American Society for Parenteral and Enteral Nutrition Clinical Guidelines: The Validity of Body Composition Assessment in Clinical Populations

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Abstract

On behalf of the American Society for Parenteral and Enteral Nutrition (ASPEN), a systematic review was conducted to evaluate the best available evidence regarding the validity of relevant body composition methods (eg, dual energy X-ray absorptiometry [DXA], ultrasound [US], and bioelectrical impedance analysis [BIA]) in clinical populations. The guidelines targeted adults >18 years of age with a potentially inflammatory condition or pathological end point associated with a specific disease or clinical condition. In total, 7375 studies were retrieved, and 15 DXA, 7 US, and 23 BIA studies provided applicable data. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses was used to assess the diagnostic accuracy of the test method against a "gold standard" reference. The Grading of Recommendations, Assessment, Development and Evaluation criteria were used to separate the evaluation of the body of evidence from the recommendations. Based on a limited number of studies and expert opinion, DXA is recommended for the assessment of fat mass in patients with a variety of disease states; however, the validity of DXA for lean mass assessment in any clinical population remains unknown. No recommendations can be made at this time to support the use of US or BIA in the clinical setting, as data to support its validity in any specific patient population are limited in scope or by the proprietary nature of manufacture-specific BIA regression models to procure body composition data, respectively. Directions for future research are provided. These clinical guidelines were approved by the ASPEN Board of Directors. (*JPEN J Parenter Enteral Nutr.* 2019;00:1–32)

Preliminary Remarks (Intent of Guidelines)

The most recent identification of criteria for the diagnosis of malnutrition proposed by the Global Leadership Initiative on Malnutrition emphasizes the importance of human body composition in the nutrition assessment of various patient populations.[1] Although not validated, these etiology-based guidelines highlight the influence of acute and chronic

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inflammation on alterations in body composition, underscoring their importance during nutrition assessment. The validity of specific body composition techniques is well established in a wide array of healthy populations[2]; however, for persons with acute or chronic illness, the validity of these methodologies is yet to be determined. Therefore, the intent of these guidelines is to provide the American Society for Parenteral and Enteral Nutrition (ASPEN) clinicians and researchers with practical, evidenced-based direction and recommendations on body composition assessment in various clinical populations.

Guideline Limitations

These ASPEN guidelines are based on general conclusions of health professionals who have examined the available literature focused on the diagnostic accuracy of the most common, clinically available methods for assessment of body composition (ie, dual energy x-ray absorptiometry [DXA], ultrasound [US], and bioelectrical impedance analyses [BIA]) and made recommendations for use in patient populations. This report is intended to be practical, applied, and translatable. As such, it does not address the use of other predominantly research-based techniques (eg, magnetic resonance imaging [MRI], neutron activation analysis) or techniques with limited accessibility (eg, air displacement plethysmography.) These tools are typically not readily available to most clinicians, are applied largely in a research setting, and require relatively sophisticated equipment. Additionally, any study that was technique oriented in nature, that is, comparing specific equipment against a gold standard or superior methodology in a healthy population, was excluded.

Definitions

Human body composition is an established yet still emerging field of science that explores the different distributions of lean mass (LM) versus adipose tissue and their impact on health. Despite advances in this field, human body composition research remains plagued by issues of nomenclature, in that specific compartments are often referred to in a multitude of ways, and these terms may not always be synonymous nor comparable. To address this, the body composition compartment being assessed/estimated (ie, molecular vs tissue levels) is referred to by technique (Table 1). The terminology within Table 1 refers to the central, 5-level organization model used in body composition research, which includes atomic, molecular, cellular, tissue organ, and whole body levels.[3]

Target Population for Guidelines

The target population of these guidelines are adults (≥18 years of age) with a potentially inflammatory

Table 1. Commonly Used Body Composition Terminology and Compartment Being Assessed.

Body Composition Compartment[a]	Description	Technique
Fat-free mass	Includes bone (lean tissue plus BMC)	BIA DXA
Lean soft tissue or LM[b]	Sum of all lean tissues includes protein, water, carbohydrates, nonfat lipids, soft tissue minerals (excludes bone)	DXA
Skeletal muscle mass	Primary component of lean tissue	US, CT, MRI
Fat mass	Lipid content, forms 80% of the adipose tissue compartment	BIA DXA
Adipose tissue	Formed by connective tissues (adipocytes, collagenous, and elastic fibers), fibroblasts and capillaries	US, CT, MRI

BIA, bioelectrical impedance analysis; BMC, bone mineral content; CT, computerized tomography; DXA, dual energy X-ray absorptiometry; LM, lean mass; MRI, magnetic resonance imaging; US, ultrasound.
[a]BIA estimates these compartments (vs direct measurement) as detailed in the BIA section.
[b]The term lean body mass is not specific and should no longer be used.

condition or pathological end point associated with a specific disease or clinical condition such as cancer, cardiovascular disease (CVD), cardiac failure, diabetes, hepatic or renal disease, human immunodeficiency virus, or possessing a condition that requires surgical intervention. The term "clinical population" is used in support of this concept, and studies may include persons who may or may not be in a hospital or clinical setting, yet they possess a pathological state (ie, a diagnosis). These guidelines are not intended for athletes, healthy volunteers, persons with obesity (if not linked to a clinical condition such as metabolic syndrome, hypertension, etc) or for a specific life cycle (eg, infants, children, adolescents, pregnant or postpartum women, or older adults).

Target Audience

The intended target audience of these guidelines includes clinicians or researchers involved in delivering acute or outpatient clinical care and/or conducting interventions with specific clinical populations in the community setting (eg, cancer survivors, persons with HIV)—primarily dietitians, nurses, pharmacists, physicians, or researchers in relevant biomedical fields. These guidelines do not constitute medical or other professional advice and should not be taken as

Table 2. Language for Guideline Recommendations.

Quality of Evidence	Weighing Risk vs Benefits	GRADE[a] Recommendations	Clinical Guideline Statement
High to very low	Net benefits outweigh harms	Strong	We recommend
High to very low	Trade-offs for patients or outcomes are important	Weak	We suggest
High to very low	Uncertain trade-offs	Further research needed	We cannot make a recommendation at this time

GRADE, grading of recommendations, assessment, development, and evaluation.
[a]Refer to Druyan et al[4] for a more detailed description of the GRADE system.

such. To the extent that the information published herein may be used to assist in the care of patients, this is the result of the sole professional judgment of the attending healthcare professional whose judgment is the primary component of quality medical care. The information presented in these guidelines is not a substitute for the exercise of such judgment by the healthcare professional. Circumstances in clinical settings and patient indications may require actions different from those recommended in this document, and in those cases, the judgment of the treating professional should prevail.

Methods

All ASPEN guidelines since 2011 have centered on key questions, planned data acquisition, and conflation (ie, merging) of their findings by reviewing pertinent randomized clinical trials (RCTs) and/or observational studies that addressed the focus area and relied on the Grading of Recommendations, Assessment, Development and Evaluation (GRADE) approach.[4] Previous guidelines employed GRADE and converged specific data points from RCTs and/or observational studies to guide their recommendations. The current guideline did not limit potential data points to specific study designs. Rather, studies evaluating the validity of the body composition methodologies in question (ie, DXA, US, and BIA) were included. To assess the validity, the diagnostic accuracy of the tool was assessed, which requires comparison of the test method against a "gold standard" reference (eg, DXA vs computed tomography [CT], respectively). Recently, McInnes et al[5] described the preferred reporting process that should be included in systematic reviews and meta-analyses of diagnostic test accuracy guidelines. These recommendations were used to guide question development and to evaluate the risk of bias and assessment of diagnostic accuracy of eligible studies. The GRADE methodology for standard language and the separation of the evaluation of the body of evidence from the statements of recommendations have been maintained in this guideline. The criteria for grading the evidence for each question was based on the McInnes et al[5] methods

for diagnostic test accuracy rather than those described in GRADE for RCTs and observational studies.

The task force of experts began by defining keywords used for the literature search. This was followed by development of key questions most relevant to this area of clinical practice and research and determining the database, timeframe for the literature search, target populations, and the specific outcomes to be addressed. The task force focused on the validity of body composition techniques most frequently utilized in patient populations, including DXA, BIA, and US. No study designs were excluded, provided validity end points and comparison against a "gold standard" were included. The GRADE process distinctly separated the body of evidence from the recommendation statements. This enabled incorporation of the weight of risks vs benefits that occur from adopting the recommendation. Thus, a recommendation may be "strong" despite comparatively weak published evidence if the net benefits outweigh the harms from its adoption. Recommendations based mainly on expert opinion were deemed weak. Table 2 describes the standard language and rationale for the GRADE assigned to a recommendation.

To qualify for the initial inclusion, studies that target clinical populations had to include DXA, BIA, or US and use a superior (ie, more precise) body composition modality as the comparator. For DXA, this could include comparisons to CT, MRI, or multicompartment models. For US, this could include comparisons to DXA, CT, MRI, or multicompartment models. For BIA, this could include DXA, CT, MRI, or multicompartment models. Studies using anthropometric measurements (eg, waist circumference, triceps skinfolds) were not included since these are considered surrogate measures of body composition. A standardized data abstraction form (DAF) was developed based on the GRADE approach and was modified to reflect the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methods for diagnostic accuracy tests. Articles selected for inclusion were independently reviewed by 2 task force members using the DAF. Results of the DAF were compared, differences were resolved by consensus, and a final DAF was created for each article.

Table 3. Clinical Guideline Recommendations for Body Composition Assessment using DXA, US, and BIA in Adult Clinical Populations.

Question	Recommendation	GRADE
1. Is dual energy x-ray absorptiometry a valid method of assessing body composition in various clinical populations?	Based on the correlation coefficients across studies and using different devices, DXA appears to be a reasonably valid method to assess regional and total fat mass in a wide group of adult clinical patients. We recommend the use of DXA for assessing fat mass in patients with clinical conditions. No studies explored the validity of DXA for LM assessment in any clinical population; thus, its use for this compartment remains unknown	Quality of evidence: low grade Recommendation: strong
2. Is ultrasound a valid method of assessing body composition in various clinical populations?	No recommendation can be made at this time to support the use of US in a clinical setting for assessing body composition. There are no data to support its validity in specific patient populations	Quality of evidence: very low grade Recommendation: weak
3. Is bioelectrical impedance a valid method of assessing body composition in various clinical populations?	No recommendations can be made regarding the validity of using BIA in clinical populations. Due to the proprietary nature of manufacturer-specific BIA regression models to procure body composition data, it is not possible to compare studies using different BIA devices. Furthermore, because of the variability of body compartments estimated within studies, it was not possible to conflate these data by manufacturer to support summary correlations and forest plots	Quality of evidence: low grade Recommendation: weak

BIA, bioelectrical impedance; DXA, dual energy x-ray absorptiometry; GRADE, grading of recommendations, assessment, development and evaluation; LM, lean mass; US, ultrasound.

Ultimately, 3 questions were developed for DXA, BIA, and US, which were reviewed and approved by ASPEN Board of Directors. These questions and recommendations are summarized in Table 3.

A rigorous MEDLINE database search was performed spanning January 2000 through October 2018 for each question using the MEDLINE portion of the techniques, as described by McKeever et al.[6] Filtering for validation studies, Medical Subject Heading (MeSH) folders for "Absorptiometry, Photon," "Ultrasonography," and "Electric Impedance" were searched to discover citations relevant to DXA, US, and BIA questions respectively. To meet the search criteria, citations in these folders had to be indexed in the MeSH folders for "Anthropometry," "Body Constitution," "Muscle Strength," or "Nutrition Assessment." They also had to be cross-referenced in MeSH folders for "Adults" and "Humans." To protect against miscataloged citations, the MEDLINE search was repeated using text-based search terms restricted to the title or abstract of the article. These were performed as follows.

For DXA citations, inclusion in the text-based search results required the title or abstract to contain at least 1 term each from Group 1 and Group 3, which were filtered for validation studies. Alternatively, they could contain at least 1 term each from Group 1 and Group 2, unfiltered for validation studies.

> Group 1: "DXA," "absorptiometry," "absorptiometer," and "DEXA scan"
> Group 2: "fat," "adipose," "lean," "muscle," "body composition," "height," "densitometry," and "photodensitometry"
> Group 3: "tomography," "CT scan," "CT-scan," "tomodensitometry," "Cine-CT," ("4-compartment,""4 compartment," "four compartment," and "four-compartment")

For US citations, inclusion in our text-based search results required the title or abstract to contain at least 1 term from each the following 2 groups:

> Group 4: "Sonography," "Ultrasonography," "Ultrasound," "Ultra-sound," "ultra sound," "ultrasonic," "echography," and "echotomography"
> Group 5: AND ("percent body fat," "% body fat," "percent adipose tissue," "percent adiposity," "% adipose tissue," "% adiposity," "muscle volume," "muscle thickness," "skeletal mass," "muscle mass," "skeletal muscle index," "SMI," "intraabdominal

fat," "intra-abdominal fat," "intraabdominal adipose," "intra-abdominal adipose," "intramuscular fat," "intra-muscular fat," "intramuscular adipose," "intramuscular adiposity," "subcutaneous fat," "subcutaneous adipose," "subcutaneous adiposity," "visceral adipose," "visceral adiposity," and "body composition"

For BIA citations, inclusion in our text-based search results required the title or abstract to contain at least 1 term from each the following 2 groups:

Group 6: "BIA," "Bioimpedance," "Bioelectrical impedance," "Bioelectric impedance," "phase angle," "electric resistance," "electrical resistance," and "ohmic resistance"

Group 7: "fat," "adipose," "lean," "muscle," "body composition," and "height"

Results

A total of 7375 studies were retrieved from Medline: 1361 for DXA; 2867 for US, and 3147 for BIA. Of these, 862 studies met the initial search criteria, and upon further review, 709 studies were eliminated for reasons including they were conducted in healthy populations, there were no validity data provided, only 1 body composition assessment method was used, and/or the comparator method was inferior (eg, anthropometrics). Based on the volume of studies that needed to be screened, requested, and fully read for inclusion prior to data abstraction, only 1 search engine was used. DAFs were completed on 153 initial studies. Based on the requirements of PRISMA, only studies that included correlation analyses (eg, Pearson, Spearman, Lin's, etc) were evaluated, leaving 15 DXA, 7 US, and 23 BIA studies for potential statistical analyses. After review of the abstracted data, evidence tables were generated for each question. Based on the evidence tables, an iterative process was used to develop practical recommendations for each question using the GRADE methodology, where applicable, and by consensus. The recommendations are summarized in Table 3. Tables 4–6 summarize the evidence related to each guideline question by specific body composition methodology. Each section is followed by a discussion on the rationale for the recommendation(s) and suggested areas for future investigation for the question(s).

Introduction

Clinicians face an ever-growing challenge in the general nutrition assessment of their patients, as 35%–40% of these individuals have obesity at the time of evaluation.[7] Many investigators have now demonstrated great variability in body composition, emphasizing not only the crude nature of body mass index but also the limitations of assessing simple body weight.[8-12] The study of human body composition is a science that looks beyond a unit of body weight, accounting for the distribution and proportion of LM vs adipose tissues with specific links to health outcomes. As such, human body composition assessment is of increasing interest to clinicians, who are now pressed to familiarize themselves with the language and application of different methods.[13]

Body composition has been most extensively studied in oncology populations because of the exploitation of CT imaging completed for diagnostic and surveillance purposes. Several investigators have demonstrated that depleted LM is associated with treatment toxicity and/or decreased survival in patients with breast,[14,15] colorectal,[16,17] renal,[18-20] thyroid,[21] and pancreatic[22] cancers. However, the detection of abnormal body composition has broad applications to other chronic disease populations, including patients with hepatic disease,[23,24] pulmonary disease,[25,26] cardiac failure[27] and other cardiovascular conditions,[28] rheumatoid arthritis,[29] and renal disease,[30] among others. This rapidly expanding body of work reflects the clinical appreciation that compromised LM is no longer a condition restricted to aging or older adults.

Unfortunately, current bedside nutrition assessment techniques do not possess the requisite sensitivity and specificity to detect LM abnormalities,[31] especially in patients with obesity.[26,32] Direct measurements of body composition are now considered fundamental for an in-depth evaluation of nutrition status.[33] Evaluating the validity of these techniques in clinical populations is fundamental to advancing this field and to elucidating how nutrition support or other nutrition interventions can influence body composition and associated outcomes.

Question 1: Is DXA a valid method of assessing body composition in various clinical populations?

Recommendation

Based on correlation coefficients across studies and using different devices, DXA appears to be a reasonably valid methodology to assess regional and total fat mass (FM) in a heterogeneous group of adult patients. The use of DXA is recommended for assessment of FM in patients with a specific disease or clinical outcome. No studies were found that reported the validity of DXA for LM assessment in any patient population; thus, the value of its use for this compartment remains unknown.

Quality of the Evidence: Low
GRADE Recommendation: Strong

Rationale

Fifteen studies utilizing DXA and a superior comparator method were used to provide potentially evaluable data for

Table 4. Studies Used to Examine the Validity of DXA in Various Clinical Populations.[a]

Reference	Stated Study Aims	Population (n), Eligibility	Devices	Areas of Interest	Comments
Anjana et al, 2004	To examine body fat distribution using CT, DXA, and anthropometry in relation to type 2 diabetes in urban Asian Indians	N = 82 persons with type 2 diabetes N = 82 age-matched and sex-matched controls without type 2 diabetes BMI range = 18.5–29.99 kg/m^2 Age: 45 ± 9 y	DXA (Lunar Prodigy) vs CT (Helical CT scan)	CAF (DXA) vs VAT (MRI)	Body composition tests completed on the same day for most participants Pearson correlations reported CAF (DXA) vs VAT (CT): r = 0.691, $P < 0.0001$ in healthy controls CAF (DXA) vs VAT (CT): r = 0.520, $P < 0.0001$ in persons with diabetes
Baker et al, 2012	To determine whether analysis of a single abdominal axial slice by MRI would allow estimation of FFM ALTMI by DXA	N = 31 women N = 18 men 4 participants had diabetes mellitus BMI: 37.9 ± 0.9 kg/m^2 (mean ± SD) Age: 48.8 ± 1.5 y	DXA (DPX-L) vs CT (Siemens Magnetom TrioTim 3-Tesla)	FFM area (DXA) vs SM area (MRI) ALTMI area (DXA) vs SM area (MRI)	Body composition tests completed on the same day Pearson correlations reported There were significant correlations between FFM area (DXA) vs SM area (MRI) and ALTMI area (DXA) and SM area (MRI) (P-values < 0.0001)
Bredella et al, 2010	To determine the use of DXA in persons of different weights using CT as a standard of reference To investigate the agreement between CT and DXA for measuring abdominal fat, thigh muscle mass, and thigh fat in 3 groups of premenopausal women: normal weight, obese, and in those with AN	N = 18 normal weight N = 34 overweight or obese N = 39 AN BMI range = 13.3–42.0 kg/m^2 Age: 33 ± 8.3 y	DXA (Hologic) vs CT (Not specified)	Trunk fat (DXA) vs VAT (CT) Leg fat (DXA) vs thigh fat (CT) Leg LSTM (DXA) vs thigh muscle area (CT)	Time between body composition tests not specified Pearson correlations reported There were significant correlations between trunk fat (DXA) vs VAT (CT), leg fat (DXA) vs thigh fat (CT), and leg LSTM (DXA) vs thigh muscle area (CT) in normal weight, overweight, or obese and for persons with AN (all P-values < 0.0001)

(*continued*)

Table 4. (continued)

Reference	Stated Study Aims	Population (n), Eligibility	Devices	Areas of Interest	Comments
Deschenes et al, 2003	To compare the relative importance of CT-measured abdominal adiposity compartment areas, including adipose tissue located posterior to the subcutaneous fascia, in predicting plasma lipid-lipoprotein alterations	N = 66 women included in a larger study on adipose tissue metabolism BMI range = 18.4–39.4 kg/m^2 Age: 47.2 ± 5.5 y	DXA (Hologic QDR-2000) versus CT (GE Light Speed 1.1)	FM (DXA) vs TAAT, TSAT, SSAT, VAT (CT) Lipoprotein parameters vs VAT (CT)	Body composition tests completed on the same day Spearman correlations reported There were significant correlations between FM (DXA) vs TAAT (CT), FM (DXA) vs TSAT (CT), FM (DXA) vs SSAT (CT), and FM (DXA) vs VAT (CT) (all *P*-values < 0.0001) There were significant correlations between total cholesterol, total triglycerides, total ApoB, VLDL cholesterol, VLDL triglycerides, ApoB, LDL cholesterol, LDL triglycerides, and LDL ApoB vs VAT (CT) (all *P*-values < 0.0001) There were significant correlations between HDL cholesterol (*P* = 0.02), HDL triglcerides (*P* = 0.002), HDL2/HDL3 (*P* = 0.0008), Cholesterol/HDL cholesterol (*P* = 0.0002), and LDL/HDL cholesterol (*P* = 0.0003 vs VAT [CT])
Elisha et al, 2013	To investigate the ability of the BAI to detect changes in % BF levels before and after a weight loss intervention when compared with % BF levels measured using DXA and to examine the relationship between BAI with cardiometabolic risk factors	N = 132 postmenopausal women BMI: 35.0 ± 3.7 kg/m^2 (mean ± SD) Age: 57.2 ± 4.7 y	DXA (GE Lunar) vs CT (High Speed Advantage)	% BF (DXA) vs VAT (CT) % BF vs lipoproteins, CRP, blood pressure, leptin, and insulin sensitivity	Length of time between body composition testing highly variable Pearson correlations reported There were significant correlations between % BF (DXA) and VAT (CT) and % BF (DXA) and change in leptin. All other CC were insignificant

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Table 4. (continued)

Reference	Stated Study Aims	Population (n), Eligibility	Devices	Areas of Interest	Comments
Ganpule-Rao et al, 2013	To report a comparative analysis of different trunk fat measurements predicting glycemia, IR, and β cell function in middle aged Indian men	N = 128 men included in the CRISIS study BMI (median): 21.3 kg/m^2 Age (median): 39.0 y	DXA (Lunar DPX-IQ 240) vs MRI (1 Tesla Imaging Device)	TF (DXA) vs anterior SAT, posterior SAT SAT, VAT (MRI) Trunk fat (DXA) vs anterior SAT, posterior SAT SAT, VAT (MRI) Glucose: 120 min glucose, IS, and insulin index vs Trunk fat and TF (DXA) Glucose: 120 min glucose, IS, and Insulin index vs SAT, VAT, anterior SAT, posterior SAT (MRI)	Body composition tests completed after an overnight fast and stay at the Research Center Pearson correlations reported There were significant correlations between TF and trunk fat (DXA) vs SAT, VAT, anterior SAT, and posterior SAT (MRI) (all P-values < 0.01) There were insignificant correlations between glucose vs SAT and anterior SAT (MRI) There were significant correlations between glucose vs TF, trunk fat (DXA), and posterior SAT and VAT (all P-values < 0.01) There were significant correlations between 120 min glucose vs TF and trunk fat (DXA) and SAT, anterior SAT, posterior SAT, and VAT (MRI) (all P-values < 0.01) There were significant correlations between IS vs TF and trunk fat (DXA) and SAT, anterior SAT, posterior SAT, and VAT (MRI) (all P values < 0.01) There were insignificant correlations between insulin index vs SAT, anterior SAT, posterior SAT, and VAT (MRI) There were significant correlations between insulin index vs TF and trunk fat (DXA) (all P-values < 0.01)

Table 4. (continued)

Reference	Stated Study Aims	Population (n), Eligibility	Devices	Areas of Interest	Comments
Giusto et al, 2015[103]	To verify the concordance between muscle wasting, determined by CT scan with other techniques providing muscle mass measurements, such as DXA and anthropometry, or functions using the Hand Grip test. To evaluate the correlation between muscle wasting, liver impairment, and survival	N = 46 men BMI: 25.1 kg/m² (range 17.2–35.0) N = 13 women BMI: 24.7 kg/m² (range 21–29) with liver cirrhosis being considered for liver transplant Age: 59 y (median; range 26–68y)	DXA (Lunar Prodigy Advance) vs CT (Leonardo Syngo)	FFMI, ASMI (DXA) vs SMI (CT)	Length of time between body composition testing not specified Kendall's τ statistic used for correlations There were significant correlations between FFMI (DXA) vs SMI (CT) for men (P < 0.0001) and women (P = 0.01) and between ASMI (DXA) vs SMI (CT) for men (P = 0.0002) and women (P = 0.006)
Gonzalez et al, 2007[104]	To investigate which anthropometric parameters or imaging techniques are the best determinants of the metabolic syndrome and whether DXA alone or combined with anthropometry is a good alternative to CT in predicting VAT	N = 119 men N = 280 women with overweight/obesity BMI only reported by metabolic syndrome strata Age: 38.3 ± 16.0 y	DXA (Lunar DPX) vs CT (Siemens HIQ System)	TF (DXA) vs TF, SAT, VAT (CT) AF (DXA) vs TF, SAT, VAT (CT) SF (DXA) vs TF, SAT, VAT (CT)	Time between body composition tests not stated Spearman correlations reported There were significant correlations between TF, AF (DXA), and TF, AF, and SF (CT) (all P-values < 0.005) There was an insignificant correlation between SF (DXA) and VAT (CT) (P = 0.126)
Greenfield et al, 2002	To estimate the intrasubject variability in AF compartments, particularly IAF, comparing results from 4 adjacent anatomical sites using CT To determine whether the variability follows a similar pattern in all subjects	N = 19 premenopausal women; 9 women had type 1 diabetes mellitus BMI: 24.9 ± 1.0 kg/m² (mean ± SD) Age: 35.3 ± 1.4 y	DXA (Lunar DPX-L) vs CT (Sytec 3000 scanner)	% BF (DXA) vs IAF/SAF (CT)	Time between body composition tests not stated Spearman correlations reported There was a significant correlation between % BF (DXA) vs IAF/SAF (CT) (P = 0.01)

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Table 4. (continued)

Reference	Stated Study Aims	Population (n), Eligibility	Devices	Areas of Interest	Comments
Karelis et al, 2012	To examine the ability of the Bertin index to detect changes in VAT levels before and after a weight loss intervention when compared with VAT levels measured using a CT scan. To determine if both measures of VAT have comparable associations with cardiometabolic risk factors in a population at increased risk for developing metabolic complications	N = 92 sedentary, overweight/obese postmenopausal women. BMI: range 26.1–45.8 kg/m². Age: 58.1 ± 4.7 y	DXA (not specified) vs CT (GE High Speed Advantage)	FM (DXA) vs VAT (CT). LM (DXA) vs VAT (CT). FM (DXA) vs lipoproteins, CRP, blood pressure, and insulin. LM (DXA) vs lipoproteins, CRP, blood pressure, and insulin	Time between body composition tests not stated. Pearson correlations reported. There were significant correlations between FM (DXA) vs VAT (CT) ($P < 0.01$) and LM (DXA) vs VAT (CT) ($P < 0.01$). There were significant correlations between HDL cholesterol, triglycerides, glucose, insulin, and CRP vs VAT (CT) (all P-values < 0.05). There were insignificant correlations between total LDL cholesterol and blood pressure vs VAT (CT)
Miljkovic et al, 2013	To determine if abdominal muscle myosteatosis is related to glucose, insulin, and IR	N = 393 included in the MrOS study. BMI: 26.6 ± 3.0 kg/m² (mean ± SD). Age: 74.3 ± 5.9 y	DXA (Hologic QDR 4) vs CT (variable across sites)	% BF (DXA) vs VAT (area), SAT (area), abdominal muscle IMAT (area), paraspinal IMAT (area), and psoas IMAT (area) (CT) (baseline only)	Time between body composition cholesterol, tests not stated. Spearman correlations reported. There were significant correlations between % BF (DXA) and VAT (area), SAT (area), abdominal muscle IMAT (area), paraspinal IMAT (area), and psoas IMAT (area) (CT) (all P-values < 0.0001)
Mourtzakis et al, 2008[105]	To evaluate regional CT images acquired during routine patient care as a potential resource to discriminate and to quantify important and distinct features of the body composition of patients with advanced cancer. To compare estimates of whole body composition obtained by CT with those obtained by DXA	N = 30 men. N = 21 women with locally advanced or metastatic non-small cell lung or colorectal cancer. BMI: 26.9 ± 6.2 kg/m² (mean ± SD). Age: 63 ± 10 y	DXA (Lunar Prodigy High Speed Digital Fan Beam) vs CT (not specified)	L3 adipose tissue (kg), whole body FM (kg), L3 FFM, whole body FFM, ASMM (DXA) vs adipose tissue (cm²), fat-free tissue (cm²), SM (cm²) (CT)	Time between body composition tests not stated; however, DXA testing was scheduled to coincide with CT imaging. Pearson correlations reported. There were significant correlations between L3 FM and whole body FM (DXA) vs L3 fat tissue (cm²) (CT) (P-values < 0.001). There were significant correlations between L3 FFM and whole body FFM (DXA) vs L3 fat-free tissue (cm²) (CT) (P-values < 0.001). There were significant correlations between whole body FFM and ASMM (DXA) vs skeletal muscle (cm²) (CT) (P-values < 0.001)

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Table 4. (continued)

Reference	Stated Study Aims	Population (n), Eligibility	Devices	Areas of Interest	Comments
Olarescu et al, 2014[106]	To compare the degree of agreement between measurements of VAT by DXA and by CT obtained longitudinally in a population of patients with PWS undergoing treatment with GH To investigate whether VAT estimations by these 2 methods have equivalent associations with metabolic risk factors in this population	N = 6 men N = 8 women in adult persons with PWS BMI: 33 kg/m^2 (range 23–45) Age: 29 y (mean; range 21–39 y)	DXA (GE Health-care Lunar Prodigy) vs CT (Phillips Extended Brilliance)	SAT, VAT (DXA) vs SAT, VAT (CT) VAT (DXA) vs lipoproteins, glucose, insulin, adiponectin, leptin, triglycerides, SBP, and DBP VAT (CT) vs lipoproteins, glucose, insulin, adiponectin, leptin, triglycerides, SBP, and DBP (baseline only)	Time between body composition tests not stated Pearson and Spearman correlations reported There were significant correlations between VAT (DXA) vs VAT (CT) ($P < 0.001$) and SAT (DXA) vs VAT (CT) ($P \leq 0.01$) There were significant correlations between insulin, adiponectin, triglycerides, SBP and DBP and VAT (CT) (all P-values < 0.05) There were insignificant correlations between glucose, leptin, total cholesterol, HDL, and LDL cholesterol vs VAT (CAT) There were significant correlations between insulin, adiponectin, triglycerides, SBP and DBP and VAT (CT) (all P values < 0.05) There were insignificant correlations between glucose, leptin, total cholesterol, HDL, and LDL cholesterol vs VAT (DXA)

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Table 4. (continued)

Reference	Stated Study Aims	Population (n), Eligibility	Devices	Areas of Interest	Comments
Scherzer et al, 2008	To compare regional adipose tissue quantified by both DXA and MRI in a large, nationally representative, multiethnic cohort of men and women with HIV+	N = 625 men with HIV+ BMI: 24.2 (22.1–26.4), mean (IQR) kg/m^2 Age: 43.0 y (median; range 37.0–48.0 y) N = 135 control men without HIV+ BMI: 26.7 (24.5–30.1) kg/m^2, mean (IQR) Age: 40.0 y (median; range 38.0–38.0 y) N = 252 women with HIV+ BMI: 25.8 (22.0–30.5) kg/m^2, mean (IQR) Age: 41.0 y (median; range 36.0–47.0y) N = 125 control women without HIV+ BMI: 27.6 (23.0–33.1) kg/m^2, mean (IQR) Age: 42.0 y (median; range 38.0–44.0 y)	DXA (GE Prodigy, DPX, DPX-IQ, and DPX-L and Hologic QDR 2000 [pencil beam] and 4500 [fan beam] vs MRI (not specified)	Trunk, leg, arm, and TF (DXA) vs trunk, leg, arm, and TF (MRI)	Most tests completed on the same day, some within the same week Spearman correlations reported There were significant correlations between trunk, leg, arm, and TF (DXA) vs trunk, leg, arm, and TF (MRI) for men with HIV+ and men without HIV+ (all P-values < 0.0001) There were significant correlations between trunk, leg, arm, and TF (DXA) vs trunk, leg, arm, and TF (MRI) for women with HIV+ and women without HIV+ (all P-values < 0.0001).

(continued)

Table 4. (continued)

Reference	Stated Study Aims	Population (n), Eligibility	Devices	Areas of Interest	Comments
Smith et al, 2001	To describe the radiographic anatomy of the abdominal SAT as it relates to gender and adiposity To relate these anatomically discrete compartments to metabolic risk factors in both men and women	N = 103 men Age: 40.8 ± 13.7 y N = 96 women Age: 41.5 ± 11.7 y Available CT and DXA imaging dictated inclusion BMI not reported	DXA (Hologic QDR 2000) vs CT (GE High Speed)	BF (DXA) vs TAT, VAT, DSAT, and SSAT (CT) Lipoproteins, triglycerides, insulin, blood pressure vs BF (DXA), TAT, VAT, DSAT, and SSAT (CT)	Testing had to be completed within 4 weeks of one another Pearson correlations reported Among females: There were significant associations between BF (DXA) and VAT, DSAT, SSAT, and SAT (CT) (all P-values < 0.01) There were significant associations between triglycerides, insulin, and BF (DXA), VAT, DSAT, SSAT, SAT (CT) (all P-values ≤ 0.05) There were significant associations between SBP and BF (DXA), VAT, SSAT, SAT (CT) (all P-values ≤ 0.05) There were significant associations between DBP and VAT, DSAT, SSAT, SAT (CT) (all P-values ≤ 0.05) There were significant associations between HDL cholesterol and VAT (CT) (P ≤ 0.01) Among males: There were significant associations between BF (DXA) and VAT, DSAT, SSAT, and SAT (CT) (all P-values < 0.01) There were significant associations between HDL cholesterol, triglycerides, insulin, and DBP vs BF (DXA), VAT, DSAT, SSAT, SAT (CT) (all P-values ≤ 0.05) SBP was only significantly associated with VAT (CT) (P ≤ 0.05)

AF, abdominal fat; ALTMI, appendicular lean tissue mass index; AN, anorexia nervosa; ASMI, appendicular skeletal muscle index; ASMM, appendicular skeletal muscle mass; BAI, body adiposity index; BF, body fat; BMI, body mass index; CAF, central abdominal fat; CC, correlation coefficient; CRP, C-reactive protein; CT, computed tomography; DBP, diastolic blood pressure; DSAT, deep subcutaneous adipose tissue; DXA, dual energy x-ray absorptiometry; FFM, fat-free mass; FFMI, fat-free mass index; FM, fat mass; GE, General Electric; HDL, high density lipoprotein; IAF, intraabdominal fat; IMAT, intermuscular adipose tissue; IR, insulin resistance; IS, insulin sensitivity; LSTM, lean soft tissue mass; LTMI, lean tissue mass index; MRI, magnetic resonance imaging; PWS, Prader–Willi syndrome; SAF, subcutaneous abdominal fat; SAT, subcutaneous adipose tissue; SBP, systolic blood pressure; SD, standard deviation; SF, subcutaneous fat; SSAT, superficial subcutaneous adipose tissue; TAAT, total abdominal adipose tissue; TAT, total adipose tissue; TF, total fat; TSAT, total subcutaneous adipose tissue; VAT, visceral adipose tissue.

[a]Correct body composition terminology (referring to the specific compartment being assessed) was applied throughout this table and may be different from what is stated in the original studies.

Table 5. Studies Used to Examine the Validity of Ultrasound for Body Composition Assessment in Clinical Populations.[a]

Reference	Study Aims	Population (n), Eligibility	Devices	Areas of Interest	Comments
Chappel et al, 2017	To describe longitudinal changes in anthropometric data and its impact on physical function in patients with traumatic brain injury; To compare the accuracy of US with DXA; To assess the relationships between anthropometrical data and self-reported physical function	N = 37 adults with moderate to severe traumatic injury (87% male, 13% female); BMI: 26.7 ± 6.5 kg/m^2; Age: 45 ± 16 y (mean ± SD)	DXA (Prodigy GE Healthcare) vs US (SonoSite X Porte, 13-6 MHz Transducer)	LM (DXA) vs muscle layer thickness (US); LLM (DXA) vs QMT (US)	DXA measures were obtained within 7 days after hospital discharge and 3-mo follow-up Time between body composition tests not specified; Pearson correlations reported LM (DXA) vs QMT (US): $r = 0.74$, $P = 0.037$, n = 8; LLM (DXA) vs QMT (US): $r = 0.59$, $P = 0.12$, n = 8
Emmons et al, 2011	To evaluate associations between DXA-measured and US-measured adiposity in men with spinal cord injury	N = 24 males (8 paraplegic, 16 tetraplegic); BMI: 26.2 ± 5.4 kg/m^2; Age: 39 ± 11 y (mean ± SD)	DXA (GE Lunar Prodigy Advance) vs US (GE Logiq Book XP with a GE 3C-RS 2-5 MHz transducer)	% FM trunk (DXA) vs SAT thickness (US); % FM trunk (DXA) vs VAT thickness (US)	Body composition measures were obtained on the same day; Pearson correlations reported; There was a significant correlation between Android % FM (DXA) vs VAT thickness (US): $r = 0.42$, $P < 0.05$; No other significant correlations reported
Gong et al, 2007	To study the relationship between the AIPPF and anthropometric, imaging and cardiovascular risk factors of metabolic syndrome	N = 72 Mongolian men with metabolic syndrome; BMI: 27.56 ± 2.9 kg/m^2; Age: 49.7 ± 8.4 y women; 48.6 ± 9.8 y men (mean ± SD)	MRI (GYROSCAN S15, Philips with a 1.5 T [64 MHz] magnetic field) versus US (Phillips 5000 SonoCT with an abdominal C 5-2 40R 2-5 MHz transducer)	IAF, AIPPF; MRI VAT vs US IAF and MRI VAT and AIPPF in women only	Time between body composition tests not specified; Pearson correlations reported; There were significant correlations between VAT (MRI) and IAF (US) as well as VAT (MRI) and AIPPF (US); VAT (MRI) and IAF (US): $r = 0.770$, $P < 0.001$, n = 44 men; $r = 0.788$, $P < 0.001$, n = 28 women; VAT (MRI) and AIPPF (US): $r = 0.768$, $P < 0.001$, n = 72

(*continued*)

Table 5. (continued)

Reference	Study Aims	Population (n), Eligibility	Devices	Areas of Interest	Comments
Menon et al, 2012	To validate the use of ultrasound in COPD patients against DXA to measure responsiveness to changes in quadriceps after resistance training	N = 45 patients with COPD; N = 19 matched controls COPD: BMI: 26.4 ± 5.3 kg/m² Age: 68.2 ± 8.2 y Controls: BMI: 26.9 ± 2.8 kg/m² Age: 66.2 ± 5.0 y (mean ± SD)	DXA (GE Lunar Prodigy Advance with manufacturer's software) vs US (Hitachi EUB-425 with a 7.5 linear transducer)	Thigh LM (DXA) vs rectal femoral thickness and QMT (US)	Body composition measures were obtained on the same day. Spearman correlations reported. There was a significant correlation between thigh LM (DXA) and rectal femoral thickness (US): r = 0.68, $P > 0.00001$, n = 64 as well as between thigh LM (DXA) vs QMT (US): r = 0.63, $P < 0.0001$, n = 64
Pontiroli et al, 2002	To compare anthropometric, US, and CT measurements of body fat distribution at baseline and 1 year after laparoscopic adjustable gastric banding	N = 120 (27 men, 93 women) N = 40 re-evaluated after 1 yr after surgery BMI: 44.6 ± 0.59 kg/m² Age: 40.6 ± 0.99 y (mean ± SD)	CT (Toshiba TCT – 900S) versus US (GE RT 2800 convex transducer 3.5 MHz)	VAT thickness (CT) versus VAT thickness (US) SAT thickness (CT) versus SAT thickness (US)	Time between body composition tests not specified. Pearson correlations reported. VAT thickness (CT) versus VAT thickness (US): r = 0.91, P-value missing. SAT thickness (CT) versus SAT thickness (US): r = 0.78, P-value missing
Robiero-Filho et al. 2001	To assess the correlation between US and CT for the evaluation of visceral adiposity in women with obesity (including those with hypertension and mild-to-moderate disturbances of lipid profile)	N = 101, women with obesity and adverse metabolic profile BMI: 39.2 ± 5.4 kg/m² Age: 50.5 ± 7.7 y (mean ± SD)	CT (not specified) vs US (not specified, 3.5 MHz probe)	VAT (CT) vs VAT (US)	Time between body composition tests not specified. Pearson correlations reported that a significant correlation between CT and US VAT was observed (r = 0.67, $P = 0.0001$)
Seymour et al, 2009	To assess the correlation between US quadriceps muscle size with quadriceps strength and FFM in patients with COPD	N = 10 adults with COPD, BMI: 26 ± 4.5 kg/m² Age: 67 ± 9 y N = 8 healthy adults BMI: 25 ± 3.5 kg/m² Age: 63 ± 9 y (mean ± SD)	CT (Siemens SOMATOM Sensation 64-slice scanner, MagicView VE 40 software) vs US (Toshiba PLM805)	Rectus femoralis cross-sectional area (US) vs rectus femoralis cross-sectional area (CT)	Body composition tests (CT and US) completed between 2 and 4 weeks apart. Pearson and Spearman correlations conducted but not reported

AIPPF, area of the inferior part of the perirenal fat; CC, correlation coefficient; COPD, chronic obstructive pulmonary disease; CT, computerized tomography; DXA, dual energy X-ray absorptiometry; FFM, fat-free mass; FM, fat mass; IAF, intra-abdominal fat; LLM, lean mass leg; LM, lean mass; MRI, magnetic resonance imaging; QMT, quadriceps muscle thickness; SAT, subcutaneous adipose tissue; US, ultrasound; VAT, visceral adipose tissue;

[a] Correct body composition terminology (referring to the specific compartment being assessed) was applied throughout this table and may be different from what is stated in the original studies.

these guidelines. All DXA studies included in this review assessed FM (regional or total), yet based on the reported correlation coefficients, the validity of DXA to assess LM could not be determined. None of the 15 studies included sensitivity or specificity analysis. A portion of these studies included Bland-Altman analysis to reflect the quality of the data within their study; however, these cannot be used to calculate sensitivity and specificity parameters or be conflated among studies. Correlation coefficients (denoted by the letter "r") measure the strength and direction of a linear relationship between 2 variables (eg, appendicular skeletal muscle mass (SMM) (kg) from DXA vs muscle mass (kg) from CT). Correlation coefficients were categorized as very low ($r = 0$–0.20), low ($r = 0.21$–0.40), moderate ($r = 0.41$–0.60), high ($r = 0.61$–0.80), and very high ($r = 0.81$–1.0). Table 4 provides details regarding the studies utilizing DXA. Three studies included patient populations with diabetes mellitus; however, these studies did not provide comparable end points for joint analyses within this patient subgroup.[34-36] Ultimately, Pearson correlations between DXA and the reference methods were used in 8 studies for statistical comparisons to generate summary correlations and forest plots.

Seven studies used CT to validate DXA measures of abdominal FM and/or total body FM,[34,37-42] and 2 studies used MRI to validate DXA measures for regional adiposity and total FM.[43,44] Of these, 4 studies with heterogeneous patient populations ($N = 874$) were used to examine the correlation between CT-derived visceral adipose tissue (VAT) with DXA-derived abdominal adipose tissue[34,37,43,44] (Figure 1A). Because of differences in the patient populations in these studies, the random effects model was used to assess the summary correlation and examine the heterogeneity between studies (I^2). The individual study correlations ranged from moderate to very strong (0.52–0.86), and the overall random effects summary correlation between the DXA measure of trunk fat/intra-abdominal fat/VAT and the CT assessment of VAT was strong (0.74, 95% confidence interval [CI] 0.52-0.86). As expected, heterogeneity between studies was very large ($I^2 = 0.87$) because of the different patient populations assessed.

Seven studies using patients with varying clinical diagnoses were used to examine the correlations between CT-derived or MRI-derived VAT and DXA-derived total FM[38-44] (Figure 1B). The individual study correlations ranged from moderate to very strong (0.49–0.80), and the overall random effects summary correlation between the DXA measure of total body fat or % body fat and the CT or MRI assessment of VAT was strong (0.71, 95% CI 0.45-0.86). As expected, heterogeneity between studies was very large ($I^2 = 0.98$) because of the different patient populations assessed.

Five studies involving patients with CVD examining the correlations between CT-derived or MRI-derived VAT and

DXA-derived total FM were conflated[38-40,42,43] (Figure 1C). The individual study correlations ranged from moderate to very strong (0.49–0.87), and the summary correlation between the DXA measure of body fat and the CT or MRI assessment of VAT was strong (0.71, 95% CI 0.45-0.84). As expected, the heterogeneity between studies was very large ($I^2 = 0.95$) because of the different populations assessed.

Comments

DXA relies on x-ray technology and can be applied to human participants of any age because of the low radiation exposure involved. For a comprehensive review of this methodology, please refer to Heymsfield et al.[2] The use of DXA for body composition assessment is more challenging in the acute care setting and at this time would likely not procure results to directly impact clinical care, specifically nutrition support. For example, transporting a critically ill patient to the DXA machine to measure LM may not be a relevant priority in the context of his/her overall care. Furthermore, there is no evidence yet to guide the alteration of nutrition provision based on DXA findings. As a result, the lack of DXA studies conducted in the inpatient setting is not surprising. Its more direct application in the outpatient setting is intuitive, as these patients tend to be healthier, mobile, and possess fewer acute health conditions. However, some clinicians may be unaware of the fact that for patients referred for DXA imaging in the outpatient environment, only images of the femoral and/or lumbar spine region are obtained (ie, whole body data are not collected). Quantifications of femoral neck bone mineral density are the reference standard for diagnosing osteoporosis and for projecting future risk of hip fracture.[45] Obtaining a whole body DXA for body composition assessment requires additional scanning by the radiology technician and may have increased costs. However, whole body analyses provide essential information on total and regional adiposity, as well as quantification of LM for the classification of sarcopenia.[46] Newer DXA software is now available to calculate a more comprehensive definition of sarcopenia, taking into account measures of strength and LM.[47] Although the use of DXA for whole body composition assessment is relatively easy and poses minimal participant burden, having access to this machine and appropriately trained personnel further limits its use in select patient populations.

Future Directions

Traditionally, DXA has been considered the "gold standard" assessment technique to evaluate bone health. Despite its use since the 1980s and its demonstrated validity in healthy populations, its use to assess body composition across a breadth of disease entities remains relatively

Table 6. Studies Used to Examine the Validity of BIS, MF-BIA, and SF-BIA for Body Composition Assessment in Various Clinical Populations Organized by Device.[a]

Reference	Study Aims	Population (n), Eligibility	Comparator	BIS or MF-BIA Device and Equation	Body Compartment and CC
Donadio et al, 2008	To evaluate the adequacy of SF-BIA and MF-BIA, in comparison with DXA to evaluate body composition in maintenance hemodialysis patients	Patients treated with a 3-dialysis/wk schedule, 3–4 h long for each session N = 9 women N = 18 men Age: 65.3 y (32–88 y) BMI: range 17.5–34.4 kg/m²	DXA Hologic QDR 4500	QuadScan 4000 Manufacturer's equations	Pearson CC reported DXA vs $FFM_{Quadscan}$: CC = 0.9213 DXA vs $FM_{Quadscan}$: CC = 0.7530
Fürstenberg et al, 2011	To determine the reliability of MF-BIA in assessing the nutrition status of hemodialysis patients	Adults attending for thrice weekly outpatient hemodialysis treatments N = 28 women N = 25 men Age: 57.1 ± 17 y BMI: range 16.2–36.7 kg/m²	DXA Hologic QDR Discovery W	InBody 720 segmental Manufacturer's software	Type of correlation not specified DXA vs Total body $FFM_{InBody720}$: CC = 0.8447 DXA vs Trunk $LM_{InBody720}$: CC = 0.7200 DXA vs Right leg $LM_{InBody720}$: CC = 0.7844 DXA vs Left arm $LM_{InBody720}$: CC = 0.5615
Fürstenberg et al, 2011	To evaluate MF-BIA in assessing body composition compared with standard DXA scanning in peritoneal dialysis patients	Stable chronic peritoneal dialysis patients N = 54 women N = 50 men Age: 57.1 ± 17 y BMI: range 16.2–36.7 kg/m²	DXA Hologic QDR Discovery W	InBody 720 segmental Manufacturer's software	Type of correlation not specified DXA vs $FFM_{InBody720}$: CC = 0.95 DXA vs $FM_{InBody720}$: CC = 0.93 DXA vs Total $LBM_{InBody720}$: CC = 0.95 DXA vs Trunk $LM_{InBody720}$: CC = 0.90 DXA vs left arm $LM_{InBody720}$: CC = 0.86 DXA vs right arm $LM_{InBody720}$: CC = 0.84 DXA vs left leg $LM_{InBody720}$: CC = 0.89 DXA vs right leg $LM_{InBody720}$: CC = 0.90

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Table 6. (continued).

Reference	Study Aims	Population (n), Eligibility	Comparator	BIS or MF-BIA Device and Equation	Body Compartment and CC
Hosono et al, 2015	To determine the availability of BIA, CT, and MRI for measurement of SMM in patients with rheumatic diseases and quantitatively assess skeletal muscle loss after glucocorticoid treatment	Patients with rheumatic disease N = 17 women N = 5 men Mean age: 61 y, range 42–80 y	CT scanner GE Healthcare, LightSpeed ultra MRI scanner GE 1.5-Tesla	Tanita model MC-190 Manufacturer's software	Spearman correlation reported Whole body SMI_{Tanita} × total thigh muscle volume$_{CT}$: CC = 0.81 Whole body SMI_{Tanita} × total mid-thigh muscle CSA_{CT}: CC = 0.83 Right leg SMI_{Tanita} × right mid-thigh muscle CSA_{CT}: CC = 0.62 Left leg SMI_{Tanita} × left mid-thigh muscle CSA_{CT}: CC = 0.72 Whole body SMI_{Tanita} × total thigh muscle volume$_{MRI}$: CC = 0.76 Whole body SMI_{Tanita} × total mid-thigh muscle CSA_{MRI}: CC = 0.76 Right leg SMI_{Tanita} × right mid-thigh muscle CSA_{MRI}: CC = 0.65 Left leg SMI_{Tanita} × left mid-thigh muscle CSA_{MRI}: CC = 0.68
Hronek et al, 2013	To analyze precisely and critically which method SFA, BIA, and BIS is most accurate and available for common use in clinical practice for measurement of FFM in patients with COPD	COPD patients N = 7 women N = 34 men Age: 66.5 ± 7.7 y BMI: 28.2 ± 6.1 kg/m²	DXA Hologic Discovery A	BIA dual frequency InnerScan using manufacturer's software	Lin's concordance correlation reported DXA vs $FFM_{InnerScan}$: CC = 0.94
Hung et al, 2014	To compare the agreement of absolute values estimated by BIS relative to ADP and DXA and changes in body composition detected by BIS relative to ADP at 3 months after peripheral blood stem cell transplantation	Hematologic cancer patients underwent peripheral blood stem cell transplantation N = 21 women N = 23 men Mean age: 56.5 y BMI: range 16.4–47.6 kg/m²	DXA Hologic QDR 4500 A and BOD POD	BIS ImpSFB7 Impedimed Manufacturer's equations Bioimp software version 5.3.1.1 or alternative equations used by De Lorenzo; Matthies, Moissl and equation produced by the authors in an independent study	Lin's concordance correlation reported DXA vs FFM_{SFB7}: CC = 0.81 DXA vs FM_{SFB7}: CC = 0.69 DXA vs % FM_{SFB7}: CC = 0.33

Table 6. (continued).

Reference	Study Aims	Population (n), Eligibility	Comparator	BIS or MF-BIA Device and Equation	Body Compartment and CC
Ida et al, 2013	To elucidate early change of intra-abdominal fat in response to calorie restriction in patients with obesity, diabetes or metabolic syndrome by weekly evaluation using a dual BIA	Japanese patients with BMI >25 kg/m^2 hospitalized for calorie restriction therapy or diet education N = 31 women N = 36 men Age: 54.7 ± 14.7 y BMI: 29.3 ± 6.5 kg/m^2	CT scanner not specified	Dual BIA Manufacturer's equation	Pearson correlation reported CT vs IAFA$_{Xitron}$: CC = 0.821
Kafri et al, 2014	To assess MF-BIA against DXA in patients with recent stroke or TIA using FM and FFM; the secondary objective was to examine the internal validity of MF-BIA	Patients with recent stroke or TIA N = 3 women N = 7 men Age: 66 ± 11 y Normal BMI: 5; overweight: 4; obese: 1	DXA Hologic QDR series	Maltron BioScan Manufacturer's equations	Pearson correlation reported DXA vs FFM$_{MFBioScan}$: CC = 0.884 DXA vs %FFM$_{MFBioScan}$: CC = 0.648 DXA vs FM$_{MFBioScan}$: CC = 0.778 DXA vs % FM$_{MFBioScan}$: CC = 0.631
Kaysen et al, 2005	To evaluate the use of multifrequency BIS measurements of ICV to model total body SMM and limb SMM in hemodialysis patients	Maintenance hemodialysis patients N = 18 women N = 20 men Median age 53.5 y range: 33–73 y Median BMI 27.5 kg/m^2 (19.4–46.6)	MRI scanner GE 1.5-Tesla	Xitron 4200 Developed model using ICV from MF-BIS	Type of correlation not specified Correlations of MRI vs BIS total and limb SMM only reported graphically.
Kyle et al, 2001	To determine the applicability of a single BIA formula in subjects who were pre or post liver, lung, and heart transplantation	Liver, lung, and heart transplant patients N = 86 women Age: 48.6 ± 10.2 y BMI: 22.8 ± 5.1 kg/m^2 N = 158 men Age: 49.0 ± 12.6 y BMI: 24.8 ± 4.5 kg/m^2	DXA Hologic QDR-4500	Xitron 4000 B	Type of correlation not specified DXA vs FFM$_{Xitron}$: CC = 0.974

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Table 6. (continued).

Reference	Study Aims	Population (n), Eligibility	Comparator	BIS or MF-BIA Device and Equation	Body Compartment and CC
Molfino et al, 2012	To apply a model to estimate FM using MF-BIS in hemodialysis patients and control subjects	Control subjects: N = 14 women N = 11 men Median age: 46 y, range 21–55 y BMI: 29.8 ± 5.5 kg/m^2 Hemodialysis patients: N = 1 woman N = 10 men Median age: 40 y, range 20–53 y BMI: 25.7 ± 4.67 kg/m^2	DXA Hologic W	BIS ImpSFB7 Impedimed Manufacturer's software	Spearman correlation reported Control subjects DXA vs FM$_{SFB7}$: CC = 0.85 Hemodialysis patients DXA vs FM$_{SFB7}$: CC = 0.914
Otto et al, 2015	To analyze the validity of BIA for determining VF course in bariatric patients PO	Bariatric patients following to Roux-en-Y gastric bypass N = 14 women N = 4 men (3 dropout) Age: 42 ± 3 y, mean BMI: 43 ± 5 kg/m^2	MRI Siemens 1.5 T MAGNETOM Avanto	Nutriguard-M Data Input	Pearson correlation reported MRI vs FM$_{Nutriguard-M}$ VF Preoperative: CC = 0.07 PO 6 wk: CC = 0.15 PO 12 wk: CC = 0.13 PO 24 wk: CC = 0.47 MRI vs FM$_{Nutriguard-M}$ SCFV Preoperative: CC = 0.33 PO 6 wk: CC = 0.74 PO 12 wk: CC = 0.61 PO 24 wk: CC = 0.56
Pérez-Matute et al, 2013	To validate the data obtained by BIA to measure FM in HIV+ patients with/without lipoatrophy and to determine if BIA correctly diagnoses lipoatrophy in HIV+ patients	N = 39 HIV-negative patients: N = 6 women N = 8 men Age: 36.2 ± 7.8 y BMI: 24.1 ± 2.4 kg/m^2 HIV+ without lipoatrophy: N = 5 women N = 9 men Age: 43.2 ± 11.6 y BMI: 23.8 ± 3.2 kg/m^2 HIV+ with lipoatrophy: N = 4 women N = 7 men Age: 49.9 ± 3.4 y BMI: 21.3 ± 3.5 kg/m^2	DXA model Norland XR-46	Tanita MC-180MA Manufacturer's software	Spearman correlation reported HIV+ patients: DXA vs FM$_{Tanita}$: CC = 0.739 DXA vs % FM$_{Tanita}$: CC = 0.880 DXA vs % trunk fat$_{Tanita}$: CC = 0.819 DXA vs % leg fat$_{Tanita}$: CC = 0.771 DXA vs % arm fat$_{Tanita}$: CC = 0.779 Non-lipoatrophic HIV+: DXA vs FM$_{Tanita}$: CC = 0.516 DXA vs % FM$_{Tanita}$: CC = 0.811 DXA vs % trunk fat$_{Tanita}$: CC = 0.732 DXA vs % leg fat$_{Tanita}$: CC = 0.582 DXA vs % arm fat$_{Tanita}$: CC = 0.827 Lipoatrophic HIV+: DXA vs FM$_{Tanita}$: CC = 0.964 DXA vs % FM$_{Tanita}$: CC = 0.939 DXA vs % trunk fat$_{Tanita}$: CC = 0.945 DXA vs % leg fat$_{Tanita}$: CC = 0.773 DXA vs % arm fat$_{Tanita}$: CC = 0.836

Table 6. (continued).

Reference	Study Aims	Population (n), Eligibility	Comparator	BIS or MF-BIA Device and Equation	Body Compartment and CC
Pichler et al, 2013	To assess the accuracy and precision of a BIS device and the relative contribution of BIS beyond the anthropometric parameters	Healthy: N = 14 women Age: 32.55 ± 12.56 y BMI: 21.26 ± 2.26 kg/m² N = 18 men Age: 51.93 ± 19.41 y BMI: 25.24 ± 2.13 kg/m² Patients with several clinical conditions: N = 28 women Age: 73.28 ± 12.27 y BMI: 26.63 ± 5.84 kg/m² N = 55 men Age: 69.53 ± 14.43 y BMI: 24.97 ± 4.76 kg/m²	DXA Hologic QDR4500A software version 12.6	BIS ImpSFB7 Impedimed Manufacturer's software	Type of correlation not specified DXA vs FM_{SFB7}: CC = 0.89
Van Venrooij et al, 2010	To assess preoperative and postoperative agreement in FFM between BIS and DXA in patients undergoing cardiac surgery to assess preoperative and postoperative agreement in FFM between BIS and DXA in patients undergoing cardiac surgery	Patients undergoing cardiac surgery N = 5 women N = 21 men Age: 59.9 ± 8.1 y BMI: 29.1 ± 5.2 kg/m²	DXA Hologic QDR 4500W	BodyScout Fresenius Kabi manufacturer's equation	Pearson and Spearman correlation conducted Only the correlations between preoperative and postoperative changes in FFM, FM, and ICW for DXA and BIA reported.
Vine et al, 2011	To evaluate the ability of BIS to estimate FFM in end-stage renal disease patients using DXA as a reference	N = 9 women N = 42 men Control subjects: N = 23 Age: 45.85 ± 8.40 y BMI: 26.55 ± 4.35 kg/m² Hemodialysis patients: N = 16 Age: 42.30 ± 14.80 y BMI: 27.19 ± 5.21 kg/m² Undialyzed patients: N = 12 Age: 47.68 ± 10.00 y BMI: 28.83 ± 4.15 kg/m²	DXA GE Lunar Prodigy scanner	BIS ImpSFB7 Impedimed Manufacturer's software: FFM Hanai mixture theory equations: ECF, ICF, and FFM	Pearson correlation reported Control subjects: DXA vs FFM_{SFB7}: CC = 0.950 Hemodialysis Patients: DXA vs FFM_{SFB7}: CC = 0.924 Undialyzed patients: DXA vs FFM_{SFB7}: CC = 0.871

Table 6. (continued).

Reference	Study Aims	Population (n), Eligibility	Comparator	BIS or MF-BIA Device and Equation	Body Compartment and CC
Yamakage et al, 2014	To examine the utility of a Dual BIA for measuring IAFA in patients with obesity and Metabolic Syndrome during weight reduction	100 Japanese patients with BMI ≥25 kg/m^2 N = 52 women N = 48 men Age: 57.5 ± 1.4 y BMI: 30.2 ± 0.5 kg/m2	CT scanner not specified	Dual BIA-IAFA Omron Manufacturer's software	Pearson and Spearman correlation reported Baseline: CT vs TFA$_{Omron}$: CC = 0.962 CT vs IAFA$_{Omron}$: CC = 0.743 CT vs SCFA$_{Omron}$: CC = 0.925 There were significant correlations between glucose, HbA1C, total cholesterol, triglycerides, HDL-C, leptin, adiponectin, hs-CRP, and IAFA$_{Omron}$ (all P-values < 0.05) Change baseline/6 mo: CT vs TFA$_{Omron}$: CC = 0.730 CT vs IAFA$_{Omron}$: CC = 0.482 CT vs SCFA$_{Omron}$On: CC = 0.622 Changes in leptin were significantly correlated with changes in IAFA$_{Omron}$ (P < 0.01).
Zhu et al, 2015	To evaluate the relationship of calf bioimpedance with total body composition and fluid status as measured by gold standard methods	Hemodialysis patients N = 18 women N = 23 men Age 54.7 ± 11 y	MRI not specified	Hydra 4200 Xitron Manufacturer's software Specific equation calf Re and Ri	Type of correlation not specified MRI vs MM$_{Xitron}$: CC = 0.92 (R^2 = 0.85) MRI vs TAT$_{Xitron}$: CC = 0.92 (R^2 = 0.85)

Reference	Study Aims	Population (n), Eligibility	Comparator	SF-BIA Device and Equation	Body Compartment and CC
Aghdassi et al, 2007	To compare the estimates of body FM by 2 simple bedside techniques such as BIA and skin fold measurements	HIV-infected patients receiving stable antiretroviral therapy for at least 6 mo N = 47 men Age: 49.21 ± 1.2 y BMI: 25.81 ± 0.50 kg/m^2	DXA Hologic QDR 4500A	BIA-103 RJL system Manufacturer's software	Pearson correlation reported DXA vs %FM$_{RJL}$: CC = 0.783 WHR ≤0.90 (N = 6) DXA vs FM$_{RJL}$: CC = 0.196 WHR >0.90 (N = 41) DXA vs FM$_{RJL}$: CC = 0.811

(continued)

Table 6. (continued).

Reference	Study Aims	Population (n), Eligibility	Comparator	SF-BIA Device and Equation	Body Compartment and CC
Donadio et al, 2008	To evaluate the adequacy of SF-BIA and MF-BIA, in comparison with DXA to evaluate body composition in maintenance hemodialysis patients	Patients treated with a 3-dialysis/week schedule, 3 h long for each session N = 9 women N = 18 men Age: 65.3y (range 32–88 y) BMI: range 17.5–34.4 kg/m^2	DXA Hologic QDR 4500	STA-BIA Akern and Biascan, Maltron Manufacturer's software for both devices	DXA vs FM$_{Akern}$: CC = 0.8846 DXA vs FM$_{Maltron}$: CC = 0.8512 DXA vs FFM$_{Akern}$: CC = 0.9241 DXA vs FFM$_{Maltron}$: CC = 0.9213
Lerario et al, 2006	To compare anthropometry with BIA in relation to DXA as methods of nutrition assessment and body composition in outpatients with COPD	COPD patients N = 19 women N = 42 men Age: 66.5 ± 7.9 y BMI: 24.5 ± 4.5 kg/m^2	DXA Hologic QDR 4500A	RJL Quantum X Manufacturer's software	Type of correlation not specified DXA vs FFM$_{RJL}$: CC = 0.95
Silva et al, 2013	To evaluate which method (BIA, anthropometry and body adiposity index), presents the higher accuracy to estimate body adiposity compared with DXA in nondialyzed CKD patients	Clinically stable nondialyzed chronic kidney disease patients N = 60 women N = 74 men Age: 64.9 ± 12.5 y BMI: 25.9 ± 4.4 kg/m^2	DXA Lunar DPX Bone Densitometer	BIA Model 310 Biodynamics Manufacturer's software	Lin's concordance correlation reported DXA vs % FM$_{Biodynamics}$: CC = 0.70

(*continued*)

Table 6. (continued).

Reference	Study Aims	Population (n), Eligibility	Comparator	SF-BIA Device and Equation	Body Compartment and CC
Vassimon et al, 2011	To compare estimates of body FM and FFM by BIA and skinfold measurements with values obtained from DXA in males with HIV vs healthy controls	Males with HIV Without lipodystrophy (HIV+LIPO−): N = 22 Age: 43 ± 6 y BMI: 24 ± 3 kg/m^2 Males with HIV with lipodystrophy (HIV+LIPO+): N = 10 Age: 46 ± 5 y BMI: 24 ± 3 kg/m^2 Male controls: N = 12 Age: 45 ± 5 y BMI: 24 ± 5 kg/m^2	DXA Hologic QDR 4500A	BIA-103 RJL system Manufacturer's software	Pearson correlation reported HIV+LIPO−: DXA vs % FM$_{RJL}$: CC = 0.74 DXA vs FM$_{RJL}$: CC = 0.90 DXA vs FFM$_{RJL}$: CC = 0.92 HIV+LIPO+: DXA vs % FM$_{RJL}$: CC = 0.66 DXA vs FM$_{RJL}$: CC = 0.87 DXA vs FFM$_{RJL}$: CC = 0.93 Controls: DXA vs % FM$_{RJL}$: CC = 0.71 DXA vs FM$_{RJL}$: CC = 0.61 DXA vs FFM$_{RJL}$: CC = 0.73
Ziai et al, 2014	To determine the agreement of FFM, FM, and % FM measurements taken with DXA and BIA in adults with cystic fibrosis	Cystic fibrosis patients N = 19 women N = 15 men Age: 30 ± 9 y BMI: 22.0 ± 2.56 kg/m^2	iDXA GE Lunar	Tanita TBF-310 Manufacturer's software	Spearman correlation reported DXA vs FFM$_{Tanita}$: CC = 0.915 DXA vs FM$_{Tanita}$: CC = 0.914 DXA vs % FM$_{Tanita}$: CC = 0.833

ADP, air-displacement plethysmography; BIA, bioelectrical impedance analysis; BIS, bioimpedance spectroscopy; BMI, body mass index; CC, correlation coefficient; CKD, chronic kidney disease; COPD, chronic pulmonary obstructive disease; CSA, cross-sectional area; CT, computed tomography; DXA, dual energy x-ray absorptiometry; ECF, extracellular fluid; FFM, fat-free mass; FM, fat mass; HDL, High density lipoprotein; hs-CRP, high sensitivity C-reactive protein; IAFA, intra-abdominal fat area; ICF, intracellular fluid; ICV, intracellular volume; ICW, intracellular water; LBM, lean body mass; LM, lean mass; MM, muscle mass; MRI, magnetic resonance imaging; MF-BIS, multifrequency bioimpedance spectroscopy; MF-BIA, multi-frequency bioelectrical impedance analysis; PO, postoperatively; SCFV, subcutaneous fat volume; SFA, skin fold anthropometry; Re, extracellular resistance; Ri, intracellular resistance; SMI, skeletal muscle mass index; SMM, skeletal muscle mass; TFA, total fat area; TIA, transient ischemic attack; VF, visceral fat; WHR, waist to hip ratio.
[a]Correct body composition terminology (referring to the specific compartment being assessed) was applied throughout this table and may be different from what is stated in the original studies.
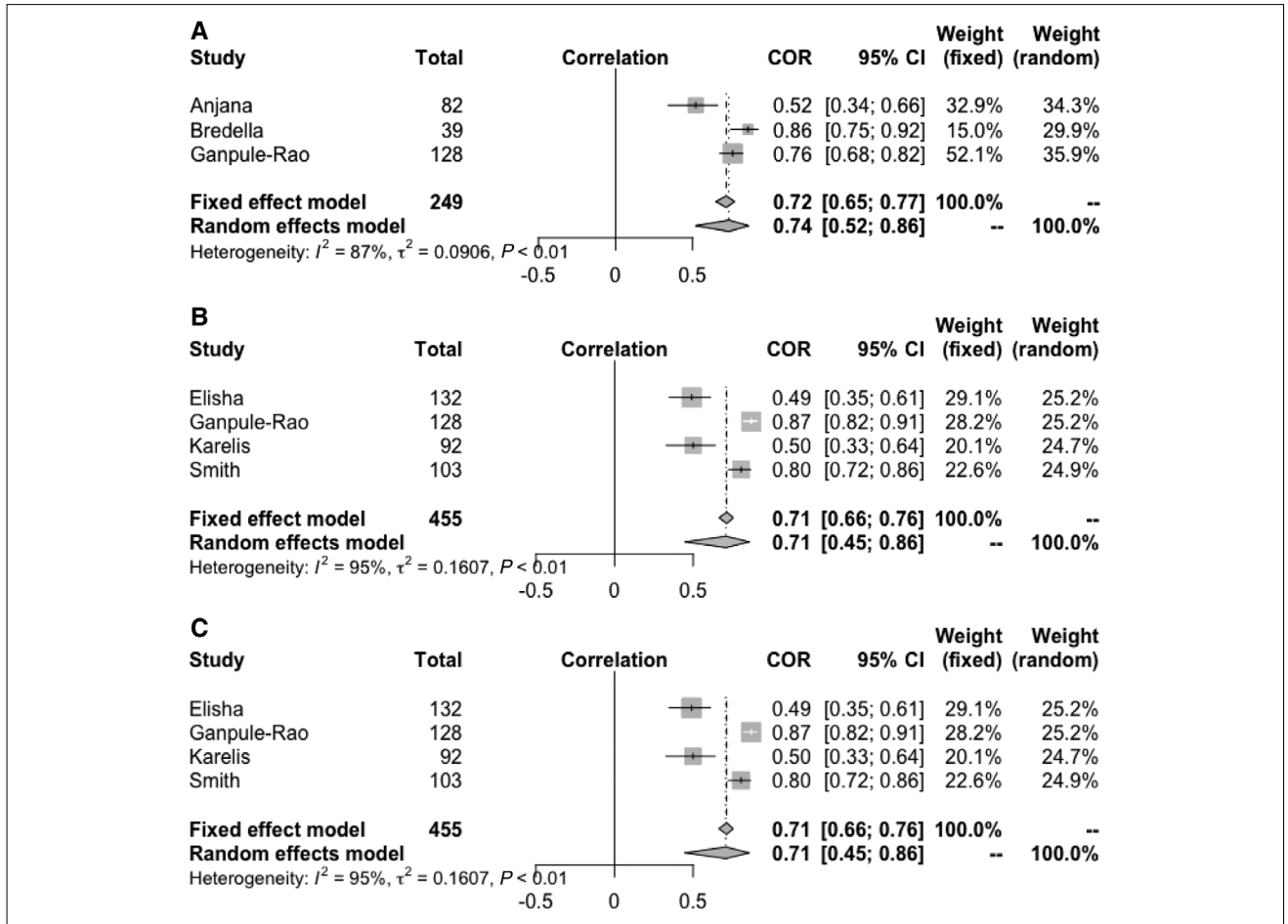
Figure 1. (A) Quantifications of DXA derived abdominal fat compared to CT or MRI derived VAT for patients with any disease using any hardware. (B) Quantifications of DXA derived total body fat compared to CT or MRI derived VAT for patients with any disease. (C) Quantifications of DXA derived total body fat compared to CT or MRI derived VAT for patients with cardiovascular disease.

limited. Given the growing interest in LM assessment to diagnose malnutrition,[1] additional research is also needed to evaluate the validity of DXA for the quantification of this compartment. For example, many individuals undergoing cancer therapy or those in the surveillance phase of cancer care undergo routine CT imaging. Obtaining whole body DXA images in these individuals would permit the validation of DXA for LM assessment in several subgroups of patients. Moreover, data obtained from whole body DXA could be used to evaluate potential differences in body composition for individuals with cancer compared with healthy population controls, using publicly available data from the National Health and Nutrition Examination Survey (NHANES).[48] Although patients with cancer are used as an example here, further research is critically needed in other patient populations in which CT imaging is routinely used (eg, chronic obstructive pulmonary disease [COPD], CVD, hepatic disease). Finally,

evaluating body composition in patients from more diverse racial/ethnic backgrounds would allow us to address if body composition assessment is valid in a heterogeneous patient sample.

Question 2: Is US a valid method of assessing body composition in various clinical populations?

Recommendation

No recommendation can be made at this time to support the use of US in the clinical setting for body composition assessment. No data exist to support its validity in adult patient populations.

Quality of the Evidence: Very Low
GRADE Recommendation: Weak

Rationale

Seven studies utilizing US and a superior comparator method met the inclusion criteria for initial review and DAF completion. Studies included assessment of both adipose tissue and skeletal muscle. No studies included sensitivity or specificity analyses, and 2 included Bland-Altman analysis to compare measurements between techniques. Correlation analysis was included in all studies (see Table 5 for details regarding these studies). Patient populations included those with severe traumatic brain injury,[49] spinal cord injury,[50] COPD,[51,52] obesity with metabolic syndrome/metabolic abnormalities,[53,54] and patients with severe obesity post-bariatric surgery.[55] Three studies used DXA to validate US measures,[49-51] 3 used CT imaging,[52,54,55] and 1 used MRI.[53] The studies by Chappel et al,[49] Menon et al,[51] and Seymour et al[52] compared LM (DXA) or muscle mass (CT) against US assessment of muscle thickness and cross-sectional area, whereas the work of Emmons et al,[50] Pontiroli et al,[55] and Ribeiro-Filho et al[54] compared FM (DXA) or visceral adiposity (MRI or CT) with US-assessed visceral adiposity. The variability in which reference technique was used (ie, CT, MRI, or DXA) and different correlation coefficients used (Spearman vs Pearson) precluded any further statistical comparisons across studies.

Comments

US uses high-frequency sound waves to capture live images and soft tissue structures. For a thorough review of this methodology, please refer to Heymsfield et al.[2] US is a promising low-cost, low-risk, noninvasive, portable technique with wide applications in the clinical setting. It has been used to assess body composition, with most studies focusing on visceral and subcutaneous adiposity,[56] although it has been increasingly used for the assessment of SMM. An advantage of US for skeletal muscle assessment includes the quantification of muscle quantity and "quality" through different parameters (ie, muscle thickness, cross-sectional area, and echogenicity). Hydration status, reliability, and accuracy were previously considered inherent disadvantages of the method. However, these no longer pose as absolute contraindications, since several investigators have demonstrated that edema does not significantly influence body composition findings[57-59] and that adequate training results in excellent intraobserver and interobserver agreement.[60,61] Currently, the major setback for its universal use is the lack of standardized measurement protocols, including which parameters to analyze, since data obtained from US measurements seem very informative yet are difficult to interpret and compare. Furthermore, there is no evidence yet to guide the alteration of nutrition provision based on US findings.

Future Directions

Within healthy, nonminority, free-living populations (ie, noninstitutionalized), US is a highly portable technique that can accurately measure VAT if completed by experienced, trained technicians. In patients with critical illness, US has the potential to be 1 of the best available methods for body composition evaluation, as the use of other techniques is largely infeasible in these patients.

The number of studies using US in clinical populations remains limited by several factors. First, most of the studies included in this review examined a single muscle. The utility and relevance of extrapolating single muscles to reflect overall nutrition status has yet to be determined. Further research efforts should evaluate whether the measurement of a single muscle or if select muscle groups can be used for clinical assessment, as measuring several anatomical sites is time consuming and limits widespread clinical use of this technique. In addition, since muscle atrophy can be disproportionate,[62] previous investigators have demonstrated the importance of investigating both upper and lower body muscle groups when evaluating longitudinal changes in body composition.[63] Second, US measurements often report muscle and/or adipose tissue as thickness (mm) or cross-sectional area (mm^2), whereas DXA data are presented as whole body mass (kg) and CT data may be reported as muscle cross-sectional area (cm^2). Furthermore, DXA and CT data can be indexed to height (kg/m^2 or cm/m^2, respectively). Thus, it can be difficult to directly compare or interpret these data across devices. Methods to unify data reporting or interpretation are needed. Finally, the use of US in clinical settings would be significantly enhanced by establishment of measurement protocols for US muscle evaluation, including the handling of obtained parameters and their adequate interpretation.

Question 3: Is BIA a valid method of assessing body composition in various clinical populations?

Recommendation

No recommendations can be made regarding the validity of using BIA in clinical populations. Because of the proprietary nature of manufacture-specific BIA regression models to acquire body composition data, it is not possible to compare studies using different BIA devices. Furthermore, because of the variability of body compartments estimated within studies and the limited number of studies using the same device, it was not possible to merge data by manufacturer to support summary statistics.

Quality of the Evidence: Low
GRADE Recommendation: Weak

Rationale

Twenty-nine studies using BIA and a superior comparator method were considered initially eligible for this review, and data were extracted using DAFs. However, BIA differs from the other methods (DXA and US) because it does not directly measure any specific body compartment. Rather, it provides estimates by using equations/algorithms populated by resistance, reactance, and impedance output from the BIA device combined with other parameters, including weight, height, sex, and age. Additionally, unlike other body composition techniques, BIA can be performed using a single frequency BIA (SF-BIA), multifrequency BIA (MF-BIA), or bioimpedance spectroscopy (BIS), all of which are produced from several different manufacturers. Each device works with a specific inbuilt algorithm to estimate body composition compartments.

To examine validity, device equations/algorithms would be tested against more precise body composition reference methods or use equations that were previously validated in a healthy population possessing similar characteristics to the clinical population under evaluation (eg, healthy Swiss men vs Swiss men with HIV). For this reason, 6 studies were further excluded, as (1) equations were used as the comparator method to validate body composition estimates using different target populations or (2) intraclass correlations and/or Bland-Altman statistics were used to show agreement.[64-69] Only studies that compared the manufacturer's equation/algorithm against a superior method for body composition assessment (ie, DXA, CT, or MRI), studies that applied equations developed for the target population, or studies that provided correlation coefficients were considered in this review.

Table 6 details the final 23 studies: 17 using MF-BIA or BIS devices,[70-86] 5 using SF-BIA devices,[87-91] and 1 using MF-BIA and SF-BIA in the same study.[92] Most of the MF-BIA studies (13 of 16 MF-BIA) and all of the SF-BIA studies estimated FM and fat-free mass (FFM) either in kilograms or as a percentage of total body weight. Other compartments were estimated by using MF-BIA: total or segmental SMM[78,82] or SMM index (SMI),[76] total or segmental LM,[74,75] and total total fat area, intra-abdominal fat area, or subcutaneous fat area.[83,84] Table 6 provides essential details for studies using BIA.

The majority of BIA studies included outpatients and reflects several clinical conditions, specifically hematologic;[70] end-stage chronic kidney disease (CKD)[73]; end-stage CKD receiving hemodialysis[74,78,82,92]; CKD receiving peritoneal dialysis[75] or nondialyzed CKD[89]; rheumatic disease[76]; HIV[77,87,90]; COPD[79,88]; pre-liver or post-liver, lung, or heart transplantation[80]; cardiac surgery[81]; obesity with metabolic syndrome[84]; cystic fibrosis[91]; and nonalcoholic fatty liver disease.[67] Only 4 studies were performed in hospitalized patients, encompassing several clinical conditions (congestive heart failure, coronary heart disease, essential hypertension, atherosclerosis, kidney disease, chronic renal failure, gastrointestinal diseases, type II diabetes, morbid obesity, osteoporosis, cancer, chronic polyarthritis, and anorexia nervosa),[72] obesity with caloric restriction[83] or bariatric surgery candidates,[86] and patients following stroke or transient ischemic attack.[85] Due to the proprietary nature of manufacturer-specific BIA regression models to estimate body composition, it was not possible to compare studies using different BIA devices (eg, Inbody 720 vs Quadscan 4000). Furthermore, within studies using the same device (eg, all studies using the Inbody 720), it was not possible to conflate these data due to the variability of body compartments estimated.

Comments

BIA measures the opposition of an electrical current through body tissues (ie, impedance), which can then be used to estimate total body water and body composition. For a detailed review of this methodology, please refer to Heymsfield et al.[2] BIA is a practical, portable, noninvasive tool that poses minimal risks and low costs relative to the other body composition assessment methods. These characteristics allow its use in any setting, such as epidemiological and clinical studies, and render BIA an ideal assessment technique for follow-up studies, in which repeated measurements are necessary and easily obtained. At the present time, SF-BIA or MF-BIA devices can measure total body or segmental impedance or its components (resistance and reactance). All BIA devices, except BIA spectroscopy, use equations/algorithms that have been developed based or validated against other body composition reference methods. BIA equations are highly specific for the device and for the population for which they were developed. Therefore, BIA validation studies only have an external validity when the same combination of device/equation/population is used.[80] An acceptable mean level accuracy for BIA assessments has been established in healthy, nonobese participants.[93] In the clinical setting, good correlations between BIA-assessed body compartments were found when compared with gold standard techniques; however, the large limits of agreement confirmed the need for cautious interpretation for individual patients.[94] Because BIA precision and accuracy are highly influenced by fever, certain medications, and fluid and electrolyte disturbances, these common clinical occurrences may nonuniformly alter BIA findings among clinical populations.

Future Directions

BIA demonstrates good correlations with superior reference methods in several outpatient populations; however, very few BIA validation studies have been performed in

hospitalized patients. Given its superiority to other body composition methods with regard to portability, cost, and risk, the lack of validation studies may reflect limited access to the necessary reference methods, such as DXA or CT, for validation. This merits exploration in future research efforts. Additionally, an emerging area of research is derived from the fact that BIA can accurately estimate phase angle (PA), now considered a surrogate of not only LM[95] but also of LM quality.[96] Different from BIA body composition estimations, PA is directly obtained from resistance and reactance; raw BIA parameters are available from any single frequency BIA device. Intervention studies, which include resistance training, show improvements in PA, which then correlate with gains in LM.[97] Future studies comparing PA with skeletal muscle estimation from CT images or other gold standard techniques may show its relevance and wide-ranging applications for body composition assessment in clinical settings.

Summary

Initially and ideally, the task force wanted to compare studies by target population and within body composition assessment methodology (eg, patients with hepatic disease analyzed using DXA). Additionally, the goal was to further analyze studies comparing investigations that included healthy volunteers and a clinical population within body composition assessment methodology (eg, patients with hepatic disease vs healthy controls analyzed using DXA). It was also speculated that the analyses would include studies by exact hardware (eg, patients with hepatic disease vs healthy controls analyzed using a specific DXA machine). When the searches failed to yield any studies that met these criteria to apply and converge data for evaluation using GRADE, the task force was charged with establishing the diagnostic accuracy of these methods in nonhealthy populations. The PRISMA recommendations[5] are summarized and include 22 items. Only the first 13 items in the checklist were available in the studies included in this systematic review. Thus, for the final analyses, correlation coefficients were combined based on a specific body compartment and all disease entities and hardware grouped together (eg, CT VAT vs DXA abdominal fat, any disease state, any manufacturer). Although this was not the original intended approach and the results do not highlight the usefulness of these techniques in certain clinical populations, this review and evaluation provides a snapshot of where the science is today in the clinical arena. This work lays an important foundation for establishing guidelines in the future and affords the opportunity to make recommendations for advancement.

To comprehensively evaluate the utility of these techniques in specific patient populations, several gaps require attention going forward. First, the lack of standardized body composition terminology across studies is problematic, regardless of technique. A multitude of names are used by investigators for similar, although distinct, body compartments. As noted in Table 1, lean soft tissue is often referred to as skeletal muscle, muscle tissue, or FFM. However, the term FFM technically includes lean soft tissue plus the bone mineral compartment, whereas skeletal muscle does not. Similar issues arose involving studies investigating abdominal obesity, as the terms VAT, intraabdominal fat, trunk fat, visceral fat, or visceral FM were used by numerous investigators. Unifying and applying appropriate body composition terminology is an important fundamental step to avoid confusion, to improve accuracy, and to allow more precise comparisons across studies. For example, CT analyses can differentiate 2 types of subcutaneous adipose tissue—superficial vs deep—and studies support differential disease risks associated with these distinct tissues.[98,99] Using the term intraabdominal fat or trunk fat would not permit this important differentiation. Thus, as imaging becomes more sophisticated, using the appropriate language to discriminate and distinguish these compartments is vital to advancing general knowledge on the potential relationships between specific body compartments and health outcomes. Researchers, clinicians, and editors should ensure that future work apply and adhere to a similar human body composition vernacular.

Second, there is a considerable need to develop cut-points to categorize characteristics of interest in body composition, such as "malnourished," "inadequate or optimal lean mass," or "inadequate, adequate, or excess fat mass." Without these cut-points to then classify or categorize patients, clinicians are greatly limited in their abilities to utilize measures of body composition in the context of patient care. For example, the term "sarcopenia" is often used synonymously with the term "malnourished." Considering that the root cause of these 2 conditions may be inherently different, using these terms interchangeably is clinically inaccurate. Furthermore, once cut-points are established, sensitivity and specificity measurements (thus, true and/or false positives and true and/or false negative classifications) with 95% confidence intervals can be calculated. For now, body composition data must be evaluated as a continuous variable, and only agreement estimates can be used to appraise the overall quality of the studies used.

Third, basic principles of study design and inclusion require greater focus. Studies with sufficient sample size and statistical power are needed. Only a few studies (DXA and BIA) included in this systematic review possessed study populations larger than 100 participants. To achieve adequate numbers, studies of longer duration are warranted to ensure adequate accrual or investigations with >1 study site may be required. Furthermore, to make adequate comparisons across techniques, the inclusion of "healthy controls" is critical. This review was greatly limited by this

basic principle and by the lack of inclusion of minority populations. Several studies have documented differences in body composition by race/ethnicity for predicting disease risk.[100-102] Therefore, consideration should be given to potential sources of relevant comparative data in the public domain (eg, NHANES) or for collaborating with investigators who have published in diverse, healthy populations. Equally important are concerns related to statistical analyses and data interpretation. One of the challenges in working with body composition data is the belief that these tissue compartments behave independently. That is, as LM changes, FM stays the same (or vice versa). For interventions focused on diet and physical activity, changes in both compartments would be anticipated. Therefore, in order to examine clinically relevant outcomes, it is important to appreciate and understand the interplay between these metabolically and anatomically distinct compartments. Moreover, linking changes in lean and/or FM with serum biomarkers of disease (eg, blood lipids, insulin, leptin, adiponectin, C-reactive protein) may require sophisticated statistical modeling to account for simultaneous, bidirectional changes.

In conclusion, the task force acknowledges the paucity of high-level evidence for body composition assessment in clinical populations, especially those with the same underlying diagnosis. Although the systematic search strategy followed by meticulous data abstraction allowed us to capture the majority of relevant studies, it is important to note that a portion of the data abstraction was conducted in studies that were not necessarily driven by validity but possessed other study purposes. Thus, the task force may have inadvertently missed studies that could have provided evaluable data points. Also, the analyses were limited to aggregating simple agreement statistics across studies, and several authors did not report such findings. Bland-Altman and concordance correlation coefficients (which reflect precision and accuracy) would have been ideal to assess agreement between body composition methodologies; however, the availability of these statistics would have restricted this review to only a handful of investigations. Regardless of these limitations and potential oversights, we have summarized key areas for future investigations and future guideline development. As our interest in body composition continues to gain substantial interest, a more comprehensive evaluation of the validity of these techniques in various clinical populations is warranted, especially those that reflect the ethnic and racial diversity in our hospitals and clinics.

Acknowledgments

Statement of Authorship

Patricia Sheean contributed to conception, design, analysis, and interpretation of the research; M. C. Gonzalez contributed to conception, design, analysis, and interpretation of the research; C. M. Prado contributed to conception, design, analysis, and interpretation of the research; L. McKeever contributed to the acquisition, conception, analysis, and interpretation of the research; A. M. Hall contributed to the design and analysis of the research; and C. A. Braunschweig contributed to the conception, design, analysis, and interpretation of the research.

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