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Measuring Abdominal Adipose Tissue: Comparison of Simpler Methods with MRI

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MRI · Obesity · Abdominal obesity · Abdominal adipose tissue · Central obesity

Summary
Objective: This cross-sectional study compares the relationship of visceral and total abdominal adipose tissue (VAT and TAAT) measurements obtained with magnetic resonance imaging (MRI) and a range of 'simpler' techniques suitable for field or bedside use: BMI, waist circumference (WC), bioelectrical impedance (BIA) devices and dual X-ray absorptiometry (DXA). **Method:** 120 participants were recruited, stratified by gender and BMI (20 men and 20 women within each group: lean, overweight and obese). Measurements included height, weight, WC (at midpoint), DXA L2-L4 fat, and BIA (two whole-body and one abdominal device). MRI was used as the reference. **Results:** MRI data showed that men have more VAT than women, (mean 147 vs. 93 cm^2) despite less TAAT (362 vs. 405 cm^2). Correlations of simpler abdominal fat measures showed significantly higher correlations with TAAT than with VAT in men and women. Similarly, trunk and whole-body fat measures were significantly more strongly correlated with TAAT than with VAT. **Conclusion:** None of the simpler techniques show strong correlations with VAT measured by MRI, but WC, abdominal BIA 'visceral fat level' and DXA L2-L4 fat all show similar and strong correlations with TAAT and may be useful in large scale surveys.

Introduction

Abdominal adipose tissue can be measured accurately using well-established imaging techniques such as computed tomography (CT) and magnetic resonance imaging (MRI) [1, 2]. Both techniques are able to differentiate between and quantify subcutaneous abdominal adipose tissue (SAAT) and visceral adipose tissue (VAT) depots. These imaging techniques have been used to demonstrate the relationship between abdominal obesity and morbidity [3, 4] and premature mortality [5].

Quantifying abdominal adipose tissue to assess clinical risk in studies of obesity and disease is challenging. Because of ionising radiation risks, it is inappropriate to measure abdominal fat with CT in many research and clinical situations. MRI, while low risk, requires specialised resources and is relatively expensive for measurements of fat distribution alone.

Many more simple clinical measurements are available which may serve as useful proxies for abdominal fat. BMI, an index of whole-body weight, and waist circumference (WC), an index of abdominal size, are established proxy measures for adiposity and have shown good correlations with abdominal fat measures from CT and MRI [6, 7]. Such measurements have also demonstrated important relationships with morbidity [8–11] and premature mortality [12] and are used clinically to assess health risks [13].

Other techniques available include whole-body bioelectrical impedance (BIA) devices that predict total and regional body adiposity from gender-specific equations using a combination of weight, height and BIA measures. A new abdominal BIA device has recently been developed to measure and use WC and BIA results to estimate abdominal adiposity from gender-specific equations. Dual X-ray absorptiometry (DXA), while a more expensive and time-consuming technique than

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either BIA or the manual measurements, is able to differentiate lean and fat tissue, from a 2-D low energy X-ray. It has been suggested to be a low-risk, quicker and cheaper technique than CT or MRI to quantify whole-body and regional adipose tissue distribution [14–16].

Objectives

This study explores the relationships between the available simpler techniques (BMI, WC, BIA, and DXA), measuring abdominal, trunk and whole-body fat, with VAT, SAAT and total abdominal adipose tissue (TAAT) measures from MRI.

Material and Methods

Study Design

The study was approved by the Local Research Ethics Committee (08/H0306/64). Participants gave written, informed consent before inclusion in the study. The study had a cross-sectional design, with each participant completing two study visits within 7 days. On the first visit, at MRC Human Nutrition Research, all anthropometry, BIA and DXA measurements were made. On the second visit, at the MRIS Unit at Addenbrookes Hospital, the MRI was performed.

Recruitment

120 participants, aged between 18 and 79 years were recruited into one of 6 groups, stratified by gender and BMI (<25, 25–29.9 and 30–35 kg/m^2, or lean, overweight and obese groups). Exclusion criteria were designed to exclude subjects for whom the MRI or BIA was unsuitable and for whom results may be unreliable due to unusual changes in body weight or composition. Participants were excluded if they were not weight stable (defined as a self-reported weight change of more than 2 kg in the previous month), were pregnant or lactating women, were athletes, had been previously diagnosed with lipodystrophy, had any disorder or concomitant medication known to affect fat distribution, experienced cancer within last 5 years, or had been treated with surgical aneurysm clips in the brain, inner ear implants, replacement joints, prosthetic limbs, metal implants or a pacemaker.

Anthropometry

Height was measured using a wall-mounted stadiometer (Holtain Ltd, Dyfed, Wales, UK), to the nearest 0.5 cm, with the participant's head in the Frankfort plane. Body mass, wearing light indoor clothing but no shoes, was measured using a whole-body BIA device, the BC-420 MA (Tanita Corp, Tokyo, Japan), to the nearest 0.1 kg. A correction factor of –1 kg was used to adjust for the weight of clothes. WC was measured using a tape measure to the nearest 0.5 cm at both the level of the umbilicus and the level of the midpoint waist, as defined by the World Health Organisation, by measuring at the mid-point between the lowest palpable rib and the top of the iliac crest, in the mid-axillary line. The WC measurements within a participant were taken in triplicate by the same trained observer, repositioning the tape between measurements, with the average at each level taken and reported.

Abdominal BIA

For the first 13 participants the AB-100 (Tanita Corp) was used, for the remaining 107 participants the AB-140 was used (Tanita Corp). The two devices differ cosmetically but use the same core components. For all abdominal BIA measurements, participants were in a supine position, without a pillow, with arms laid across the chest. The device was positioned perpendicularly to the participant's body at the umbilical level according to the manufacturers' instructions, with the multi-frequency electrode device positioned on the abdomen in direct contact with the skin. Trunk fat% and 'visceral fat level' measurements were made in triplicate, repositioning the device between each measurement. The average of the triplicate results was used to compare with the MRI results.

Whole-Body BIA

Two whole-body BIA devices were used to estimate body composition, the BC-420 and the MC-180 (Tanita Corp), recording data using an anonymised record in the GMON Customer Administration programme. The BC-420 MA measures total body composition based on the leg-to-leg impedance technique, while the MC-180 MA measures compartmental composition based on a multi-compartmental impedance technique. Height (cm) was entered into both devices which measured body mass and impedance and calculated fat mass (kg), lean mass (kg) and bone mass (kg) in the whole body or in specific regions. All measurements were made in triplicate, and the average value was used in data analysis.

DXA

Whole-body DXA was performed using a Lunar MD with software 4.7e (GE Lunar Corporation, Madison, WI, USA). For sagittal diameters between 13 and 25 cm the standard mode was used, and for diameters greater than 25 cm the thick mode was used. Participants removed all outer clothing, and were measured wearing underwear and a dressing gown. Scans were analysed using standard Encore software to estimate fat, fat-free mass and bone mass. Two regions of interest were defined: abdominal, as the region marked by vertebrae L2-L4, and trunk, as the whole-body minus limbs and head. The two regions of interest were identified on each individual scan by a trained observer.

Abdominal MRI

Participants were each examined once at 1.5T (HDx, GE Healthcare, Waukesha, WI, USA) using an 8-channel torso-phased array coil, and analysed with SliceOmatic, version 4.3 software, licensed by TomoVision (TomoVision, Montreal, QC, Canada). A single shot fast spin echo (SSFSE) sequence was applied with the following parameters: TE / TR / BW / matrix size / FOV (minfull / min / 62.5 KHz / 256 × 256 / 32–48 cm). The field of view was set to encompass both VAT and SAAT. The slice thickness was 10 mm with a 5 mm inter-slice gap. Slices were obtained from the level of the xiphisternum to the pubic symphysis. For measurement of VAT and SAAT area in the abdominal region, the single slice selected for analysis was in line with the iliac crests at the L4/5 vertebrae, a commonly selected slice close to the umbilicus, previously shown to be correlated with multi-slice VAT and SAAT volumes [17]. VAT and SAAT areas were identified by an experienced trained technician with 5 years experience in quantifying abdominal adipose tissue; each assessment was agreed in consensus with a radiologist with over 20 years experience in adipose tissue quantification. VAT and SAAT areas were summed to give the TAAT area.

Statistical Analysis

Raw data was checked and analysed by an independent statistician. Pearson's correlation coefficients with 95% confidence intervals were calculated to determine the relationship between different simpler measures and the MRI measures. Linear regression was used to separate the effects of the simpler measures in their relationships with MRI measures. All analysis was performed using SPSS version 16 (SPSS Inc, Chicago, IL, USA).

Results

Table 1 shows the characteristics of the participants by gender and BMI group. The design, with stratification by BMI, achieved a similar mean and spread of BMI in men and

Table 1. Descriptive characteristics of the participants

	Male	Female
Abdominal fat		
MRI TAAT, cm^2	362 (155)	405 (134)
MRI VAT, cm^2	147 (85)	93 (46)
MRI SAAT, cm^2	215 (104)	312 (110)
DXA L2-L4 fat, %	36.1 (11.4)	47.0 (8.2)
Midpoint WC, cm	101.3 (12.3)	93.4 (11.7)
Umbilical WC, cm	101.6 (12.1)	97.5 (12.4)
Abdominal BIA 'visceral fat level'	13.6 (5.5)	9.5 (3.2)
BC-420 'visceral fat level'	12.6 (5.1)	8.8 (3.0)
MC-180 'visceral fat level'	11.8 (4.8)	8.4 (2.9)
Trunk fat		
DXA trunk fat, %	32.2 (10.4)	43.2 (7.6)
Abdominal BIA trunk fat, %	28.6 (8.3)	42.1 (7.6)
MC-180 trunk fat, %	23.4 (8.1)	31.5 (5.6)
Whole-body fat		
BMI, kg/m^2	27.5 (4.4)	27.4 (4.1)
DXA whole-body fat, %	27.8 (8.7)	42.8 (6.6)
BC-420 whole-body fat, %	24.0 (7.2)	37.4 (5.6)
MC-180 whole-body fat, %	22.2 (6.9)	35.5 (5.0)

Data presented as mean (SD).

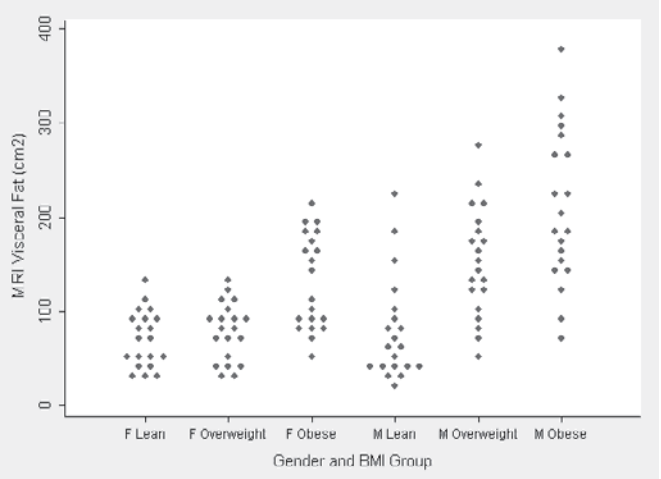

Fig. 1. Distribution of individual VAT values, divided by gender and BMI groups.

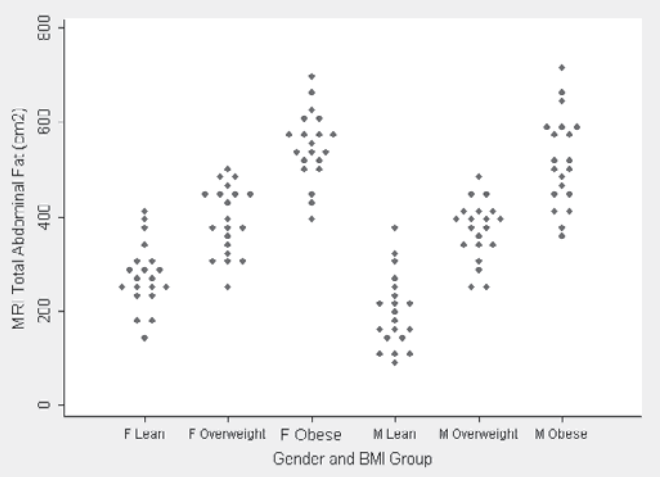

Fig. 2. Distribution of individual TAAT values, divided by gender and BMI groups.

women. The stratification also achieved a broad range of VAT values in men and women (fig. 1). Men tended to have more VAT than women, (mean 147 vs. 93 cm^2) and a greater spread of VAT values (SD 85 vs. 46 cm^2). Figure 2 shows the distribution of individual TAAT values of participants in each gender and BMI group. There was less difference between men and women for TAAT than for VAT. Men tended to have slightly lower TAAT values than women (mean 362 vs. 405 cm^2). Differences in SAAT were similar to TAAT, with men tending to have lower SAAT than women (mean 215 vs. 312 cm^2).

Table 1 shows an absolute difference in WC measurements at two commonly reported sites. The mean difference between the two WC measurements was 0.3 cm in men and 4.1 cm in women and was similar across the three BMI groups.

Relationship between Total Abdominal and Visceral Adipose Tissue

Data from MRI (table 2) showed that, while VAT and TAAT are correlated, they are not directly proportional (0.77 and 0.65 in men and women respectively). In contrast, SAAT and TAAT tend to be more highly correlated, especially in women (0.86 and 0.95 in men and women respectively). The correlation of SAAT with TAAT is significantly higher than the correlation of SAAT with VAT in both men and women.

Relationship between Simpler Indices and MRI VAT, SAAT and TAAT

Results in table 2 show that all simple indices of whole-body fat, abdominal fat, and trunk fat are significantly correlated with VAT, SAAT, and TAAT. In general, correlations tended to be highest with TAAT, followed by SAAT, and are lowest with VAT. Almost all simpler techniques were significantly better correlated with TAAT than with VAT in both men and women.

Comparing the abdominal fat measures, four of the measures, DXA L2-L4, WC (midpoint and umbilical) and abdominal BIA 'visceral fat level', were all similarly correlated in both men and women with each of the three MRI outcomes: VAT, SAAT, and TAAT (table 2, fig. 3). All four of these variables in men and three of four (not umbilical WC) in women showed significantly higher correlations with TAAT than with VAT (table 2). Abdominal BIA 'visceral fat level' from the specific abdominal fat BIA device showed a significantly higher correlation with SAAT in men and women, and with TAAT in women, than with the 'visceral fat level' from

Table 2. Pearson's correlation coefficients between results from the MRI, with simpler techniques (manual, BIA and DXA) to measure abdominal, trunk and whole-body fat

	Male			Female		
	MRI VAT	MRI SAAT	MRI TAAT	MRI VAT	MRI SAAT	MRI TAAT
Abdominal fat						
MRI VAT, cm^2	1.00	0.33 (0.08–0.54)	0.77 (0.64–0.85)	1.00	0.37 (0.13–0.57)	0.65 (0.47–0.77)
MRI SAAT, cm^2	0.33 (0.08–0.54)	1.00	0.86 (0.77–0.91)*	0.37 (0.13–0.57)	1.00	0.95 (0.92–0.97)*#†
MRI TAAT, cm^2	0.77 (0.64–0.85)	0.86 (0.77–0.91)	1.00	0.65 (0.47–0.77)	0.95 (0.92–0.97)*#†	1.00
DXA L2-L4 fat, %	0.70 (0.54–0.81)	0.77 (0.64–0.85)	0.90 (0.83–0.94)*	0.62 (0.43–0.75)	0.83 (0.73–0.89)#†	0.90 (0.83–0.94)*#†
Midpoint WC, cm	0.75 (0.61–0.84)	0.82 (0.71–0.89)	0.96 (0.93–0.97)*#	0.75 (0.61–0.84)	0.80 (0.68–0.87)#†	0.91 (0.85–0.94)*#†
Umbilical WC, cm	0.71 (0.55–0.81)	0.85 (0.76–0.90)	0.96 (0.93–0.97)*#	0.74 (0.60–0.84)	0.76 (0.63–0.85)†	0.88 (0.80–0.92) #†
Abdominal BIA 'visceral fat level'	0.65 (0.47–0.77)	0.87 (0.79–0.92)*#†	0.94 (0.90–0.96)*	0.64 (0.46–0.77)	0.86 (0.77–0.91)*#†	0.92 (0.87–0.95)*#†
BC-420 'visceral fat level'	0.80 (0.68–0.87)	0.64 (0.46–0.77)	0.87 (0.79–0.92)	0.64 (0.46–0.77)	0.47 (0.25–0.65)	0.61 (0.42–0.74)
MC-180 'visceral fat level'	0.82 (0.71–0.89)	0.67 (0.50–0.79)	0.90 (0.83–0.94)	0.61 (0.42–0.74)	0.45 (0.22–0.63)	0.58 (0.38–0.73)
Trunk fat						
DXA trunk fat, %	0.69 (0.53–0.80)	0.77 (0.64–0.85)	0.89 (0.82–0.93)*	0.63 (0.44–0.77)	0.82 (0.71–0.89)	0.89 (0.82–0.93)*
AB-140 trunk fat, %	0.65 (0.47–0.77)	0.85 (0.76–0.90)	0.93 (0.88–0.95)*	0.61 (0.42–0.74)	0.83 (0.73–0.89)	0.89 (0.82–0.93)*
MC-180 trunk fat, %	0.64 (0.46–0.77)	0.80 (0.68–0.87)	0.89 (0.82–0.93)*	0.81 (0.70–0.88)	0.65 (0.47–0.77)	0.71 (0.55–0.81)
Whole-body fat						
BMI, kg/m^2	0.64 (0.46–0.77)	0.84 (0.74–0.90)	0.92 (0.87–0.95)*	0.58 (0.38–0.73)	0.86 (0.77–0.91)*	0.91 (0.85–0.94)*
DXA whole-body fat, %	0.65 (0.47–0.77)	0.80 (0.68–0.87)	0.89 (0.82–0.93)*	0.52 (0.30–0.68)	0.80 (0.68–0.87)*	0.84(0.74–0.90)*
BC-420 whole-body fat, %	0.71 (0.55–0.81)	0.76 (0.63–0.85)	0.90 (0.83–0.94)*	0.65 (0.47–0.77)	0.71 (0.55–0.81)	0.81 (0.70–0.88)
MC-180 whole-body fat, %	0.69 (0.53–0.80)	0.80 (0.68–0.87)	0.92 (0.87–0.95)*	0.61 (0.42–0.74)	0.71 (0.55–0.81)	0.80 (0.68–0.87)

Data presented as Pearson's correlation coefficient (95% CI).
*Significantly different from correlation of same simpler variable with VAT.
#Significantly different from correlation with BC-420 'visceral fat level' within gender
†Significantly different from correlation with MC-180 'visceral fat level' within gender.

either of the two whole-body BIA devices (BC-420 and MC-180) (table 2).

All three trunk fat measures were highly correlated with TAAT in men, but the whole-body BIA devices showed a significantly lower correlation with TAAT than either DXA trunk fat or abdominal BIA trunk fat in women (table 2).

Comparing the four whole-body fat measures, all were well correlated with TAAT in men, while in women BMI tended to show higher correlations (though not significantly higher) than DXA and whole-body BIA (table 2).

To separate the relationship between the simpler indices of whole-body and abdominal fat, linear regression was performed. Results showed that adding BMI into models for correlating abdominal BIA 'visceral fat level' and DXA L2-L4 fat with MRI TAAT, improved the R, with both independent variables remaining significant (R for model was 0.96 or 0.95 in men and 0.95 or 0.94 for women respectively). Adding BMI to the model for midpoint WC did not improve the R for the model for men (0.96), but increased it slightly for women (from 0.91 to 0.94).

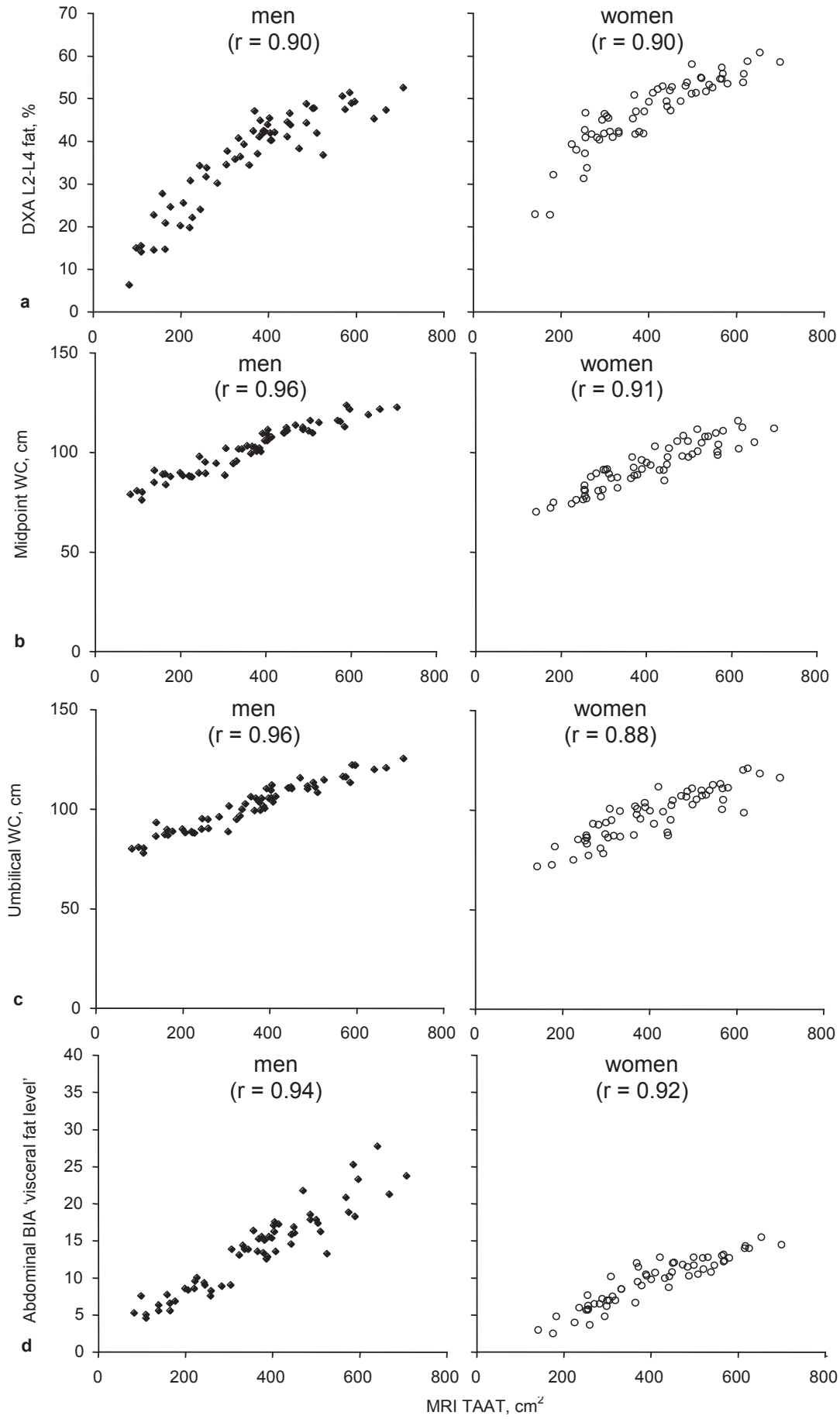

Fig. 3. Scatter plots of the relationship between MRI total abdominal adipose tissue (TAAT) and simpler measures of abdominal fat: **a** DXA L2-L4 fat, **b** midpoint WC, **c** umbilical WC and **d** Abdominal BIA 'visceral fat level'.

Discussion

This study shows that abdominal BIA 'visceral fat level', DXA L2-L4 fat, and WC (measured at either umbilical or midpoint waist) are all useful, simple proxy measures of TAAT. Conversely, none of the simpler measures of abdominal fat are good correlates of VAT, and hence to accurately assess VAT the expense of an MRI is warranted. This study provides little evidence to distinguish the usefulness of DXA L2-L4 fat, WC, and the abdominal BIA 'visceral fat level' as proxies for TAAT. However, in selecting a simpler method, the accuracy of each must be considered with its practical advantages and disadvantages.

Of the three BIA devices, the abdominal BIA device has a clear benefit over whole-body BIA devices for the measurement of abdominal fat, which was particularly evident in women. Correlations of the 'visceral fat level' from the abdominal BIA with MRI SAAT in men and women or MRI TAAT in women were significantly higher than those of the 'visceral fat levels' from BC-420 and MC-180 measurements. In men, the MC-180 trunk fat and abdominal BIA trunk fat results are similar, though in women the abdominal BIA trunk fat shows a significantly higher correlation than the MC-180 trunk fat. Previously, results from whole-body BIA devices have shown poorer correlations with VAT than other simpler indices, particularly in obese individuals [18].

WC measurements are inexpensive and quick, although open to large observer error. In this study WC measurements were made under highly controlled conditions, with standardised protocols and rigorous training leading to high precision [19]. However, in field situations, the accuracy of measurements is likely to be more variable, particularly where more than one observer is responsible for making WC measurements. It has previously been shown that inter-observer differences are larger than intra-observer differences [20, 21]. For DXA, even though precision is high, expensive equipment and, although very small, an additional X-ray exposure are required.

These results confirm previous observations of absolute differences in the WC measurement obtained at different measurement sites, particularly in women [22–24]. However, the present study shows that both midpoint and umbilical WC measurements have similar relationships with MRI abdominal adipose tissue areas, suggesting that both are useful proxy measures for TAAT. Importantly, both WC measures are better correlates of TAAT than of VAT. A previous study has suggested that the site of measurement of WC does not matter for its ability to predict disease [25].

The strong correlation between BMI and TAAT in this study was unexpected and may simply reflect the fact that as whole-body fat increases so too does abdominal fat. However, the linear regression results suggest that the simpler measures of whole-body fat and abdominal fat do have independent relationships with TAAT. Further, strong correlations with TAAT do not necessarily transfer to their usefulness as predictors of disease, and it is known from other cross-sectional and prospective studies that the BMI and WC have independent relationships with obesity-related disease.

Conclusion

Simpler indices of obesity such as WC, abdominal BIA, and DXA L2-L4 fat are useful proxies for TAAT. However, no simpler technique offers a good proxy for VAT. Thus to quantify VAT accurately, a sophisticated imaging technique such as MRI is warranted.

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Disclosure Statement

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