

## Original article

# Accuracy of direct segmental multi-frequency bioimpedance analysis in the assessment of total body and segmental body composition in middle-aged adult population

Carolina H.Y. Ling<sup>a,\*</sup>, Anton J.M. de Craen<sup>a,d</sup>, Pieternella E. Slagboom<sup>b</sup>, Dave A. Gunn<sup>e</sup>, Marcel P.M. Stokkel<sup>c</sup>, Rudi G.J. Westendorp<sup>a,d</sup>, Andrea B. Maier<sup>a,d</sup>

<sup>a</sup> Department of Gerontology and Geriatrics, Leiden University Medical Center, Albinusdreef 2, 2333 ZA Leiden, The Netherlands

<sup>b</sup> Department of Molecular Epidemiology, Leiden University Medical Center, Albinusdreef 2, 2333 ZA Leiden, The Netherlands

<sup>c</sup> Department of Nuclear Medicine, Leiden University Medical Center, Albinusdreef 2, 2333 ZA Leiden, The Netherlands

<sup>d</sup> Netherlands Consortium for Healthy Aging, Leiden University Medical Center, Albinusdreef 2, 2333 ZA Leiden, The Netherlands

<sup>e</sup> Unilever Discover, Sharnbrook, Bedfordshire, United Kingdom

## ARTICLE INFO

## Article history:

Received 25 January 2010

Accepted 5 April 2011

## Keywords:

Body composition

Bioelectrical impedance

Dual energy X-ray absorptiometry

Middle-aged adults

## SUMMARY

**Background & aims:** Body composition measurement is a valuable tool for assessing nutritional status and physical fitness in a variety of clinical settings. Although bioimpedance analysis (BIA) can easily assess body composition, its accuracy remains unclear. We examined the accuracy of direct segmental multi-frequency BIA technique (DSM-BIA) in assessing different body composition parameters, using dual energy X-ray absorptiometry (DEXA) as a reference standard.

**Methods:** A total of 484 middle-aged participants from the Leiden Longevity Study were recruited. Agreements between DSM-BIA and DEXA for total and segmental body composition quantification were assessed using intraclass correlation coefficients and Bland–Altman plots.

**Results:** Excellent agreements were observed between both techniques in whole body lean mass (ICC female = 0.95, ICC men = 0.96), fat mass (ICC female = 0.97, ICC male = 0.93) and percentage body fat (ICC female = 0.93, ICC male = 0.88) measurements. Similarly, Bland–Altman plots revealed narrow limits of agreements with small biases noted for the whole body lean mass quantification but relatively wider limits for fat mass and percentage body fat quantifications. In segmental lean muscle mass quantification, excellent agreements between methods were demonstrated for the upper limbs (ICC female  $\geq$  0.91, ICC men  $\geq$  0.87) and lower limbs (ICC female  $\geq$  0.83, ICC male  $\geq$  0.85), with good agreements shown for the trunk measurements (ICC female = 0.73, ICC male = 0.70).

**Conclusions:** DSM-BIA is a valid tool for the assessments of total body and segmental body composition in the general middle-aged population, particularly for the quantification of body lean mass.

© 2011 Elsevier Ltd and European Society for Clinical Nutrition and Metabolism. All rights reserved.

## 1. Introduction

Body composition assessment is being increasingly recognized as an important tool in the evaluation of nutritional status in a variety of clinical conditions<sup>1–3</sup> and for fitness assessment in both research and clinical settings.<sup>4</sup> Moreover, in the elderly, assessment of age-related alterations in body composition<sup>5</sup> will enable development of strategies to minimize the detrimental impact these changes may have on their wellbeing. Furthermore, evaluation of fat mass distribution has been shown to be valuable in predicting cardiometabolic risk.<sup>6,7</sup>

Dual energy X-ray absorptiometry (DEXA) and bioimpedance analysis (BIA) are two frequently used methods for the quantification of body composition. DEXA estimates of body composition have been widely compared to other techniques for assessing body composition such as hydrostatic weighing, CT and MRI,<sup>8–11</sup> and it is now increasingly being utilized as a validation tool for more novel techniques. BIA offers advantages in terms of its simplicity and portability, thus making it an appealing tool in measuring body composition especially in the elderly and less mobile subjects. It is also relatively inexpensive compared to the other techniques and does not expose subjects to radiation.

Previous validation studies of the accuracy of BIA technique using DEXA as reference standards have shown contradictory results. The discordance between results may be due to methodological

\* Corresponding author. Tel.: +31 71 5266640; fax: +31 71 5248159.  
E-mail address: [c.h.y.ling@lumc.nl](mailto:c.h.y.ling@lumc.nl) (C.H.Y. Ling).

differences such as the various BIA and DEXA devices used, as well as the heterogeneity in the study populations.<sup>12–15</sup> Of the BIA devices developed over the years, the direct segmental multi-frequency BIA (DSM-BIA) has been shown to be superior in the estimation of body composition.<sup>14,16,17</sup> To our knowledge, the use of DSM-BIA in assessing segmental body composition in addition to total body composition in a large middle-aged general population have not been previously reported. Therefore, the aim of the present study was to examine the accuracy of DSM-BIA in the various body composition assessments in a general middle-aged population, using DEXA as the reference method.

## 2. Methods

### 2.1. Study sample

The subjects were participants in the Leiden Longevity Study, where 420 families consisting of long-lived Caucasian siblings together with their offspring and the partners of the offspring were recruited.<sup>18,19</sup> The sample of offspring-partner in the study was representative of middle-aged Dutch population. Four hundred and eighty four of the offspring and their partners in whom body composition was measured by DSM-BIA and DEXA were included in the present study. Both investigations were done on the same day 2 h apart. There were no selection criteria on health or demographic characteristics. Information on medical history was requested from the participants' treating physicians. The Medical Ethical Committee of the Leiden University Medical Centre approved the study, and written informed consent was obtained from all subjects.

### 2.2. Body composition assessment

#### 2.2.1. Direct segmental multi-frequency bioelectrical impedance analysis (DSM-BIA)

DSM-BIA was performed using the In-Body (720) body composition analyzer. This equipment has previously been shown to have high test-pretest reliability and accuracy.<sup>20</sup> Unlike conventional BIA equipment which often takes only partial measurements and therefore relies upon formulas to estimate whole body composition, the DSM-BIA technique employs the assumption that the human body is composed of 5 interconnecting cylinders and takes direct impedance measurements from the various body compartments. A tetrapolar eight-point tactile electrode system is used, which separately measures impedance of the subject's trunk, arms, and legs at six different frequencies (1 kHz, 5 kHz, 50 kHz, 250 kHz, 500 kHz, 1000 kHz) for each of the body segment. The spectrum of electrical frequencies are used to predict the intracellular water (ICW) and extracellular water (ECW) compartments of the total body water (TBW) in the various body segments. Low-level frequencies (eg, 1–50 kHz) rely on the conductive properties of extracellular fluid, whereas, at high-level frequencies (eg, 250 kHz), the conductive properties of both ICW and ECW are instrumental. LBM was estimated as TBW (ICW + ECW)/0.73. FM was calculated as the difference between total body weight and LBM. The machine gives immediate and extensive quantitative values of various body composition parameters. The test was carried out by trained research nurses. The In-Body (720) body composition analyzer has in-built hands and feet electrodes. Subjects wore normal indoor clothings and advised to stand barefooted in upright position with their feet on the feet electrodes on the machine platform and their arms abducted with hands gripping on to the hands electrodes on the handles. Subjects were not require to fast for the test.

### 2.2.2. Dual energy X-ray absorptiometry (DEXA)

A total body DEXA scan was performed (Hologic QDR 4500, Hologic Inc., Bedford, USA) in a standard fashion. Measurements were performed by a trained technologist with dual energy X-ray beams at 70 and 140 keV. Single rectilinear scanning mode was used on a 148 × 330 pixel matrix in a 196 × 80 cm window. The differential attenuation of the two energies is used to estimate the bone mineral content and the soft tissue composition. Defined regions on the arms, legs and trunk were drawn automatically by the DEXA software and then adapted manually when necessary. The regions of interest for the arms and legs were defined by cut lines positioned proximally at the coracoid process and superior iliac crest and lower ramus respectively. Subjects wore a standard light cotton shirt to minimize clothing absorption.

### 2.3. Statistical analysis

To account for the gender-related difference in body composition, data was analyzed separately for male and female. Continuous variables with Gaussian distribution are presented as mean (standard deviation). The paired Student's *t*-test was used to compare differences in body composition measurements between the two methods. Intraclass correlation coefficients were used to assess the relationships between whole body composition measurements and segmental lean mass measurements by DEXA and BIA. Systematic differences between LBM<sub>DEXA</sub> and LBM<sub>BIA</sub>, FM<sub>DEXA</sub> and FM<sub>BIA</sub> and %FM<sub>DEXA</sub> and %FM<sub>BIA</sub> were examined by Bland–Altman plots. As there was evidence of proportional bias for the FM and %FM measurements, Pearson's correlation was performed to quantify the bias seen in the Bland–Altman plots. To increase clinical utility, linear regression equations were formulated to correct for BIA estimations in relation to DEXA. A 2-tailed *p*-value of <0.05 was considered significant. All statistical analyses were performed using SPSS for Windows (SPSS Inc, Chicago), version 16.

## 3. Results

Table 1 shows the baseline clinical characteristics and anthropometric parameters of the study population according to gender. Women were slightly younger than men and had lower prevalence

**Table 1**  
Subjects characteristics and anthropometric parameters according to gender.

	Female (N = 242)	Male (N = 242)
Age, years	61.2 (6.4)	63.5 (6.5)
Comorbidity (%)	15.9	24.7
Myocardial infarct <sup>a</sup>	0.5	3.4
Stroke <sup>b</sup>	1.5	3.9
Diabetes mellitus <sup>c</sup>	4.1	8.9
Malignancy <sup>d</sup>	9.6	7.0
Chronic obstructive pulmonary disease <sup>e</sup>	2.5	7.0
Rheumatoid arthritis <sup>f</sup>	0.5	0.5
Anthropometric parameter		
Height, m	1.66 (0.06)	1.79 (0.07)
Weight, <sup>g</sup> kg	71.8 (12.3)	84.7 (11.5)
BMI, kg/m <sup>2</sup>	26.1 (4.4)	26.5 (3.1)
BSA, m <sup>2</sup>	1.81 (0.16)	2.05 (0.16)
Waist-to-hip ratio	0.91 (0.07)	0.97 (0.06)

Values are mean (SD) unless otherwise indicated.

BSA = body surface area.

<sup>a</sup> N = 411.

<sup>b</sup> N = 412.

<sup>c</sup> N = 404.

<sup>d</sup> N = 408.

<sup>e</sup> N = 405.

<sup>f</sup> N = 408.

<sup>g</sup> weight derived from whole body mass measurement from DEXA.

of comorbidities (15.9% vs. 24.7% respectively). As expected, female subjects had smaller body surface area, but there was no significant gender difference in body mass index (BMI) ( $p = 0.508$ ).

Gender-specific body composition parameters measured by DEXA and BIA are given in Table 2. Comparison of the two methods showed excellent agreements in the measurements of LBM, FM and %FM for both genders ( $ICC \geq 0.88$ , all  $p < 0.001$ ). Similarly, there were excellent agreements between the methods in the measurements of segmental lean mass in the limbs ( $ICC \geq 0.83$ , all  $p < 0.001$ ), with good agreement seen in the measurement of truncal lean mass in both genders ( $ICC > 0.70$ ,  $p < 0.001$ ).

In addition, agreements between the two techniques were assessed using the Bland–Altman plots (Fig. 1). There was a narrow limit of agreement on Bland–Altman for LBM measurement and relatively wider limits for FM and %FM measurements. There was a systematic small positive bias with an overall underestimation of LBM measurements by BIA. Proportional bias was noted for FM measurement, with underestimation by BIA at lower FM and overestimation at higher FM ( $r = -0.654$ ,  $p < 0.001$  and  $r = -0.571$ ,  $p < 0.001$  for female and male respectively). Similar bias was also noted for %FM measurement ( $r = -0.566$ ,  $p < 0.001$  and  $r = -0.557$ ,  $p < 0.001$  for female and male respectively). However, overall BIA appeared to overestimate the FM and %FM on the Bland–Altman plots. Table 3 showed that the underestimation of LBM and overestimations of FM and %FM by BIA increased with higher BMI (Table 3). On average, BIA underestimated LBM by 1.8% and overestimated FM and %FM by 8.0% and 7.0% respectively. To increase the clinical utility, linear regression equations were formulated to correct for the under and overestimations of BIA in relation to DEXA.

$$\begin{aligned} \text{LBM}_{\text{DEXA}}(\text{kg}) &= [0.94(\text{CI}, 0.91 - 0.98) \times \text{LBM}_{\text{BIA}}(\text{kg}) \\ &+ [1.7(\text{CI}, 0.9 - 2.4) \\ &\times \text{gender}(\text{female} = 0, \text{male} = 1)] + 3.4 \\ R^2 &= 0.951, \text{Residual standard deviation} = 2.42, p < 0.001. \end{aligned}$$

$$\begin{aligned} \text{FM}_{\text{DEXA}}(\text{kg}) &= [0.79(\text{CI}, 0.77 - 0.81) \times \text{FM}_{\text{BIA}}(\text{kg}) \\ &+ [-2.1(\text{CI}, -2.5 \text{ to } -1.8) \\ &\times \text{gender}(\text{female} = 0, \text{male} = 1)] + 4.3 \\ R^2 &= 0.942, \text{Residual standard deviation} = 1.80, p < 0.001. \end{aligned}$$

#### 4. Discussion

The present study examined the accuracy of DSM-BIA in assessing segmental body composition in addition to the whole

**Table 2**  
Body composition parameters measured on DEXA and BIA according to gender.

Body composition parameter, mean (SD)	Female (N = 242)		Male (N = 242)			
	DEXA	BIA	ICC <sup>a</sup>	DEXA	BIA	ICC <sup>a</sup>
<b>Whole body measurement</b>						
Weight, kg	72.2 (12.5)	72.7(12.6)	1.00	84.5 (10.8)	85.5 (10.9)	1.00
Lean mass, kg	47.2 (5.8)	46.5 (5.2)	0.95	65.0 (6.8)	63.6 (7.0)	0.96
Body fat, kg	25.0 (7.8)	26.2 (9.5)	0.97	19.5 (5.9)	21.9 (7.3)	0.93
Percentage body fat, %	33.9 (5.5)	35.1 (7.3)	0.93	22.7 (4.6)	25.3 (6.2)	0.88
<b>Segmental lean mass measurement</b>						
Right arm, kg	2.5 (0.4)	2.5 (0.4)	0.93	4.0 (0.6)	3.8 (0.5)	0.87
Left arm, kg	2.3 (0.4)	2.4 (0.4)	0.91	3.8 (0.5)	3.7 (0.5)	0.92
Trunk, kg	24.1 (3.0)	21.3 (2.5)	0.73	32.5 (3.5)	28.8 (3.1)	0.69
Right leg, kg	7.6 (1.1)	7.0 (0.9)	0.83	10.4 (1.3)	9.8 (1.2)	0.85
Left leg, kg	7.4 (1.1)	7.0 (0.9)	0.86	10.2 (1.3)	9.7 (1.2)	0.85

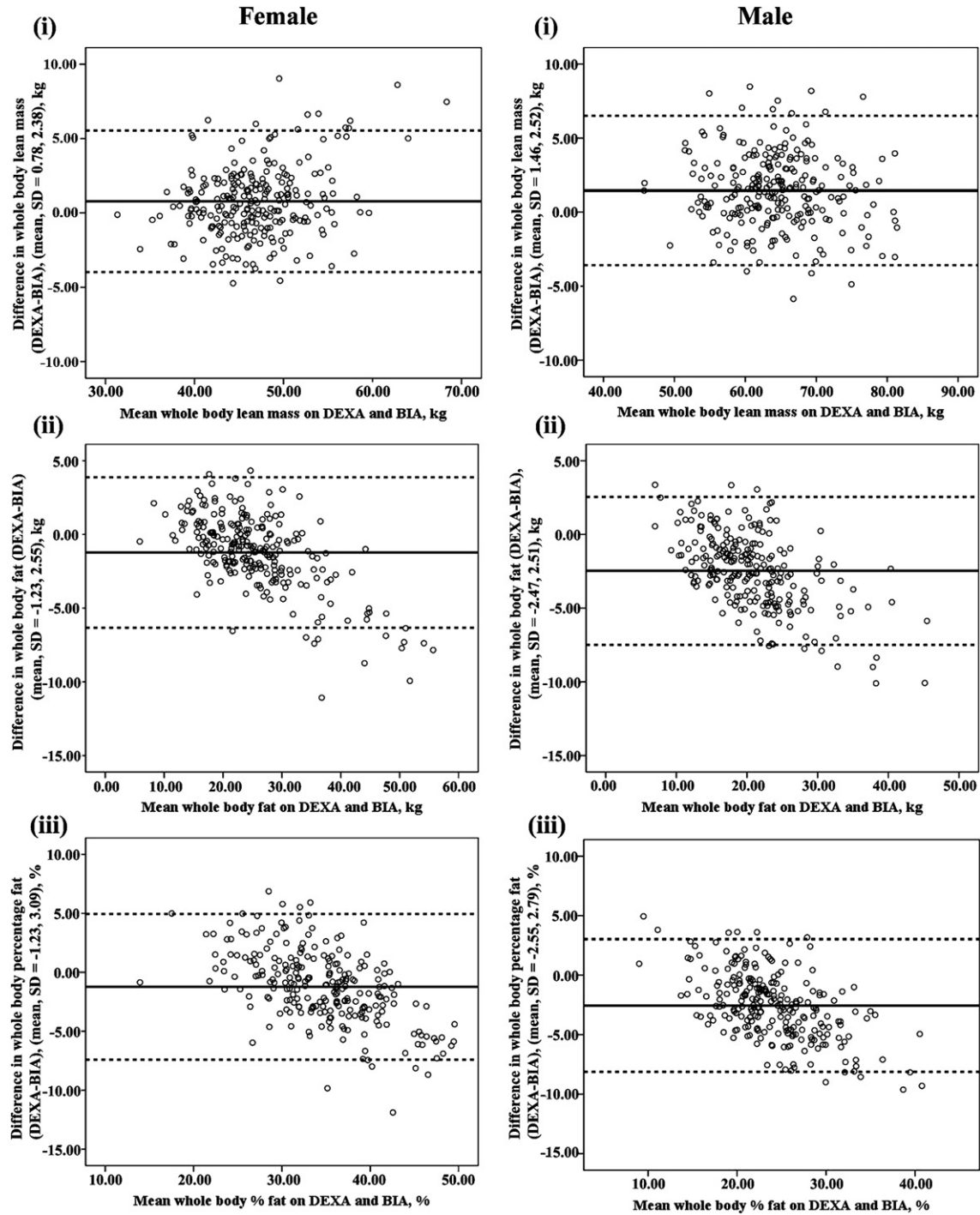
<sup>a</sup> intraclass correlation coefficient, all  $p < 0.001$ .

body composition in a large representative sample of middle-aged Dutch population, using DEXA as a reference standard. We showed excellent agreements between the two methods for the estimation of LBM, FM and %FM in both genders. There were also significant, albeit slightly lower agreements between the techniques in segmental lean mass measurements.

Body composition is an important indicator of health and physical fitness. The accurate measurements of body composition is crucial for the assessment of nutritional status in various clinical circumstances, and this in turn has important prognostic value for survival.<sup>1–3,21</sup> Although hydrostatic weighing has generally been considered as a reference standard for body composition studies, the need for subjects to be submerged in water makes its routine clinical use impractical. Newer imaging techniques such as magnetic resonance imaging (MRI) and computerized tomography (CT) have replaced hydrostatic weighing as “gold standards” for quantifying whole body and regional muscle and fat mass, but their applications are limited by cost, availability of instruments and the need for highly trained technicians. Furthermore, acquisition of whole body MRI is time consuming and total body composition estimates are often extrapolated from single-slice or multiple-slice acquisitions over selected regions of the body to save scanning and analysis time but at the cost of accuracy.<sup>22</sup> Moreover, CT imaging has the drawback of exposing subjects to radiation.

DEXA and BIA are two additional techniques which are increasing being utilized in body composition analyses. DEXA exposes subjects to significantly less radiation compared to CT scan and it allows concurrent quantifications of soft tissue body composition and bone mineral content, making it widely applicable clinically. The DEXA technique has been validated against various reference standards and is generally accepted as being an accurate and precise technique in assessing body composition.<sup>8–11</sup> However, the routine clinical use of DEXA is limited by the relatively high cost of the equipment. Furthermore, subjects must remain motionless during the procedure which may be burdensome and uncomfortable for some patients. Another technology which has applications in the various fields of medicine including body composition analyses is the bioimpedance method. BIA has the advantages of being non-invasive, simple and easily accessible. However, the accuracy of this technique remains controversial. In recent years, DSM-BIA has been made available and shown to have better accuracy compared to other BIA devices.<sup>14,16,17</sup> Despite its enhanced accuracy, previous body composition studies utilizing this technique had reported mixed results, especially in the estimations of percentage fat mass when validated against DEXA.<sup>12–15</sup>

We found in our study that the DSM-BIA underestimated LBM and overestimated FM and %FM relative to DEXA. The underestimation of LBM and overestimation of FM and %FM appeared to increase with increasing BMI. There was a narrow limit of agreement on Bland–Altman for the LBM measurement, but relatively wider limits of agreements for FM and %FM measurements. This suggests that some caution be used when measuring FM by BIA, especially in those with extreme body fat composition. In such circumstances, BIA measurements may need to be complimented by another method of assessment if clinically doubtful. Nevertheless, the overall overestimations of FM by BIA were probably clinically less detrimental than if the biases were in the opposite direction. Furthermore, regression equations for the BIA-derived body composition estimates were generated in order to give an even more comparable data to DEXA. Comparison of our results with other studies is difficult due to the different BIA devices used. Moreover, the sample sizes in previous studies were relatively small compared to the present study.<sup>13,15,23</sup>



**Fig. 1.** Bland–Altman plots showing the difference vs. mean value of (i) whole body lean mass, (ii) whole body fat and (iii) whole body fat percentage measured on DEXA and BIA for both genders. The solid line represents the mean and the broken line the  $\pm 2$  SD.

**Table 3**  
Body composition parameters measured on DEXA and BIA according to BMI.

Whole body composition parameter, mean (SD)	Normal N = 168 (BMI 18.5–24.9)			Overweight N = 246 (BMI 25.0–29.9)			Obese N = 67 (BMI $\geq 30$ )		
	DEXA	BIA	ICC <sup>a</sup>	DEXA	BIA	ICC <sup>a</sup>	DEXA	BIA	ICC <sup>a</sup>
Lean mass, kg	51.25 (9.57)	51.45 (9.64)	0.99	58.21 (10.30)	56.97 (10.20)	0.99	61.55 (10.94)	57.48 (11.24)	0.96
Body fat, kg	17.04 (4.14)	17.49 (4.34)	0.95	22.69 (4.74)	24.67 (4.71)	0.90	34.16 (7.58)	39.16 (8.55)	0.89
Percentage body fat, %	25.32 (6.61)	25.70 (6.73)	0.96	28.43 (6.88)	30.58 (6.67)	0.94	35.81 (7.04)	40.66 (7.65)	0.87

<sup>a</sup> intraclass correlation coefficient, all  $p < 0.001$ .



Despite our finding of a slightly lower agreement between DSM-BIA and DEXA in segmental body composition measurements, several previous studies have shown the usefulness of the segmental BIA technique, especially for the assessment of fluid sub-compartments such as in patients with abnormal fluid distribution.<sup>24,25</sup> Furthermore, the additional information obtained from segmental measurements has been shown to improve prediction of whole body components in certain conditions such as in malnourished subjects.<sup>26</sup>

It is important to highlight that various BIA machines are supplied with proprietary prediction equations for the estimations of different body composition parameters. The details of these equations, as well as the raw measurement values generated by the BIA machine are generally unavailable to the users. As these equations are formulated on population-specific data, they may contribute to error in body composition measurements in different populations. Therefore, care needs to be taken in the selection of prediction equations to ensure that they are applicable to the characteristics of the subjects under study. Another limitation of the study is the use of DEXA as reference method for the BIA device. Although DEXA has been found to compare well with other reference standards, different densitometers and software versions have been shown to give different estimates of body composition.<sup>27–29</sup> Furthermore, the present study comprised of a moderately small proportion of participants who were underweight or severely obese. Additionally, the hydration status of study subjects was not determined prior to the body composition assessment. Therefore, the results of this study may not be generalizable to other adult populations with extreme body weight and abnormal hydration status. Another limitation of BIA is that it cannot be performed in subjects with implanted electronic devices, metallic prostheses or missing limbs. None of our study subjects have the aforementioned contraindications.

In conclusion, this study shows DSM-BIA to be a valid tool for the assessment of whole body composition and segmental lean mass measurements in middle-aged population when validated against DEXA. Our findings are consistent with previous body composition studies which also showed good correlation between BIA technique and other reference standards such as MRI, total body potassium and isotope dilution techniques.<sup>30–31</sup> Future research should aim at determining the usefulness of DSM-BIA in clinical practice and to include subjects with altered body geometry or fluid compartmentalization.

#### Conflict of interest

This study was supported by the Netherlands Genomics Initiative/Netherlands Organization for scientific research (NGI/NWO; 05040202 and 050-060-810 NCHA) and the seventh framework programme MYOAGE (HEALTH-2007-2.4.5-10). None of the authors had conflict of interest.

#### Statement of authorship

CHYLing conducted a literature search, analysed the data, interpreted the data and results and wrote the manuscript. AJM de Craen and AB Maier contributed to the study design, collection of data and critically reviewed and contributed to the final draft. PE Slagboom and RGJ Westendorp contributed to the study design and provided significant advice and consultation. DA Gunn contributed to the study design and critically reviewed and contributed to the final draft. MPM Stokkel contributed to the collection of data and critically reviewed and contributed to the final draft. All authors read and approved the final manuscript.

#### References

- Dumler F, Kilates C. Nutritional status assessment and body composition analysis in pre-end stage renal disease patients. *Miner Electrolyte Metab* 1999;**25**:397–9.
- Nakao T, Kanazawa Y, Nagaoka Y, Iwasawa H, Uchinaga A, Matsumoto H, et al. Body protein index based on bioelectrical impedance analysis is a useful new marker assessing nutritional status: applications to patients with chronic renal failure on maintenance dialysis. *Contrib Nephrol* 2007;**155**:18–28.
- Royall D, Greenberg GR, Allard JP, Baker JP, Jeejeebhoy KN. Total enteral nutrition support improves body composition of patients with Active Crohn's disease. *J Parenter Enteral Nutr* 1995;**19**:95–9.
- Mattila VM, Tallroth K, Marttinen M, Pihlajamaki H. Physical fitness and performance. Body composition by DEXA and its association with physical fitness in 140 conscripts. *Med Sci Sports Exerc* 2007;**39**:2242–7.
- Gillette-Guyonnet S, Vellas B. Body composition and age-related diseases. *Mech Ageing Dev* 2003;**124**:247–8.
- Pou KM, Massaro JM, Hoffmann U, Lieb K, Vasan RS, O'Donnell CJ, et al. Patterns of abdominal fat distribution: the Framingham heart study. *Diabetes Care* 2009;**32**:481–5.
- Gavi S, Feiner JJ, Melendez MM, Mynarcik DC, Gelato MC, McNurlan MA. Limb fat to trunk fat ratio in elderly persons is a strong determinant of insulin resistance and adiponectin levels. *J Gerontol A Biol Sci Med Sci* 2007;**62**:997–1001.
- Prior BM, Cureton KJ, Modlesky CM, Evans EM, Sloniger MA, Saunders M, et al. In vivo validation of whole body composition estimates from dual-energy X-ray absorptiometry. *J Appl Physiol* 1997;**83**:623–30.
- Salamone LM, Fuerst T, Visser M, Kern M, Lang T, Dockrell M, et al. Measurement of fat mass using DEXA: a validation study in elderly adults. *J Appl Physiol* 2000;**89**:345–52.
- Park YW, Heymsfield SB, Gallagher D. Are dual-energy X-ray absorptiometry regional estimates associated with visceral adipose tissue mass? *Int J Obes Relat Metab Disord* 2002;**26**:978–83.
- Andreoli A, Scalzo G, Masala S, Tarantino U, Guglielmi G. Body composition assessment by dual-energy X-ray absorptiometry (DXA). *Radiol Med* 2009;**114**:286–300.
- Erselcan T, Candan F, Saruhan S, Ayca T. Comparison of body composition analysis methods in clinical routine. *Ann Nutr Metab* 2000;**5–6**:243–8.
- Volgyi E, Tylavsky FA, Lyttikainen A, Suominen H, Alen M, Cheng S. Assessing body composition with DXA and bioimpedance: effects of obesity, physical activities and age. *Obes (Silver Spring)* 2008;**16**:700–5.
- Shafer KJ, Siders WA, Johnson LK, Lukaski HC. Validity of segmental multiple-frequency bioelectrical impedance analysis to estimate body composition of adults across a range of body mass indexes. *Nutrition* 2009;**25**:25–32.
- Bolanowski M, Nilsson BE. Assessment of human body composition using dual-energy x-ray absorptiometry and bioelectrical impedance analysis. *Med Sci Monit* 2001;**7**:1029–33.
- Malavolti M, Mussi C, Poli M, Fantuzzi AL, Salvioi G, Battistini N, et al. Cross-calibration of eight-polar bioelectrical impedance analysis versus dual-energy X-ray absorptiometry for the assessment of total and appendicular body composition in healthy subjects aged 21–82 years. *Ann Hum Biol* 2003;**30**:380–91.
- Bedogni G, Malavolti M, Severi S, Poli M, Mussi C, Fantuzzi AL, et al. Accuracy of an eight-point tactile-electrode impedance method in the assessment of total body water. *Eur J Clin Nutr* 2002;**56**:1143–8.
- Schoenmaker M, de Craen AJ, de Meijer PH, Beekman M, Blauw GJ, Slagboom PE, et al. Evidence of genetic enrichment for exceptional survival using a family approach: the Leiden longevity study. *Eur J Hum Genet* 2006;**14**:79–84.
- Westendorp RG, van Heemst D, Rozing MP, Frolich M, Mooijaart SP, Blauw GJ, et al. Nonagenarian siblings and their offspring display lower risk of mortality and morbidity than sporadic nonagenarians: the Leiden longevity study. *J Am Geriatr Soc* 2009;**57**:1634–7.
- Gibson AL, Holmes JC, Desautels RL, Edmonds LB, Nuudi L. Ability of new octapolar bioimpedance spectroscopy analyzers to predict 4-component-model percentage body fat in hispanic, black, and white adults. *Am J Clin Nutr* 2008;**87**:332–8.
- Faisy C, Rabbat A, Kouchakji B, Laaban JP. Bioelectrical impedance analysis in estimating nutritional status and outcome of patients with chronic obstructive pulmonary disease and acute respiratory failure. *Intensive Care Med* 2000;**26**:518–25.
- Abate N, Garg A, Coleman R, Grundy SM, Peshock RM. Prediction of total subcutaneous abdominal, intraperitoneal, and retroperitoneal adipose tissue masses in men by a single axial magnetic resonance imaging slice. *Am J Clin Nutr* 1997;**65**:403–8.
- Tengvall M, Ellegord L, Malmros V, Bosaeus N, Lissner L, Bosaeus I. Body composition in the elderly: reference values and bioelectrical impedance spectroscopy to predict total body skeletal muscle mass. *Clin Nutr* 2009;**28**:52–8.
- Nescolarde L, Garcia-González MA, Rosell-Ferrer J, Doñate T, Querfeld U. Thoracic versus whole body bioimpedance measurements: the relation to hydration status and hypertension in peritoneal dialysis patients. *Physiol Meas* 2006;**27**:961–71.

25. Song JH, Lee SW, Kim GA, Kim MJ. Measurement of fluid shift in CAPD patients using segmental bioelectrical impedance analysis. *Perit Dial Int* 1999;**19**:386–90.
26. Pirlich M, Schutz T, Ockenga J, Biering H, Gerl H, Schmidt B, et al. Improved assessment of body cell mass by segmental bioimpedance analysis in malnourished subjects and acromegaly. *Clin Nutr* 2003;**22**:167–74.
27. Roubenoff R, Kehayias JJ, Dawson-Hughes B, Heymsfield SB. Use of dual-energy x-ray absorptiometry in body-composition studies: not yet a "gold standard. *Am J Clin Nutr* 1993;**58**:589–91.
28. Paton NI, Macallan DC, Jebb SA, Pazianas M, Griffin GE. Dual-energy X-ray absorptiometry results differ between machines. *Lancet* 1995;**346**:899–900.
29. Tataranni PA, Pettitt DJ, Ravussin E. Dual energy X-ray absorptiometry: inter-machine variability. *Int J Obes Relat Metab Disord* 1996;**20**:1048–50.
30. Carter M, Zhu F, Kotanko P, Kuhlmann M, Ramirez L, Heymsfield SB, et al. Assessment of body composition in dialysis patients by arm bioimpedance compared to MRI and 40K measurements. *Blood Purif* 2009;**27**:330–7.
31. Strain GW, Wang J, Gagner M, Pomp A, Inabnet W, Heymsfield SB. Bioimpedance for severe obesity: comparing research methods for total body water and resting energy expenditure. *Obesity* 2008;**16**:1953–6.