) [17,18▪▪].

The first adult QMR validation study reported an underestimation in fat mass and an overestimation FFM compared with a 4-compartment model [18▪▪] but when authors simulated body composition changes by adding water or oil during the measurements, there were differences between QMR and 4-compartment results. In a study of adults, whereas QMR fat mass measurements were highly correlated with 4-compartment estimates, systematic differences were noted between the sexes [17]. The difference between the QMR and 4-compartment model was constant such that it was not dependent on the participant's fatness level. The latter is a positive finding as it suggests that the QMR may be capable of accurately assessing changes in fat under conditions of both weight loss and weight gain. In a study of healthy men (27 ± 4 years), after 1 week of overfeeding, body weight increased on average 1.8 ± 0.7 kg, and QMR measured increases in FFM and fat mass of 1.0 ± 0.6 and 0.8 ± 0.6 kg, respectively [21], indicating that QMR is able to detect changes in body composition in the presence of small body weight changes. Collectively, these studies reinforce Napolitano *et al.* [18▪▪] early conclusion that EchoMRI-QMR may be a technique more relevant for longitudinal body composition assessment rather than cross-sectional analyses, as single measurements are not as precise as the 4-compartment model, whereas the QMR is able to accurately measure changes in body composition over time.

The EchoMRI-QMR systems provide an estimate of TBW. The gold standard method for TBW assessment is D_2O, a stable isotope, which requires a fasting blood draw (saliva sampling is frequently employed in children), ingestion of the isotope, followed by an equilibration period and a second blood draw at 180 min. There has been one study that has reported on the accuracy of QMR-derived TBW estimates compared with TBW by D_2O [20▪▪], in which no differences were found between the two techniques for TBW in newborns (12–69 h postbirth).

Air displacement plethysmography

Air displacement plethysmography (ADP) measures body volume through air displacement inside a sealed chamber. This is a noninvasive and fast technique that does not require extensive training of technicians. The adult ADP requires participant cooperation to follow instructions. The infant ADP (PEA POD) has been validated in infants up to 6 months (or 8 kg). Currently, the PEA POD is the only commercially available technology that allows for accurate body composition assessment of newborns. The ADP has been validated for use in infants from birth to 8 kg (~6 months) and in children older than 5 years. However, there remains a gap for use in children from 6 months to about 5 years of age. Crook *et al.* [22▪] found that body fat percentage reported by the BodPod (COSMED, USA) (using a pediatric adapter seat) for children ages 3–5 years were inaccurate compared with deuterium oxide stable isotope dilution, whereas one study reported no statistical difference between percentage body fat by the ADP with pediatric attachment and percentage body fat measured by 4-compartment [23▪▪]. It is important to note that in the 4-compartment comparison study, of the 74 children enrolled, useable data were obtained on 31 (42%) only, indicating that, although results compared favorably with 4-compartment estimates of body fat percentage, the ADP is not well tolerated among children 1–5 years, thereby limiting its use.

A limitation of ADP is the assumption of a hydration constant for FFM. When FFM hydration violates the assumption, FFM might be underestimated or overestimated. If FFM is overhydrated (compared with the assumption), FFM density will be lower and, thus, FFM will be underestimated (and fat mass will be overestimated). If FFM is dehydrated, the opposite occurs. Indeed, underestimation of fat mass and overestimating FFM by ADP has been reported in male athletes [24,25] and overestimation of fat mass and underestimation of FFM has been reported in neonates [26].

Dual-energy X-ray absorptiometry

DXA is one of the most widely used techniques for body composition research. The advantages of DXA are its use across the entire age range and at relatively low-cost. A whole-body scan output provides values for fat, bone, and bone-free lean for each limb and the trunk. This is currently the only available technique that measures bone mineral density and content. Estimates of visceral adipose tissue (VAT) by DXA have been compared with VAT by MRI in a large cohort with DXA overestimating VAT in obese individuals, although high correlations and small mean differences were found between techniques [27▪,28], with the advantage of the rapid scan time and ability to scan persons with claustrophobia.

The limitations of DXA are the requirement of a certified radiology technician (or physician) to administer a test that involves a low dose of radiation. Accordingly, this technique is not suitable for pregnant women and, although safe, is not always accepted by parents for use in young children. A study

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in male cyclists showed that changes in muscle concentrations of glycogen and/or creatine resulted in erroneous readings of increased lean body mass by DXA as muscle hydration was altered [29].

MRI

MRI is the only available nonradiation technique that allows for the in-vivo quantification of total adipose tissue and its subdepots, subcutaneous, intramuscular, and VAT. MRI also allows for the quantification of important FFM components, skeletal muscle mass (arms, legs, and trunk), and specific organ mass. Organs such as heart, liver, and brain have high resting metabolic rates relative to their masses which is highly relevant to investigations of the effects of weight perturbations (gain and loss) on resting energy expenditure. MRI can also provide estimates of bone marrow adipose tissue [30].

Adults with type 2 diabetes whose body weight did not change over a 2-year period (-0.44 ± 0.60 kg) experienced a significant loss in skeletal muscle (by MRI) (1.2 ± 0.2 kg) [31▪▪]. Andersen *et al.* reported that, for patients with facioscapulohumeral muscular dystrophy type 1 (FSHD), a condition that is characterized by asymmetrical and progressive wasting of leg muscles, leg MRI was able to detect disease progression before the clinical test of functional outcomes (such as FSHD score, muscle strength by hand-held dynamometry, walking, or step-stair tests) [32]. A single slice cross-sectional area at mid-femur has also been proposed to be used in clinical practice for a fast and noninvasive diagnosis of sarcopenia in older adults [33].

Collectively, these studies highlight the increased sensitivity of MRI to assess regional or depot-specific tissues with relevance for prognosis of health outcomes. MRI is most valuable for clinical research studies due to its ability to quantify body compartments not measurable by any other technique, and allows for the assessment of change over time either through designed interventions (e.g., lifestyle, exercise, and drug therapy) or nonintervential longitudinal studies (e.g., growth, aging, and disease progression). Limitations of MRI include high cost to acquire the scan, specialized postprocessing software required for tissue volume analysis by a highly trained analyst, participant required to remain completely motionless during scan (making it difficult for young children) and not feasible for persons with claustrophobia.

NMR spectroscopy

NMR is a noninvasive technique and the standard noninvasive technique for measurement of intrahepatic lipid [34] and intramyocellular lipid (IMCL) and extramyocellular lipid (EMCL) in muscle fibers. NMR is a surrogate for liver biopsies to detect fat content in liver [35]. Physical activity and overall fitness have been associated with increased IMCL, whereas EMCL is increased in persons with overweight or obesity. Hasegawa *et al.* [36] found that increased EMCL and decreased IMCL in the vastus lateralis muscle are independently associated with arterial stiffness in adults.

PET/computed tomography, PET/MRI

In the PET, a tracer (usually 18F-fluorodeoxyglucose) is introduced in the body and accumulate in clusters of high glucose metabolism, that can be visualized in the PET scan [alone or, more commonly combined with computed tomography (CT)]. PET scans are used to identify highly metabolically active areas in the body. Recently, this technology (18F-fluorodeoxyglucose PET/CT) became the gold standard for detection of brown adipose tissue (BAT) depots in humans. Although the prevalence of BAT in humans is estimated to be very low (2–7%), studies found an inverse association between BAT and BMI in children and adults [37–40]. Thus, BAT has been proposed to be protective against obesity or obesity-related complications [39–42]. There is large interest in better understanding how to activate BAT, as well as how to induce transformation (or browning) of white adipose tissue (WAT) into BAT naturally or through the use of pharmacological therapies. Therefore, accurate and safe tools for assessing BAT are needed.

The biggest disadvantage of using PET–CT for BAT detection is the significant radiation dosimetry associated with the CT scans, coupled with the high cost. Recently, PET/MRI has been proposed as an alternative to PET/CT thereby avoiding ionizing radiation while allowing for studies in children, as well as repeated measurements in healthy children and adult populations [38]. Further, PET/MRI allows for discriminations of WAT and BAT in children, whereas differentiating active and nonactive BAT depots [37].

CONCLUSION AND FUTURE DIRECTIONS

A range of techniques are available to safely and accurately assess body composition in living humans from birth through senescence. Research efforts should concentrate on developing new or tailoring available techniques for simple, inexpensive, safe, and accurate assessments across the lifespan. Moreover, techniques should be accurate and adequate for use both at the cross-sectional level (that is, single measure) as well as for monitoring the effects of interventions (behavioral, pharmacological, and

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surgical) aimed at promoting a healthy weight and a healthy body composition include longitudinal measurement of changes in body weight.

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Conflicts of interest

There are no conflicts of interest.

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- ■ of special interest
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