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A comparison of three methods to assess body composition

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ABSTRACT

Objective: The aim of this study was to compare the accuracy of measurements of body composition made using dual x-ray absorptiometry (DXA), analysis of computed tomography (CT) scans at the L3 vertebral level, and bioelectrical impedance analysis (BIA).
Methods: DXA, CT, and BIA were performed in 47 patients recruited from two clinical trials investigating metabolic changes associated with major abdominal surgery or neoadjuvant chemotherapy for esophagogastric cancer. DXA was performed the week before surgery and before and after commencement of neoadjuvant chemotherapy. BIA was performed at the same time points and used with standard equations to calculate fat-free mass (FFM). Analysis of CT scans performed within 3 mo of the study was used to estimate FFM and fat mass (FM).
Results: There was good correlation between FM on DXA and CT ($r^2 = 0.6632$; $P < 0.0001$) and FFM on DXA and CT ($r^2 = 0.7634$; $P < 0.0001$), as well as FFM on DXA and BIA ($r^2 = 0.6275$; $P < 0.0001$). Correlation between FFM on CT and BIA also was significant ($r^2 = 0.2742$; $P < 0.0001$). On Bland–Altman analysis, average bias for FM on DXA and CT was 0.2564 with 95% limits of agreement (LOA) of −9.451 to 9.964. For FFM on DXA and CT, average bias was −0.1477, with LOA of −8.621 to 8.325. For FFM on DXA and BIA, average bias was −3.792, with LOA of −15.52 to 7.936. For FFM on CT and BIA, average bias was −2.661, with LOA of −22.71 to 17.39.
Conclusion: Although a systematic error underestimating FFM was demonstrated with BIA, it may be a useful modality to quantify body composition in the clinical situation.

Introduction

The assessment of fat-free mass (FFM) and fat mass (FM) has been shown to correlate better with relevant reduction in muscle mass than change in body weight or body mass index (BMI) [1]. Sarcopenia recently has been defined as reduced skeletal muscle mass associated with low muscle strength, poor physical performance, or both [2]. Skeletal muscle index at the L3 level, normalized for height, of ≤38.5 cm^2/m^2 in women and ≤52.4 cm^2/m^2 in men [1,3] has been used as part of the definition of sarcopenia. Several studies have suggested that presence of sarcopenia, particularly in obese patients, is associated with poor outcomes in some cancers [1,4]. Therefore, the analysis of body composition is being translated from a research tool to a potentially important clinical prognosticator.

A number of techniques have been used to assess body composition. Dual x-ray absorptiometry (DXA) is the gold standard noninvasive method of measuring FM and FFM [5]. However, it requires exposure to radiation, albeit at a low dose. Recently, analysis of computed tomography (CT) or magnetic resonance imaging (MRI) scans using software to assess surface areas of different tissues at a certain level has emerged as a useful technique for assessing FFM and FM and calculating skeletal muscle index [6]. Scans that are taken for clinical indications are used to avoid exposing the patient to repeated imaging and, in the case of CT, high radiation doses. Bioelectrical impedance analysis (BIA) has been used as a simple, noninvasive tool for assessment of body

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composition over the past 40 y [7]. Results have been reported as comparable to those obtained from other methods in some studies [8,9]; however, there are reports that question its accuracy. This study sought to compare results obtained for measures of body composition from CT analysis and BIA with DXA.

Methods

Results were taken from two clinical trials on metabolic effects of surgery [10] and neoadjuvant chemotherapy (NAC) for esophagogastric cancer [11].

Study protocols

The first study included 16 obese and 16 non-obese patients aged between 18 and 80 y [10]. Obese patients had BMI >30 kg/m^2 or waist circumference ≥94 cm in men or ≥80 cm in women. Non-obese patients had BMI 18.5 to 25 kg/m^2 or waist circumference <94 cm in men or <80 cm in women. Body composition was analyzed preoperatively before any intervention, using DXA scans, BIA, and analysis of CT scans.

The second study included two cohorts of patients receiving NAC for esophagogastric cancers [11]. The first cohort (n = 5) was observed before any intervention was introduced (i.e., they received current standard hospital dietetic care). The second cohort (n = 10) was enrolled into an intensive nutritional support program during NAC. Interventions in the support program group include dietetic assessment/advice and oral nutritional supplementation with or without nasojejunal supplementation, as deemed appropriate by the study dietitian. Body composition was analyzed before any intervention, using DXA scans, BIA, and analysis of CT scans in both cohorts (N = 15).

Body composition analysis

All DXA scans were performed by research personnel trained and certified in DXA using a GE LUNAR II scanner (GE Healthcare, Madison, WI, USA).

Electronic copies of CT scans taken routinely for clinical reasons were obtained from the hospital Picture Archiving and Communication System. Once accessed, the scans were anonymized, and one CT image slice at the third lumbar

Table 1
Participant demographic characteristics

Parameter	All patients (N = 47)	Study 1 (n = 32)	Study 2 (n = 15)	*P*-value
Age, y (median, IQR)	65 (57–68)	61 (50–67)	66 (59–70)	0.08
Gender				
Male	37	23	14	
Female	10	9	1	
Baseline BMI, kg/m^2 (mean ± SD)	27.65 ± 5.31	28.3 ± 5.45	26.24 ± 4.86	0.112
Waist circumference, cm (median, IQR)	94 (87–105.1)	93 (86.5–106.5)	94 (88–102)	0.99
Comorbidities				
Ischemic heart disease	4	3	1	
Inflammatory bowel disease	6	6	0	
Peripheral vascular disease	1	0	1	
Cerebrovascular disease	1	0	1	
Previous cancer	5	4	1	
Regular medications				
Diuretic	3	2	1	
Steroid	1	1	0	
Antihypertensive	14	7	7	
Statin	9	2	7	
NSAID	8	8	0	
Opiate	9	8	1	
Proton pump inhibitor	19	10	9	
Bronchodilator	4	3	1	
Antipsychotic	2	2	0	
Surgery type (study 1)				
Pancreatic bypass procedure	9	9		
Whipple procedure	6	6		
Colorectal resection	6	6		
Incisional hernia repair	3	3		
Formation of/surgery to ileoanal J pouch	2	2		
Reversal of colostomy	2	2		
Abdominal rectopexy	1	1		
Completion proctectomy	1	1		
Distal pancreatectomy/splenectomy	1	1		
Open bile duct exploration	1	1		
Tumor location (study 2)				
Mid esophagus	2		2	
Distal esophagus	5		5	
Esophagogastric junction	7		7	
Stomach	1		1	
Pathology (study 2)				
Adenocarcinoma	13		13	
Squamous cell carcinoma	2		2	
pTNM classification (study 2)				
$pT_{is}N_1\ M_0$	1		1	
$pT_2\ N_0\ M_0$	2		2	
$pT_2\ N_1\ M_0$	1		1	
$pT_3\ N_0\ M_0$	3		3	
$pT_3\ N_1\ M_0$	2		2	
$pT_3\ N_2\ M_0$	1		1	
$pT_3\ N_3\ M_0$	1		1	
$pT_{4\ a}N_1\ M_0$	1		1	

IQR, interquartile range; NSAID, nonsteroidal antiinflammatory drug.

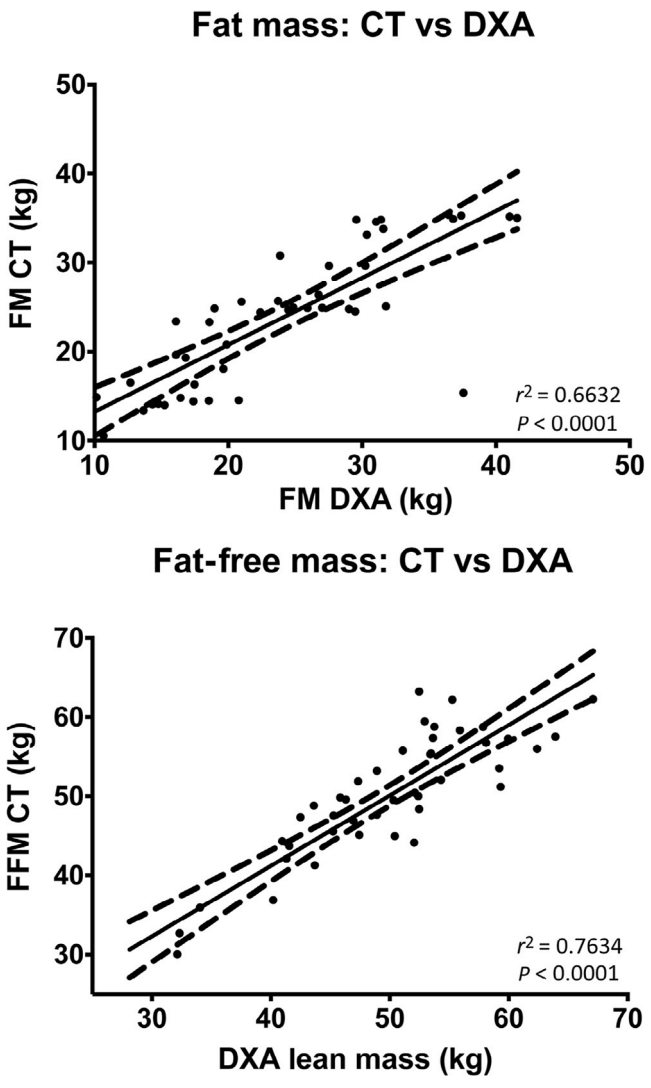

Fig. 1. Correlation between CT and DXA. CT, computed tomography; DXA, dual x-ray absorptiometry; FFM, fat-free mass; FM, fat mass.

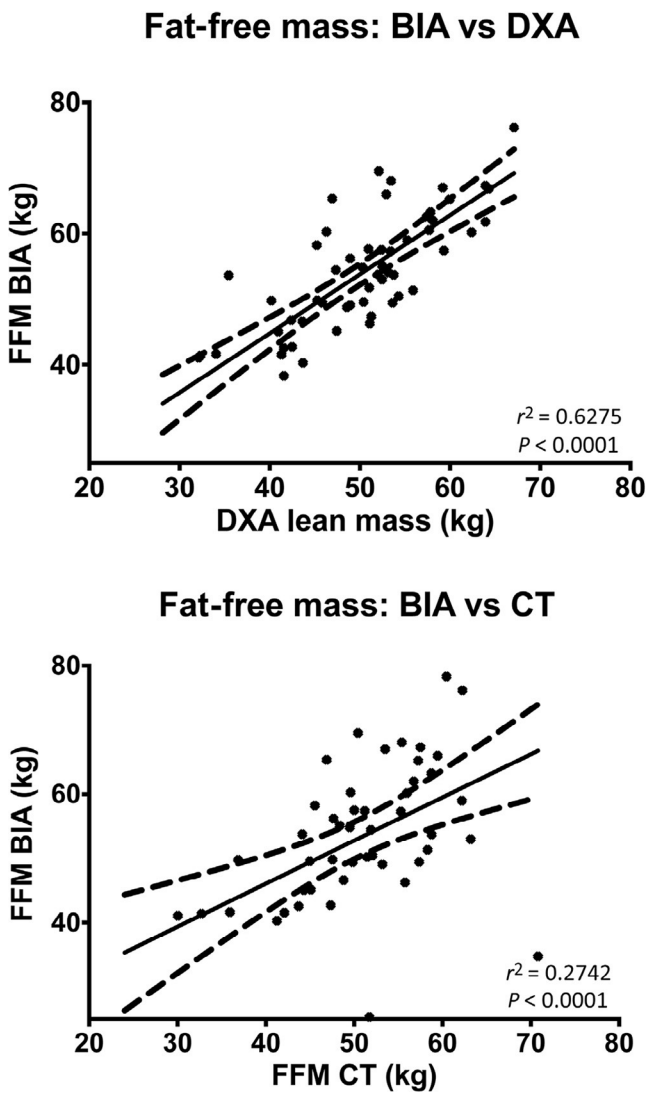

Fig. 2. Correlation between BIA and DXA/CT. BIA, bioelectrical impedance analysis; CT, computed tomography; DXA, dual x-ray absorptiometry; FFM, fat-free mass.

vertebrae (L3) level was selected. The images were analyzed using SliceOmatic V4.2 software (Tomovision, Montreal, Canada) to calculate the surface area of the specific tissue types: skeletal muscle tissue, visceral adipose tissue, and subcutaneous/intramuscular adipose tissue. Within the L3 region are the psoas, erector spinae, quadratus lumborum, transversus abdominus, external and internal obliques, and rectus abdominus muscles.

SliceOmatic software relies on the variation in density of the different tissue types to identify and, thereby, quantify the surface area of the tissue of interest. The different tissue densities are represented by specific Hounsfield unit (HU) thresholds. The HU thresholds used for skeletal muscle were −29 to +150 [12]; for visceral adipose tissue, −150 to −50 [13]; and for subcutaneous and intramuscular adipose, −190 to −30 [14]. Once the tissues were identified, the cross-sectional surface area (cm^2) of each tissue was calculated by the software [15].

These data were used to estimate whole body stores of FFM and FM using the regression equations of Mourtzakis et al, as given here [16]:

$$\text{FFM (kg)} = 0.3 \times \text{skeletal muscle area at L3 (cm}^2\text{)} + 6.06$$
$$\text{FM (kg)} = 0.042 \times \text{fat area at L3 (cm}^2\text{)} + 11.2$$

BIA was performed with a Bodystat QuadScan 400 (Bodystat Ltd., Isle of Man) at 5, 50, 100, and 200 kHz. Whole-body measurements were taken with the individual in a supine position on a nonconducting surface, with arms slightly abducted from the trunk and the legs slightly separated. Surface electrodes were placed on the right side of the body on the dorsal surface of the hands and feet proximal to the metacarpal-phalangeal and metatarsal-phalangeal joints, respectively, medially between the distal prominences of the radius and ulna, and between the medial and lateral malleoli at the ankle. Standardized equations for men and women were used to calculate FFM from resistance measurements obtained by BIA [17].

Statistical analysis

Data are presented as mean ± SD or median with interquartile range, depending on their distribution. The Student's *t* test was used to compare parametric data and Mann–Whitney U test was used to compare nonparametric data. The correlation between different methods was assessed using Spearman's coefficient of rank correlation. Bland–Altman plots were used to estimate agreement between methods and bias. Statistical analysis was performed using GraphPad Prism v6.04 (GraphPad Software Inc, La Jolla, CA, USA).

Ethics and trial registration

Ethical approval for both studies was obtained from the Nottingham Research Ethics Committee East Midlands–Northampton. The studies were registered at www.controlled-trials.com (ISRCTN16597586 and ISRCTN15674981). All studies were performed in accordance with the Declaration of Helsinki of the World Medical Association.

Table 2
Comparison of results from DXA, CT, and BIA

Parameter	DXA measurement, kg (mean ± SD)	CT measurement, kg (mean ± SD)	BIA measurement, kg (mean ± SD)
Study 1 (n = 32)			
Fat mass	27.14 ± 7.93	26.52 ± 7.69	
Lean mass/fat-free mass	48.52 ± 10.26	54.80 ± 11.78	48.39 ± 12.85
Study 2 (n = 15)			
Fat mass	22.50 ± 7.37	25.54 ± 9.74	
Lean mass/fat-free mass	51.76 ± 6.20	53.63 ± 6.83	44.03 ± 15.07

Results

Fifty-six DXA scans, 48 CTs, and 61 BIAs were performed in 47 patients. Forty-seven sets of paired results of DXA–CT and 56 paired DXA–BIA results were available. Patient demographic characteristics are provided in Table 1.

Good correlation was found between FM on DXA and CT (r^2 = 0.6632; P < 0.0001) and FFM on DXA and CT (r^2 = 0.7634; P < 0.0001; Fig. 1). There was significant correlation between FFM on DXA and BIA (r^2 = 0.6275; P < 0.0001). Correlation between FFM on CT and BIA was statistically significant (r^2 = 0.2742; P = 0.0001; Fig. 2). Table 2 shows the results of BIA, CT, and DXA in each study.

On Bland–Altman analysis, average bias for FM on DXA and CT was 0.2564, and 95% limits of agreement (LOA) were –9.451 to 9.964. For FFM on DXA and CT, average bias was –0.1477, and LOA were –8.621 to 8.325. For FFM on DXA and BIA, average bias was –3.792, and LOA were –15.52 to 7.936. For FFM on CT and BIA, average bias was –2.661, and LOA were –22.71 to 17.39 (Fig. 3).

Discussion

The aim of the present study was to compare the accuracy of commonly used measures of body composition. Body composition has emerged as an important marker of physiological function and has a close relationship with metabolism. Longitudinal assessment of body composition allows monitoring of health and disease and has implications for the understanding of clinical and nutritional interventions [18].

BMI has been used as an indicator of risk related to obesity in a variety of studies [19], but it allows no differentiation between adipose tissue and lean mass [20]. Therefore, methods of determining body composition more accurately have emerged. These include water dilution, densitometry, anthropometry, DXA, analysis of CT and MRI, and BIA. The use of DXA is limited in some situations due to the cost of equipment, the need for trained operators, the lack of portability, and the need for exposure to ionizing radiation. CT also requires expensive equipment and trained operators and exposes the patient to a high dose of Cradiation. The analysis of body composition from CT and MRI

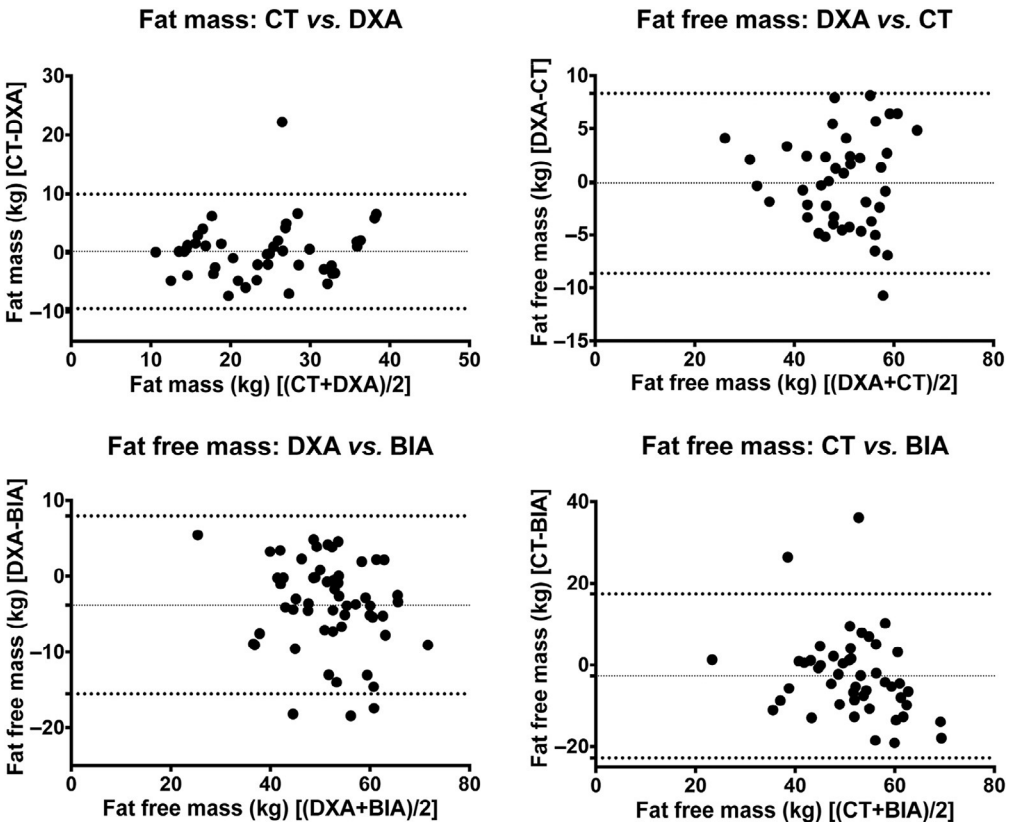

Fig. 3. Bland–Altman analysis of agreement between DXA, CT, and BIA. BIA, bioelectrical impedance analysis; CT, computed tomography; DXA, dual x-ray absorptiometry.

necessitates specialist software and training. BIA is practical, noninvasive, and easy to perform.

However, studies evaluating BIA have provided inconsistent findings, with some reporting good accuracy [21,22], whereas others have shown poor results, particularly in obese populations [23–25]. There are several equations available for the estimation of body composition from BIA. Many are sex specific and some have corrections of hydration constants for obese populations. The adoption of an inappropriate equation may explain these conflicting results. Additionally, there is variability in the equipment used to measure BIA, with some studies reporting single frequency and, more recently, some reporting multiple frequency (MF-BIA).

The present study demonstrated excellent correlation between results obtained from DXA and analysis of CT scans. There was a very strong correlation between results obtained from DXA and MF-BIA. The correlation between CT analysis and results obtained from BIA was poorer but still statistically significant. This also was reflected in the Bland–Altman analysis. Average bias was low for CT–DXA but higher for comparisons with BIA. Limits of agreement were much wider for CT versus BIA compared with DXA versus BIA and higher for DXA versus BIA than for DXA versus CT.

This study had a number of strengths. Using results from two clinical trials provided a large volume of data for comparison of methods of assessing body composition. It allowed a direct comparison of methods, as all techniques were assessed in all patients. The patients in the present study were a heterogeneous group, with both obese and lean individuals undergoing elective abdominal surgery. Others were patients with esophagogastric cancer, and therefore their hydration status may have been inconsistent. This may have had an effect on readings obtained from BIA. A previous study showed that MF-BIA underestimated body fat to a greater extent in obese men than in women [26]. However, this could have had an effect on DXA readings and even CT measurements.

Conclusion

Although BIA may not be as accurate for estimation of body composition as other more invasive methods, a recent systematic review has suggested that it is useful if implemented as a longitudinal tool (e.g., before and after an intervention), as long as hydration status does not change [27]. BIA is a practical, simple, inexpensive, and noninvasive method to access body composition (FFM) compared with DXA and CT. In the present study, BIA was used to estimate body composition, in combination with DXA and analysis of CT scans, before and after surgical intervention or chemotherapy. Therefore, in this context, it is a useful tool for research and particularly for clinical purposes.

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