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Agreement between bioelectrical impedance and dual energy X-ray absorptiometry in assessing fat, lean and bone mass changes in adults after a lifestyle intervention

Duncan J Macfarlane , Natalie T-Y Chan, Michael A Tse and Glen M Joe

Institute of Human Performance, University of Hong Kong, Pokfulam, Hong Kong

ABSTRACT

We aimed to assess the agreement of a commercially available bioelectrical impedance analysis (BIA) device in measuring changes in fat, lean and bone mass over a 10-week lifestyle intervention, with dual energy X-ray absorptiometry (DXA) as reference. A sample of 136 volunteers (18–66 years) underwent a physical activity intervention to enhance lean mass and reduce fat mass. BIA (Tanita BC545) and DXA (Hologic Explorer) measures of whole-body composition were taken at baseline and at the end of the intervention. After an average of 74 ± 18 days intervention, DXA showed significant changes in 2 of 3 outcome variables: reduced fat mass of 0.802 ± 1.092 kg ($P < 0.001$), increased lean mass of 0.477 ± 0.966 kg ($P < 0.001$); minor non-significant increase of 0.007 ± 0.041 kg of bone mass ($P = 0.052$). The respective changes in BIA measures were a significant reduction of 0.486 ± 1.539 kg fat ($P < 0.001$), but non-significant increases of 0.084 ± 1.201 kg lean mass ($P = 0.425$), and 0.014 ± 0.091 kg bone ($P = 0.074$). Significant, but moderately weak, correlations were seen in absolute mass changes between DXA and BIA: 0.511 (fat), 0.362 (lean) and 0.172 (bone). Compared to DXA, BIA demonstrated mediocre agreement to changes in fat mass, but poor agreement to lean mass changes. BIA significantly underestimated the magnitude of changes in fat and lean mass compared to DXA.

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Fat mass; lean mass; agreement; intervention

Introduction

It is widely accepted that increasing levels of obesity place considerable stress not only on overweight/obese individuals, but also on public health expenditures. Nutritional and physical activity interventions provide the potential to mitigate some of the negative consequences of poor lifestyle habits. Monitoring changes only in body mass fails to provide the more detailed feedback on body composition, which is often recommended (Thomson, Brinkworth, Buckley, Noakes, & Clifton, 2007). Advanced measurement of body composition using dual-energy X-ray absorptiometry (DXA) provides detailed analyses that are considered both valid and reliable, to the extent of being a reference method for body composition comparison (Anderson, Erceg, & Schroeder, 2012; Bosy-Westphal et al., 2008). However, DXA has several limitations in that: it is not routinely accessible since it requires a substantial capital outlay; it requires trained operators; it is not portable for field assessments; and it exposes participants to a very mild dose of ionising radiation. Therefore, use of such equipment is counter to the behavioural intervention theories, which often suggest methods to facilitate motivation and enhance compliance that include self-monitoring strategies (Michie, Johnston, Francis, Hardeman, & Eccles, 2008). For adequately powered field studies, the use of relatively inexpensive, simple and accurate methods that can be used to monitor changes in body composition, especially fat and lean mass, and using a

real-world scenario rather than a highly-controlled laboratory setting, would be more appropriate.

Consumer-based bioelectric impedance analysis (BIA) devices have become increasingly popular for self-monitoring of body composition as they are often affordable, portable, safe and require no training for use (Kyle et al., 2004a, 2004b). Although studies often report extremely high levels of reliability for a range of BIA devices (Macfarlane, 2007), there is less agreement on their criterion validity. When compared to DXA, some cross-sectional studies using healthy adults have shown acceptable levels of validity using single-frequency (Demura, Sato, & Kitabayashi, 2004) and multi-frequency devices (Anderson et al., 2012; Sun et al., 2005); however, others reported less favourable comparisons (Andreoli et al., 2002).

Although BIA devices may show significant bias compared to DXA in cross-sectional studies, it is important to be able to find widely available methods that can accurately monitor changes in body composition at the individual level during physical activity and/or dietary interventions. Simple mass scales only monitor changes in mass during lifestyle interventions, but will not vary if an individual loses 2 kg of fat whilst gaining 2 kg of lean mass. Despite attaining positive changes in body composition, the zero change in body mass may sufficiently demotivate the individual to discontinue the lifestyle intervention. Consequently, improved self-monitoring methods would help consumers

more accurately monitor their body composition changes during lifestyle interventions.

A relatively small number of similar studies have examined whether single- and/or multi-frequency BIA devices can accurately monitor changes in body composition during weight-loss programmes, although most focus on overweight/obese or clinical patients (Jebb et al., 2007; Li et al., 2013; Miyatani, Yang, Thomas, Craven, & Oh, 2012; Pietiläinen et al., 2013; Thomson et al., 2007; Verdich et al., 2011). These studies report inconsistent findings; most reported BIA accurately monitoring changes over time compared to DXA, but some (Verdich et al., 2011) suggested that the large individual errors limit BIA to monitoring changes at the group level only. Even fewer studies have examined longitudinal changes in body composition on normal-weight healthy individuals.

Whilst BIA is routinely used to estimate fat mass, it also has the advantage of being the only widely available and simple electronic predictive method that estimates lean mass (Böhm & Heitmann, 2013; Wells & Fewtrell, 2006) and, indeed, can estimate muscle mass accurately compared with DXA (Bosaeus, Wilcox, Rothenberg, & Strauss, 2014). More recently, BIA has also been used to develop predictive equations to estimate bone mineral content (Patil, Patkar, Mandlik, Kuswarkar, & Jindal, 2012). Yet, to our best knowledge, no field study to date has examined the ability of recently-developed portable dual frequency BIA to monitor changes in fat mass, lean mass and bone mass over a training programme in a mixed group of predominantly normal-weight healthy adults. Based on studies cited earlier, it was hypothesised that, compared to the reference DXA, the Tanita BIA would adequately monitor qualitative changes (a gain or loss) in fat mass and lean mass only, but be less sensitive in monitoring quantitative changes in body composition at the individual level.

Methods

Participants

A sample of 136 adults aged 18–66 years volunteered (42 males, 94 females; mean age 44 years, SD = 12), with their baseline anthropometric characteristics shown in Table 1. The participants were all recruited through the “Exercise for Life” programme within the Active Health Clinic at the University of Hong Kong, and were predominantly university staff members or family members. All participants completed a health history questionnaire, the PAR-Q, and signed an informed consent

Table 1. Participant information showing means \pm SD or *n* (%), (BMI = body mass index).

	Male (<i>n</i> = 42)	Female (<i>n</i> = 94)	Total (<i>n</i> = 136)
Age (years)	45.1 \pm 13.9	43.3 \pm 11.0	44.2 \pm 12.0
Stature (m)	1.71 \pm 0.07	1.59 \pm 0.07	1.63 \pm 0.09
Mass (kg)	77.4 \pm 12.0	60.3 \pm 11.0	65.3 \pm 13.6
BMI (kg/m ²)	26.3 \pm 3.3	23.5 \pm 3.6	24.3 \pm 3.7
Overweight \geq 25 BMI	23 (55%)	22 (23%)	45 (33%)
Obese \geq 30 BMI	6 (14%)	4 (4%)	10 (7%)
Between tests (days)	74.2 \pm 17.3	74.2 \pm 18.3	74.2 \pm 17.9

form; the study was approved by the Human Research Ethics Committee for Non-clinical Faculties at the University of Hong Kong.

Protocol

The Exercise for Life programme was designed to be a 10-week “real-world” lifestyle/fitness intervention aimed at enhancing metabolic health, with expected reductions in fat mass and improvements in lean mass. An exercise programme was individually tailored for each participant and monitored by a qualified exercise specialist. Each person participated in a supervised exercise class 3 days per week, beginning with a range of health-related measurements at baseline that included stature (to nearest millimetre, Seca stadiometer), mass (to nearest 0.1 kg, Tanita BC545 N) and body composition using both BIA and DXA. These measurements were repeated at the end of the intervention period using the same standardised procedures.

Bioelectrical impedance analysis (BIA)

The BIA machine was a portable Tanita Innerscan BC545N (Tanita Corp, Tokyo). This uses 10 electrodes (3 under each foot, and 2 in each hand using a retractable handle), with a dual-frequency analysis at 6.25 and 50 kHz (Knechtle et al., 2010), to provide estimates of total (and segmental) lean mass, fat mass and bone mass. Participants were asked to refrain from vigorous physical activity, or consuming food, alcohol or diuretic fluids for 4 h beforehand, to be normally hydrated and were invited to void bladder and bowels immediately prior to measurement. Each participant wore minimal clothing, had their gender, age and stature entered into the device, then stood on the device with bare feet and grasped the retractable handle according to the manufacturer’s recommendations. All BIA results were immediately recorded manually by the experimenter.

Dual-energy X-ray absorptiometry (DXA)

A full body DXA scanner (Explorer S/N 91075, Hologic Inc., Waltham, USA) was used to measure body composition and to report total lean mass, fat mass and bone mass. For the purpose of this study, DXA was considered the reference measure. Trained and ISCD-certified DXA technicians performed all DXA scans according to the manufacturer’s guidelines in operating the machine, positioning the participants and analysing the results. For the facility used in this study, typical coefficients of variation for each body compartment from duplicate analyses are 0.4% for lean mass, 1.4% for fat mass and 1.0% for bone mass.

Statistical analysis

The variables of lean mass, fat mass and bone mass were compared for both the BIA and the DXA using a within-method analysis (pre vs. post), and also a between-method analysis (BIA vs. DXA) via paired *t*-tests with statistical significance determined when *P* < 0.05, as well as Bland–Altman

analyses (Bland & Altman, 1986). Percentage changes after intervention, their limits of agreement (LOA), along with Cohen effect sizes (*d*) were also calculated with small, medium and large effects defined as approximately 0.2, 0.5 and 0.8, respectively (Cohen, 1988). Analyses were conducted using MedCalc statistical software (MedCalc Software, Ostend, Belgium).

Results

As shown in Table 2, over the 10 weeks of the lifestyle intervention, the participants on average reduced their total body mass by 313 g (−0.5%), which was statistically significant ($t = 2.43$, $P = 0.008$), although with a small effect size (0.20). The 0.802 kg reduction in fat mass measured by the DXA was significant ($t = 8.53$, $P < 0.001$), and a −3.7% loss of fat mass, which was statistically larger ($t = 3.072$, $P = 0.003$) than the significant 0.486 kg reduction in fat mass measured by the Tanita BIA ($t = 3.68$, $p < 0.001$), with effect size changes being small (<0.20). The reduction in fat mass measured by the BIA represented just over half (60.5%) of the fat loss measured by the reference DXA, and represented a substantial effect size difference of 0.72. The difference between the fat loss assessed by BIA and DXA is also shown in the Bland–Altman graph (Figure 1), which depicts a systematic error (with a mean bias of 0.32 kg; LoA −2.39 to 3.03) that is proportional to the size of the measured value, with the random errors relatively uniform. The mean bias of 0.32 kg shows that the BIA typically underestimated the fat mass loss. In terms of the qualitative/directional agreement, BIA only agreed 70% of the time with the directional (gain vs. loss of fat) when compared to DXA.

Over the course of the intervention, the DXA monitored a statistically significant mean gain of 0.477 kg of lean mass ($t = -5.77$, $P < 0.001$), representing a 0.3% gain in lean mass, which was not statistically different ($t = 0.86$, $P = 0.392$)

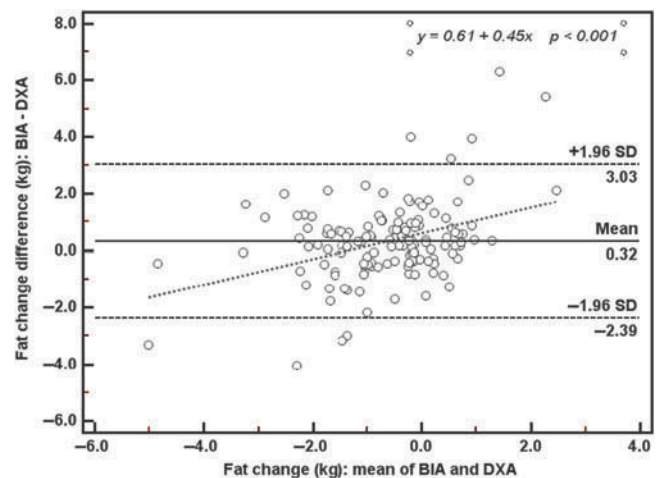


Figure 1. Bland–Altman plot of fat change-score comparing the mean of dual-energy X-ray absorptiometry (DXA) and bioelectrical impedance analysis (BIA) against the difference between BIA and DXA.

compared to the non-significant mean gain of 0.084 kg measured by BIA; effect size changes in lean mass were both trivial (<0.1). The increase in lean mass measured by the BIA represented only 17.6% of the lean mass gain measured by the reference DXA, with the effect size difference being substantial (0.79). The Bland–Altman graph (Figure 2) depicts a systematic error (with a mean bias of −0.39 kg; LoA 2.05 to −2.84) that is again proportional to the size of the measured value, with the random errors relatively uniform. The mean bias of −0.39 kg indicates the BIA typically underestimated the lean mass gained. The BIA again only agreed 70% of the time with qualitative/directional (gain vs. loss of lean mass) when compared to DXA.

Not unexpectedly, changes in bone mass were minor, with trivial effect sizes. The DXA monitored a statistically non-significant mean gain of 0.007 kg of bone tissue ($t = -1.96$, $P = 0.052$), representing a 0.3% gain in bone mass, which

Table 2. Baseline, post-intervention, change-score data and statistics for BIA and DXA measurements, as well as comparisons of change-scores (delta) between devices: means \pm SD.

	Baseline, kg	Post-intervention, kg	Change-score, kg, (%)	Change-score LOA	Change-score: P-value (t-test)	Change-score: Effect size, <i>d</i>	Correlation, <i>r</i> (P-value)
Weight (kg)	65.287 \pm 13.603	64.975 \pm 13.351	−0.313 \pm 1.500 (−0.5%)	−3.25 to 2.63	0.008	0.20 (small)	
Fat DXA (kg)	21.981 \pm 6.589	21.179 \pm 6.197	−0.802 \pm 1.092 (−3.6%)	−2.95 to 1.35	<0.001	0.16 (small)	
Fat BIA (kg)	19.554 \pm 6.898**	19.068 \pm 6.827	−0.486 \pm 1.539 (−2.5%)	−3.50 to 2.53	<0.001	0.17 (small)	
delta-Fat (DXA v BIA)					0.003	0.72 (large)	0.511 (<0.001)
Lean DXA (kg)	42.561 \pm 9.485	43.039 \pm 9.663	0.477 \pm 0.966 (+1.1%)	−1.42 to 2.37	<0.001	0.09 (trivial)	
Lean BIA (kg)	43.255 \pm 9.967**	43.339 \pm 9.908	0.084 \pm 1.201 (+0.2%)	−2.27 to 2.44	0.425	0.08 (trivial)	
delta-Lean (DXA v BIA)					<0.001	0.79 (large)	0.362 (<0.001)
Bone DXA (kg)	2.143 \pm 0.392	2.150 \pm 0.388	0.007 \pm 0.041 (+0.3%)	−0.07 to 0.09	0.052	0.08 (trivial)	
Bone BIA (kg)	2.543 \pm 0.496**	2.557 \pm 0.496	0.014 \pm 0.091 (+0.6%)	−0.16 to 0.19	0.074	0.11 (trivial)	
delta-Bone (DXA v BIA)					0.392	0.93 (large)	0.172 (0.047)

Notes: BIA = bioelectrical impedance analysis; DXA = dual-energy X-ray absorptiometry; LOA = limits of agreement; ** = BIA and DXA values at baseline were significantly different (t-test: $P < 0.01$)

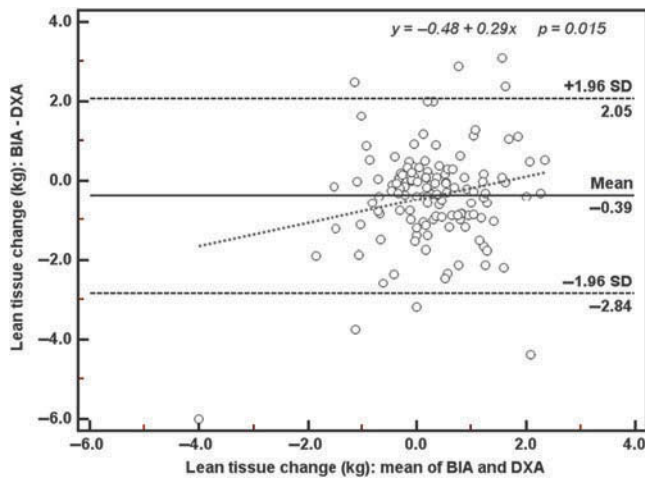


Figure 2. Bland-Altman plot of lean tissue change-score comparing the mean of dual-energy X-ray absorptiometry (DXA) and bioelectrical impedance analysis (BIA) against the difference between BIA and DXA.

was not statistically different ($t = 0.86$, $P = 0.392$), than the non-significant mean gain of 0.014 kg measured by BIA. Despite this, a large effect size (0.93) was reported for the difference between the DXA versus BIA changes. When compared to DXA, BIA correctly agreed with the direction of the bone changes (gain vs. loss) only 58% of the time.

Furthermore, [Table 2](#) shows significant, but moderate, Spearman correlations, seen in absolute mass changes between DXA and BIA of 0.511 (fat) and 0.362 (lean), whilst the correlation for bone of 0.172 was weak, but remained just statistically significant ($P = 0.047$).

Discussion

It is very helpful for not only health professionals but also motivated members of the community to be able to objectively assess aspects of body composition using relatively inexpensive and widely available consumer products. The ability of BIA devices to accurately monitor changes in body composition are of primary importance in many studies rather than their cross-sectional validity (Jebb et al., 2007). This “real-world” study presents novel data to show that, when compared to the reference device (DXA), a commonly available consumer BIA device (Tanita Innerscan BC545N) is unable to accurately monitor changes in fat and lean mass over a lifestyle intervention lasting 10 weeks. Compared to the reference DXA, the Tanita only assessed 61% and 18% of the respective mean quantitative changes in fat and lean mass. Whilst the within-device effect sizes for change-scores for fat and lean mass were similar between BIA and DXA (small or trivial changes respectively), the between-device comparisons showed poor agreement, with moderately weak correlations for fat and lean tissue (0.511 and 0.362) and large effect size for the differences (0.72–0.79).

A range of other BIA devices have been recently investigated to determine their ability to monitor changes in body composition over a lifestyle intervention, including Omron (Pietiläinen et al., 2013), InBody (Sillanpaa, Hakkinen, & Hakkinen, 2013), ImpiMed (Bosaesus et al., 2014; Moon et al.,

2013; Thomson et al., 2007), BodyStat (Verdich et al., 2011) and RJL systems (Aslam et al., 2009). As comparing BIA devices of different manufacturers is not the focus of this study and, although an overview is available (Jaffrin, 2009), the subsequent commentary will be predominantly restricted to the performance of Tanita BIA devices.

Various Tanita BIA devices have been used to monitor changes in body composition, predominantly on clinically-related patients aiming at fat loss. The Tanita 305 was reasonably accurate in monitoring fat and lean mass loss in overweight participants, but underestimated lean mass loss (BIA -1.6 kg vs. DXA -1.9 kg) and overestimated fat loss (BIA -5.2 kg vs. DXA -4.8 kg) (Frisard, Greenway, & Delany, 2005), whilst it accurately monitored changes in fat mass in obese females (Jebb et al., 2007). The Tanita Ultimate Scale 2000 reasonably assessed changes in fat and lean mass loss in overweight young women compared to DXA, but under-reported fat loss and over-reported lean tissue loss (Thomson et al., 2007). Recently the Tanita TBF-300A was considered acceptable for qualitative assessment of body changes in diabetic patients, but not sensitive enough to monitor quantitative changes in an individual (Miyatani et al., 2012). In 2013, the Tanita BC-418 was used on a sample of Taiwanese overweight/obese patients during a 6-month weight-loss intervention and significantly underestimated body fat loss compared to DXA, showing greater error in those with higher body fat (Li et al., 2013).

To date, we are not aware of published work examining a dual-frequency Tanita BIA to assess changes in fat, lean mass and potentially bone, using apparently healthy male and female individuals and over an intervention aimed at reducing fat and increasing lean mass. The results demonstrate that the BC-545N significantly under-reported the mean losses in body fat (the Tanita only reported 60.5% of the fat loss determined via DXA) and also grossly under-reported the mean increase in lean mass (the Tanita reported less than 18% of the lean mass gain determined via DXA). Changes in bone mass determined both by DXA and BIA were, as predicted, trivial and of no practical significance, other than to demonstrate they could be monitored using BIA with some degree of accuracy (i.e. agreement of no change) when compared to the reference DXA. The efficacy of using BIA to monitor changes in bone mass longitudinally remains an area of potential research, especially for countries without routine access to DXA technology.

Although the moderately weak correlations between absolute changes in mass over the intervention for fat and lean tissue show that the BC545N provides some useful qualitative (directional) information about these changes in body composition (70% accuracy of a gain v loss), the BIA is not adequately sensitive to monitor the magnitude (quantitative changes) of body composition variation in these individuals. This is supported by the Bland-Altman plots ([Figures 1 and 2](#)); despite relatively small mean bias in changes in fat and lean mass between the BIA and DXA of approximately 0.3 kg, the relatively wide LOA lines show that a much wider range variation is possible for individual scores. This suggests the BC545N was not sufficiently sensitive in monitoring changes in fat and lean mass when compared to DXA (error differences often beyond 2 kg) and, therefore, this BIA device needs to be interpreted

with considerable caution when examining changes at the individual level. These findings are very similar to that of Miyantani et al., who used the single-frequency Tanita TBF-300A leg-to-leg device on diabetic patients (Miyatani et al., 2012).

The change-score LOA's from Table 2 are also considerably larger than the mean change reported by the BIA or DXA, and are in line with the change-score effect sizes in suggesting the absolute changes seen over this short intervention were of small or trivial practical significance. However, statistically, these changes were unlikely to have happened via chance alone and, for many individuals, losing an average of 0.8 kg of fat mass and gaining nearly 0.5 kg of lean tissue (as determined via DXA) is likely to have been an important, rewarding and health-enhancing event. Yet, the BC545N would typically not have been able to adequately reflect the magnitude of these changes at the individual level.

The strengths of this study was the examination of whether, compared to a DXA reference, the consumer-oriented BC545N could monitor changes in body composition over a short-term intervention using a respectable number ($n = 136$) of apparently healthy individuals (many of whom were ethnic Chinese – a group that has been understudied via BIA); it also used an intervention that targeted not only fat loss but also lean mass gain. There are several clear limitations. Both DXA and BIA measurements are sensitive to hydration levels and food intake, and all participants were asked to attend in a state of normal hydration and standard conditions (neither prior exercise nor food in the previous 4 h; void bowels and bladder, same time of day, etc.); however, this 4-h period was not as long as a 8- to 12-h fast used in some highly controlled laboratory studies as we felt this longer fast would have significantly compromised compliance within our “lifestyle study”. Thus, some daily variations in hydration/digestion are possible, but likely to have been random and affected both devices simultaneously as the DXA and BIA scans were taken only a few minutes apart for each individual; thus, the important change-score would not have been differentially affected. The intervention only lasted a relatively short 10 weeks; however, this still permitted statistically significant changes in both fat and lean masses, although these changes were of low clinical importance. As the participants did not follow a unified/consistent dose of exercise, considerable heterogeneity/variability in the responses (fat and lean mass change) was expected, and this possibly inflated the LOA values. DXA is not a sufficiently adequate criterion method, but it is only a common reference (Bilsborough et al., 2014; Kyle et al., 2004a; Miyatani et al., 2012), and as not all measurements were taken by a single technician, but rather by qualified densitometrists using a standardised protocol, some variations in analysis might occur. Although BIA is predominantly used to estimate body water and fat mass, it is also now considered suitable to assess lean mass (Böhm & Heitmann, 2013; Bosaeus et al., 2014; Janssen, Heymsfield, Baumgartner, & Ross, 2000) and, recently, has also been used to predict bone mass in developing nations (Ekbote, Khadilkar, Chiplonkar, Mughal, & Khadilkar, 2013; Patil et al., 2012); yet, further work remains to further validate its use in predicting bone mass.

Conclusions

Changes in whole-body fat following a lifestyle intervention only showed mediocre agreement using the Tanita BC545N BIA device, with 61% of the mean quantitative change determined by DXA being detected and 70% accuracy in the qualitative changes (gain vs. loss). However, this BIA device showed poor agreement in changes in lean mass, with less than 18% of the mean quantitative changes detected, even though 70% of the qualitative changes (gain vs. loss) agreed with DXA. Insufficient changes in bone mass occurred to allow any firm conclusions to be made. Overall, the Tanita BC545N BIA significantly underestimated the magnitude of changes in both fat and lean mass compared to DXA, with effect sizes of these changes being greater than 0.7.

Disclosure statement

No potential conflict of interest was reported by the authors.

ORCID

Duncan J Macfarlane  <http://orcid.org/0000-0002-9720-301X>

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