

Assessing visceral and subcutaneous adiposity using segmented T2-MRI and multi-frequency segmental bioelectrical impedance: A sex-based comparative study

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Abstract. *Background and Aim:* This study aims to quantify abdominal visceral adipose tissue (VAT) and subcutaneous adipose tissue (SAT) using T2-weighted magnetic resonance imaging (MRI), and assess the extent of its concordance with VAT surface-area measured by a state-of-the-art segmental multi-frequency bioelectrical impedance analysis (BIA) device. A comparison between manual and semi-automated segmentation was conducted. Further, abdominal VAT and SAT sex-based comparison in healthy Arab adults was piloted. *Methods:* A cross-sectional design was followed to recruit subjects. Abdominal VAT and SAT were determined on T2-weighted MRI manually and semi-automatically. Body composition was assessed using a BIA machine. Statistical differences between the abdominal VAT areas defined by BIA, manual, and semi-automated MRI were compared. Correlation between all methods was assessed, and statistical differences between sex abdominal VAT/SAT defined areas were compared. *Results:* A total of 165 abdominal T2-weighted MR images taken for 55 overweight/obese adult subjects were analyzed. Differences between manual and semi-automated MRI-obtained abdominal VAT and SAT were found statistically significant ($P < 0.001$) for all subjects. Mean abdominal VAT using the BIA technique was found to correlate significantly with manually and semi-automated T2-weighted MRI defined VAT ($r = 0.7436$; $P < 0.001$ and $r = 0.8275$; $P < 0.001$, respectively). Abdominal VAT was significantly ($P < 0.001$) different between male and female subjects accumulating at different abdominal levels. *Conclusion:* Semi-automatic segmentation showed a stronger significant correlation with BIA compared to manual segmentation, implying a more reliable quantification of abdominal VAT/SAT. A Segmental multi-frequency BIA machine may display an initial estimation for the visceral adiposity in obese subjects that warrants further confirmation by MRI or other accurate techniques. (www.actabiomedica.it)

Keywords: Abdominal visceral adipose tissue, Central obesity, Manual segmentation, Obesity, Semi-automated segmentation, T2 Weighted Magnetic Resonance Imaging

Introduction

Nowadays, obesity is one of the most challenging diseases with the global rising prevalence of obesity-associated health problems, where amongst the 2 bil-

lion reported overweight peoples, one-third are obese (1). To date, it is appreciated that sex and ethnicity play a role in obesity susceptibility (2, 3). Accurate and reliable measures of human adipose tissue (AT) have been gaining increased interest worldwide (4), par-

ticularly with the advanced radiological non-invasive high-resolution medical imaging and highly sophisticated segmentation algorithms (5). Quantitative measures of AT distribution throughout the body are needed to establish a research database, demonstrating cross-sectional differences based on age, sex, ethnicity, and pathological condition (5, 6). Strong evidence suggesting that excessive accumulation of visceral adipose tissue (VAT), in particular, is being associated with increased risks of cardio-metabolic diseases (7, 8), insulin resistance (9) and systematic low-grade inflammation (10, 11), diabetes (12) and certain types of cancers (13), escalating the need to quantify the regional distribution of VAT and subcutaneous adipose tissue (SAT) rather than total AT.

Such compartmental quantification feeds the growing need to correlate vital signs and different metabolic biomarkers with VAT and SAT quantities to better characterize and track changes in disease implications for a certain population cohort. This is in addition to allowing assessment of the effectiveness of interventional strategies carried over longitudinal measures targeting weight loss through reducing VAT and SAT.

To date, numerous techniques have been used to assess body compositions including anthropometric, bioelectrical impedance analysis (BIA), ultrasound, dual-energy X-ray absorptiometry (DEXA), computed tomography (CT), and magnetic resonance imaging (MRI). While the majority of the techniques mentioned above provide an estimate for total body fat mass, not specifically VAT, tomography images of CT and MRI have been recognized as a state of the art methods, particularly in volumetric quantifying AT and muscles [14-16]. MRI is considered the preferable choice due to the absence of harmful ionizing radiation, provides superior soft-tissue contrast resolution comparing to CT, and enables significantly higher quantitative accuracy measures comparing to the indirect anthropometric techniques (14). Volumetric quantification of AT is particularly important because often cases of individuals with identical body mass index (BMI) and waist circumference might indoor a significant variation in VAT [17, 18]. T1- and T2-weight MR images provide high contrast ability in distinguishing water and fat components, allowing

for surface or volumetric quantification of lean tissue, muscles, and AT (14).

The study aimed to quantify and investigate statistical differences in the abdominal VAT and SAT areas in Arab subjects based on sex. Further, to investigate differences in the quantified abdominal VAT and SAT areas using MRI segmented manual and semi-automated approaches and that of BIA for VAT. The current work also aimed to investigate the feasibility of multi-frequency segmental BIA to accurately assess the visceral adiposity in overweight and obese subjects. Finally, to find out how the VAT accumulation differs across the three abdominal levels among both male and female subjects.

Materials and Methods

A cross-sectional study design was followed, and a total of 165 abdominal T2 weighted MR images taken for 55 overweight/obese (BMI>25 kg/m²) healthy adult subjects were analyzed. The study was carried out following the Declaration of Helsinki. The study protocol was approved by the Research Ethics Committee of the University of Sharjah (Reference no: REC-16-05-11-01). Overweight and obese healthy subjects were recruited using social media outlets. After explaining the research objectives, methodology, and answering their relevant questions, all recruited subjects were provided with written informed consent before starting the study.

To exclude the confounding effect of genetic variations, all the recruited subjects were Arabs mostly originating from Jordan, Palestine, Syria, Egypt and Sudan, and UAE locals. Pregnant women, subjects with implanted pacemakers, and any metal plantations were excluded. Subjects included were healthy adults with no history of malignancy, chronic kidney or liver disease, and heart issues. Subjects visited the Department of Diagnostic Imaging at the University Hospital of Sharjah, for screening and consent form collection. After signing the consent form, every subject underwent an anthropometric assessment followed immediately by an MRI scan on the same date.

Anthropometric assessment and body composition analysis

Standardized anthropometric procedures were used to assess the body measurements. Body weights of the participants were performed using Seca (Hamburg, Germany) calibrated balance beam scale and measured to the nearest 0.1 kg, without shoes and while wearing light garments. Body height was measured using Seca portable stadiometer (Hamburg, Germany) with feet close together, and the head in the Frankfort plane position, to nearest 0.01 m. All measurements were taken by well-trained research assistants.

Fat mass, fat-free mass, total body water, and VAT surface area were measured using a state-of-the-art multi-frequency segmental BIA machine according to the manufacturer's manual (Tanita, MC-980, Tokyo, Japan). The VAT values obtained using the BIA were rated from 1-20. The BIA obtained values were multiplied by 10 to express the VAT surface area in cm^2 , following the manufacturer's explicit instructions. BMI was calculated as body weight in kilograms divided by the height in square meter (kg/m^2). Classification of body weight was performed using the world health organization (WHO) standard classification (19). In an attempt to eliminate the impact of body hydration condition in the obtained body compartments, BIA and MRI were conducted sequentially on the same day in the same setting and under the same conditions.

T2-MR imaging

MRI was performed using a 60-cm bore, and a 1.5T scanner (Avanto, Siemens, Erlangen, Germany), with subjects being laying in a supine position and arms aside. The integrated body radiofrequency (RF) coil was used for signal transmission, and the combination of a spine phased-array RF coil and 2 flexible phased-array RF coils were used for signal reception. The MRI protocol consisted of a respiratory-triggered morphologic T2 sequence. A 2-dimensional morphological T2 sequence was used with the following parameters: pixel size, $1.5 \times 1.5 \text{ mm}^2$; matrix size, 260×320 ; time to echo (TE), 90 ms; time to repetition (TR), 3,830 ms; slice thickness (TH), 6 mm.

T2-MRI visceral adipose tissue assessment

The abdominal VAT and SAT areas were determined on T2-weighted MR images using two different and independent approaches: manual and semi-automated segmentation. Abdominal VAT and SAT segmentations were carried out by two independent

professional observers. In the manual approach, the reconstructed T2-MR images were transferred online to a radiological diagnostic workstation running iSite picture archive computer system (iSitePACS, Phillips 3.6) software, where abdominal VAT and SAT areas were manually delineated and measured in cm^2 . For the semi-automated segmentation, the native T2-MR images were transferred offline to a research workstation running OsiriX MD (version 8.5; Pixmeo, Geneva/Switzerland), where abdominal VAT and SAT areas were determined using a 2-dimensional grown region segmentation. In this approach, neighboring pixels are examined and added to a region classification after manually selecting a few seed pixels to be considered as an object. Each pixel included should either belong to the object or to the edges of that particular object. Several thresholding intervals were applied together with a flexibly structured brush radius to accurately exclude a non-VAT component likewise the SAT component. For precise quantification of abdominal VAT and SAT, MR images were reconstructed in the axial plane at three body levels (mid-upper, middle, and mid-lower abdomen), as shown in Fig 1. This was acquired for each subject, resulting in a total of 165 (55 subjects' \times 3) MR images. VAT and SAT area on each of the abdominal T2 weighted MRI slice was quantified and measured in cm^2 . The mean \pm SD was then calculated for each subject to represent the abdominal VAT and SAT area in cm^2 .

Statistical analyses

A statistical and graphical software package, GraphPad Prism v8.0 (GraphPad Software, La Jolla, California, USA), has been used for data plotting and analysis. Data are expressed as a range, mean, median, and standard deviations (SD). Statistical differences between the means of each MRI segmentation (manual and semi-automated) approach were calculated using Wilcoxon unpaired t -test. A Bland-Altman bias and agreement test was acquired to evaluate the difference between the VAT area measured by BIA and manual and semi-automated MRI. Statistical differences between sex-based analyses were calculated using Mann-Whitney unpaired t -test. To study the correlations of the VAT area measured by BIA and manual and semi-automated MRI, Spearman's corre-

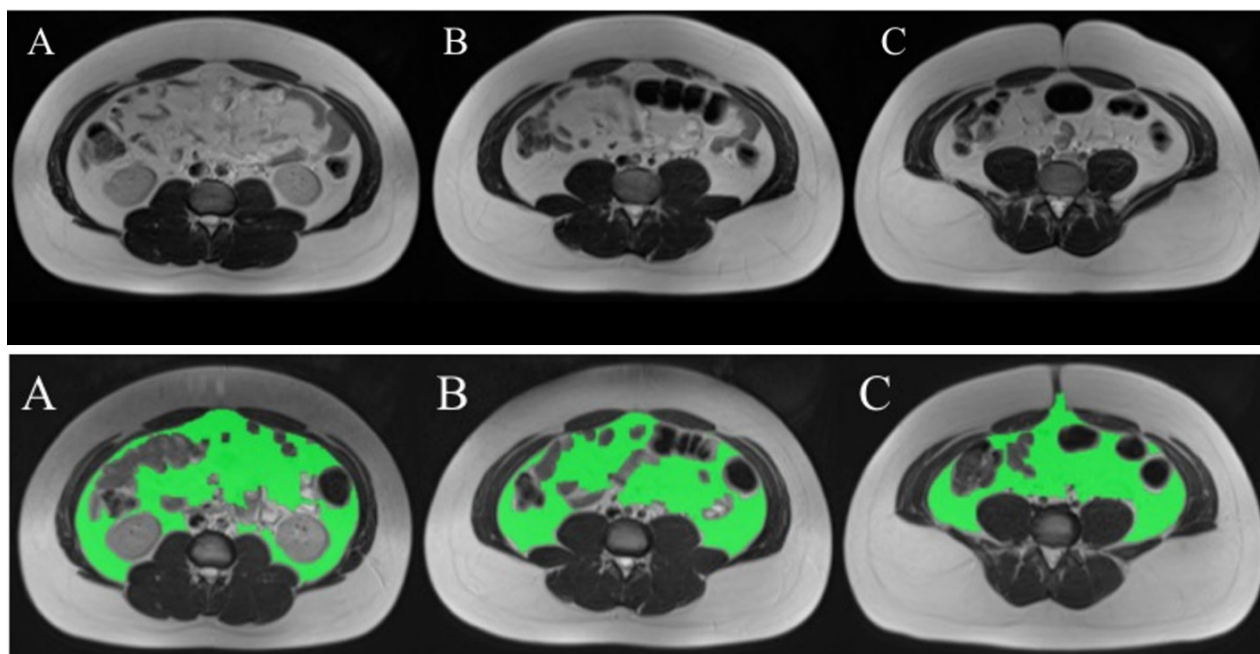


Figure 1. Axial T2-weighted MRI reconstructed slices at the mid-upper level (A) at the middle level (B), and at the mid-lower (C) of the abdominal for the analysis of visceral adipose tissue area (bottom panel with, green, color-washed presentation demonstrated semi-automated abdominal VAT).

lation coefficient test was applied. The data were tested for statistical significance at a P -value of <0.05 .

Results

Female and male adult participants (total number of 55: 21 females and 34 males) with mean BMI \pm SD of 30.5 ± 5.4 kg/m², mean age of 35.1 ± 13.2 years, and mean body fat percentage of $30.6 \pm 6\%$ were analyzed.

Quantifying abdominal VAT and SAT areas

Using the Spearman coefficient test, a positive strong ($r=0.8554$, $P<0.001$) correlation was seen between manually and semi-automated segmented abdominal VAT area on T2-weight MRI. Similarly, a positive strong ($r=0.8771$, $P<0.001$) correlation was seen between manually and semi-automated segmented abdominal SAT area (Fig. 2). Using Wilcoxon paired t -test, significant ($P<0.001$) statistical difference was found between manually and semi-automated segmented abdominal VAT and SAT areas on T2-weight MRI. With an average VAT mean \pm SD of 134.3 ± 77.2 cm² (manually), and 107.8 ± 73.9 cm² (semi-automatically), respectively measured for all 55 subjects over the

three abdominal levels (A, B and C, Fig 1). An average SAT mean \pm SD of 291.6 ± 113.5 cm² (manually), and 262.4 ± 104.7 cm² (semi-automatically), respectively. A summary of participants' age and weight profile is shown in Table 1. A big difference was found between the means of VAT area defined manually and semi-automatically measuring -28.84 with the 95% limits

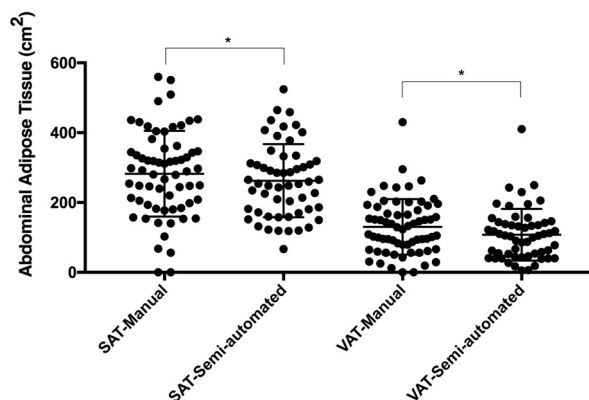


Figure 2. Statistically insignificant difference between the abdominal VAT and SAT areas quantified manually and semi-automatically using Wilcoxon paired t -test.

*Statistically significant difference at $P<0.05$

Table 1. Anthropometric characteristics of the study participants based on their sex

Characteristic	Mean (SD), range
Age, female (year)	34.4 (11.5), 20-48
Age, male (year)	36.6 (12.6), 21-59
Weight, female (kg)	80.1 (18.9), 55.5-121.8
Weight, male (kg)	94.3 (12.2), 68.4-119.5
Height, female (cm)	164.2 (6.2), 153-176
Height, male (cm)	174.7 (6.8), 164-188
BMI, female (kg/m ²)	29.9 (7.9), 20.1-47.1
BMI, male (kg/m ²)	30.8 (3.0), 24.5-40.4
Fat mass, female (kg)	28.9 (10.8), 15.1-51.3
Fat mass, male (kg)	26.3 (6.9), 12.5-44.1
Fat-free mass, female (kg)	51.2 (9.1), 38.5-76.5
Fat-free mass, male (kg)	68.0 (6.5), 55.9-78.9
Body fat %, female	35.1 (5.7), 23.2-46.6
Body fat %, male	27.4 (4.4), 18.3-36.9

BIA, bioelectrical impedance analysis; BMI, body mass index.

of agreement lying between (-92.97 to 35.3) using Bland-Altman bias and agreement test measured for all 55 subjects over the three abdominal levels (A, B and C, Fig. 1). In making use of the semi-automated segmentation, a color wash presentation on the T2 weighted MRI shows the extent and distribution of abdominal VAT within a subjects' abdomen (Fig. 1).

The mean abdominal VAT area obtained for all 55 subjects using BIA was 94.4 ± 49.1 cm². The abdominal VAT area measured using the BIA technique demonstrated highly significant positive correlations with the quantified abdominal VAT area using semi-automatically ($r=0.8275$, $P<0.001$) and manually ($r=0.7436$, $P<0.001$) on T2 weighted MRI. The semi-automated segmentation revealed a stronger correlation. The abdominal VAT area defined using BIA was

significantly different from the abdominal VAT area defined by manual ($P<0.001$) and semi-automatic techniques ($P=0.032$). Using the Bland-Altman bias and agreement test measured for all 55 subjects over the three abdominal levels, a small difference (13.51 with the 95% ranging between -79.5 to 106.6) was seen between the means of VAT area defined using semi-automatically T2-weighted MRI and that of BIA technique. In contrast, a bigger difference (40.64 with 95% ranging between -55.9 to 137.2) exists between the means of VAT area defines using manually segmented T2-weighted MRI and BIA.

Abdominal VAT and SAT heterogeneity

A descriptive VAT and SAT area distribution across the 3 abdominal scanned levels on T2 weighted MRI for the 21 female and 34 male subjects are summarized in Table 2. Implying that both VAT and SAT are heterogeneously distributed across the abdominal body region with a clear increase of SAT accumulation around the mid-upper abdomen for both female and male subjects (denoted as A, Fig 3) comparing to the middle (denoted as B, Fig 3), and mid-lower abdomen (denoted as C, Fig 3). In contrast, female subjects seem to have a slightly higher VAT accumulation around the middle abdomen (denoted as B, Fig 3) while male subjects showing a slight increase in VAT accumulation around the mid-lower (denoted C, Fig 3).

Abdominal VAT and SAT-based on sex

Using Mann-Whitney unpaired t -test, a significant statistical difference was found between male and female abdominal VAT area using semi-automated ($P<0.001$, Fig. 4a) and manual ($P<0.001$, Fig. 4b) seg-

Table 2. Sex-based VAT and SAT distribution across the 3 abdominal scanned levels.

Parameter	Abdominal level	Female	Male
		(n = 21)	(n = 34)
		Mean (SD), range	Mean (SD), range
Abdominal VAT (semi-automated measured in, cm ²)	Mid-upper (A)	55.4 (40.0), 6.0-161.6	115 (57.0), 46.3-318
	Middle (B)	57.5 (45.9), 4.6-188.1	150.5 (78.7), 45.8-420
	Mid-lower (C)	46.4 (35.4), 1.8-128.3	151.4 (87.6), 27.4-492.6
Abdominal SAT (semi-automated measured in, cm ²)	Mid-upper (A)	361.5 (146.0), 161.7-628.3	288.2 (114.3), 91.6-510.4
	Middle (B)	288.8 (131.0), 111.5-546.1	257.4 (97.3), 61.1-432.9
	Mid-lower (C)	232.2 (122.7), 55.8-444.1	199.9 (78.9), 47.9-354.6

VAT, Visceral adipose tissue; SAT, Subcutaneous adipose tissue.

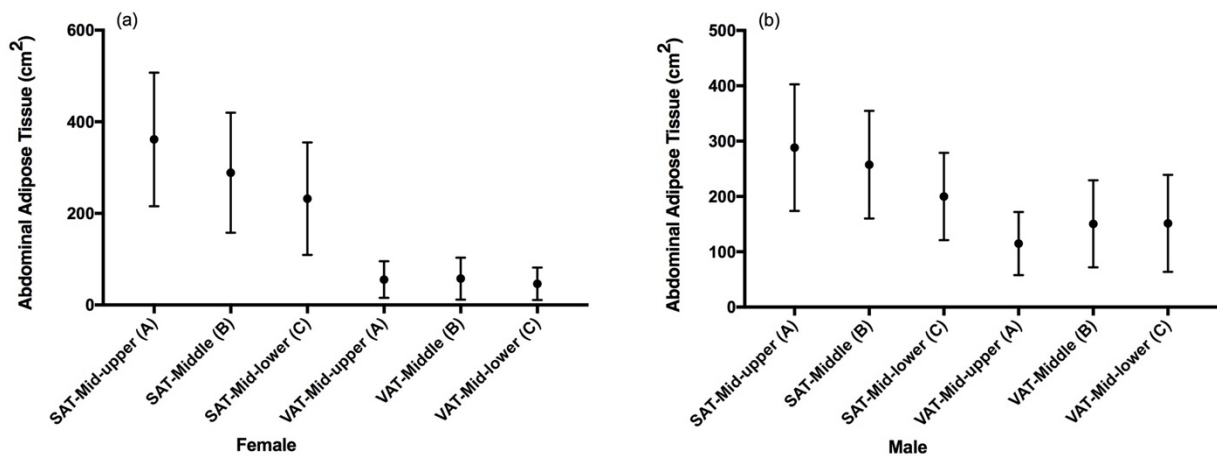


Figure 3. Demonstration for the accumulation of VAT and SAT areas at different abdominal levels for female (left graph, denoted a) and male (right graph, denoted b) subjects, more SAT accumulation at the mid-upper abdomen level for both sexes (denoted A), while VAT accumulations are showing to be sex-dependent.

mentation. In contrast, an insignificant statistical difference was found between male and female abdominal SAT areas using semi-automated ($P=0.2590$, Fig. 4c) and manual ($P=0.3321$, Fig. 4d) segmentation. A significant statistical difference was found between males' and females' abdominal VAT area using the BIA approach ($P<0.001$, Fig. 4e). Additionally, insignificant ($P=0.1406$) statistical difference was found between male and female BMI using Mann-Whitney unpaired t -test. Descriptive abdominal VAT data based on sex, manual, semi-automated, BIA, and BMI is demonstrated in Table 3.

Discussion

Establishing an obesity population-specific personalized health model based on gene variant profile, sex, and ethnicity is being suggested to help improve the efficacy of treatment outcomes. Visceral obesity is amongst the metabolic syndrome components that play an important role in developing and managing chronic diseases. It has been suggested that reducing VAT may be quite effective for reducing risks associated with chronic diseases (20).

The present work reports significant differences in quantifying abdominal VAT using semi-automatic and manual segmentations on T2 weighted MRI. Further,

the abdominal VAT area quantified using segmentation (manual and semi-automated) methods were found significantly different from the abdominal VAT measured by BIA. Nevertheless, abdominal VAT areas defined and measured using MR images and BIA were well correlated. A highly strong correlation was found between the abdominal VAT area defined using semi-automatically and BIA comparing to the abdominal VAT area defined manually and BIA. In our study, the abdominal VAT area segmented manually was found significantly higher than that segmented semi-automatically, with a mean and standard deviation of 134.3 ± 77.2 and 107.8 ± 73.9 , respectively. A similar observation was reported by Poonawalla and colleagues (21), even though they made use of different semi-automated software to segment MRI. Hui and colleagues (22) reported a strong correlation between an automated and semi-automated VAT volume segmentation on a T1 weight MRI in obese adolescence. With lowest VAT accumulation has been reported close to the diaphragm which is in line with our observation, Fig 3, mid-upper (A) level. Very good agreement was reported between fully automated methods and manually segmented organs and adipose tissue in obese women using abdominal water and fat MRI images (6). Further, Shen et al (23) proposed a strong correlation between fully automated VAT denoted measurement using deep machine learning and that using

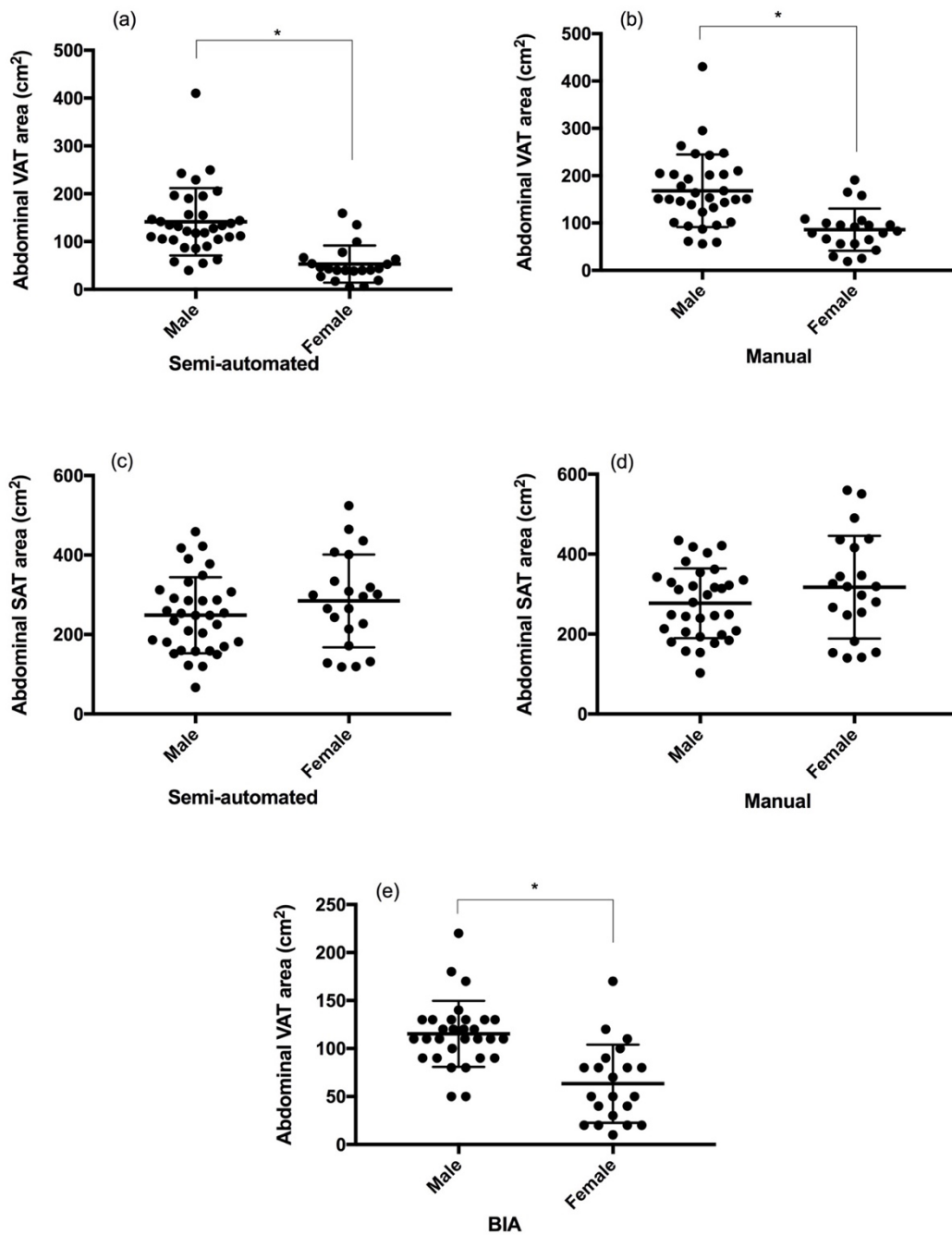


Figure 4. Abdominal VAT and SAT area profile among the 21 female and 34 male adult participants using manual and semi-automated segmentation together with the BIA method. *Statistically significant difference at $P < 0.05$.

manual segmentation on MRI of 75 subjects. An overall good agreement was reported between CT, MRI (24), and DEXA for the measurement of whole-body adipose tissue (25). While a significant discrepancy was reported between DEXA and BIA in all body seg-

ments by Wingo et al (26).

The differences between the manually and semi-automated defined abdominal VAT may be, in part, related to the qualitative nature of manual delineation, which relies on the grey shade on the MR image. In

Table 3. Sex-based abdominal VAT and SAT area using manual and semi-automated segmentation, and BIA methods.

Parameter	Female (n = 21)		Male (n = 34)	
	Mean (SD), range	Median	Mean (SD), range	Median
Abdominal VAT (manual measured, cm ²)	86 (44.6), 19-191	83.3	168.1 (76.7), 56- 430.3	151.3
Abdominal VAT (semi-automated measured, cm ²)	53.1 (38.6), 5.4-159.3	43.2	141.5 (70.4), 39.8- 410.2	129.8
Abdominal SAT (manual measured, cm ²)	317.3 (128.5), 140.3-559.7	318.7	277.1 (87.4), 102.7- 434.3	279
Abdominal SAT (semi-automated measured, cm ²)	284.5 (116.6), 118.4-524.2	295.8	248.5 (95.8), 66.9- 458.8	248.2
BIA VAT (cm ²)	63.3 (40.7), 10-170	50.0	115.3 (34.3), 50.0- 220.0	110.0

VAT, Visceral adipose tissue; SAT, Subcutaneous adipose tissue; BIA, Bioelectrical impedance analysis; BMI, Body mass index.

contrast, semi-automated segmentation techniques rely on the quantitative pixel/voxel value. Consequently, when quantifying AT structures by hand relying on visual interpretation of grey shade, non-adipose structures with similar signal intensities may be falsely included. This results in a small but statistically significant overestimation of the adipose volume.

Our results also suggest that abdominal VAT is sex-dependent at least in our UAE Arab cohort. A significant abdominal VAT difference was seen between the 21 female and 34 male adult participants despite the segmentation approach used. Using Mann-Whitney unpaired *t*-test, our data suggest significant different abdominal VAT profile among the 21 female and 34 male adult Arab participants in our cohort study using manual and semi-automated segmentation methods with significantly higher accumulation of abdominal VAT in males comparing to females with a mean for the male of 168.1 ± 76.7 cm² using manual and 141.5 ± 70.4 cm² using semi-automated, and for female of 86 ± 44.6 cm² using manual and 53.1 ± 38.6 cm² using semi-automated. The semi-automated segmented abdominal VAT also proposes different accumulations profile across the abdominal scanned levels (A, B, and C, Fig 1) between females and males abdominal VAT, with the highest VAT accumulation in males being around the middle with a mean of 150.1 ± 78.7 cm² comparing to the highest accumulation of VAT in females that happens to be around the mid-upper with a mean of 55.4 ± 40.0 cm². Further, a significant difference in abdominal VAT profile among females and males in the cohort was seen using the standard BIA

method, with mean abdominal VAT of 63.3 ± 40.7 cm² been measured for females and 115.3 ± 34.3 cm² for males. Similarly, the BMI measurement only suggests that both sexes are overweight with a median of 27.9 and 30.4 kg/m² for females and males, respectively.

Recently, Chaudry et al. (27) reported that the correlation between abdominal and visceral compartments was very close for young healthy participants (age 21-36 years) and older participants (age range: 70-86 years). Further, they found that the ratio of visceral to total abdominal fat fraction was increased in older men compared with younger men, which was not detected with BIA. Most importantly, they found that MRI and BIA measurements of the visceral measurements correlated poorly, while moderately correlated for the total abdominal volume. The last finding contradicts our finding, where the semi-automated MRI and BIA VAT measures showed good concordance. Findings of the current work contradict what was found in 2010 by Browning and colleagues (28) who found that BIA-based abdominal fat measures from the same supplier (AB 140 Tanita, Tokyo) did not appear to provide a useful proxy measure of VAT. This implies better ability and improvement in the currently used segmental multi-frequency bioelectrical impedance analysis (BIA) device in measuring the VAT. To our knowledge, no published study reported an abdominal VAT baseline for the Arab population certainly on sex-based obesity profile. Herein, not only that we demonstrated a statistically significant difference between manually and semi-automated quantified abdominal VAT area, our findings reflect a high

strong ($r=0.8275$, $P<0.001$) correlation with a minimal mean difference of 13.51 between abdominal VAT area defined semi-automatically and BIA, where the latter is considered the standard technique. Our study could benefit from increasing the number of participants, however since our findings demonstrate a strongly significant difference between manually and semi-automated quantified abdominal VAT area, it is safe to assume the sample size is sufficient as proof of concept. Armao et al (29) examined the automated segmentation of VAT on five patients only.

Regarding limitations of the present study, the whole volume T2-weighted MRI coverage of the abdomen would certainly reflect a more accurate, consistent, and reliable measure of the adipose tissue compared to averaging the VAT surface area using three abdominal body levels measurements. It will also be advisable to scan all participants with arms on the side; some cases in the present study were scanned with arms on the belly. Such inconsistency should have minimal impact if a whole volume MRI coverage scan was acquired. Otherwise, it can be a source of minimal uncertainty. Fully automated segmentation algorithms would offer several advantages over our semi-automated and certainly manual segmentation. It will permit precise, objective, reliable, and reproducible quantification of adipose tissue in a timely fashion (4). Such algorithms are not available on a wide commercial scale. Our group's preliminary data on developing a fully automated segmentation algorithm using deep learning to quantify AT utilizing can be found in (30). Another limitation of the current study was the different anatomical coverage of the MRI and BIA measurements. Further, inherited limitations of the BIA in assessing the visceral adiposity such as the inability to accurately measure visceral fat in massively obese people, who were partly included in the current work, should be considered. Finally, the inclusion of Arab subjects from different countries of the Middle East (Jordan, Palestine, Syria, Egypt and Sudan as well as the UAE) may entail some inaccuracy because of the genetic variability in body fat deposition between different Arab populations.

Conclusion

In conclusion, abdominal VAT was found significantly different between male and female participants in our study using T2-weighted MR images, the BIA method showed insignificant different abdominal VAT between males and females. Despite the significant differences in the VAT areas measured by semi-automated and manual T2-weighted MRI and BIA, they showed strong positive correlations. Therefore, it should be noted that using BIA should still be retained as a supplementary measure, especially given their low cost, and fundamental ease of measurement. Finally, the highest accumulation of VAT across the three abdominal levels is different between males and females; however, their SAT accumulation trend is the same.

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Statement of Ethics: The current work complies with the guidelines for human studies and includes evidence that the research was conducted ethically in accordance with the World Medical Association Declaration of Helsinki.

Conflicts of interest: Each author declares that he or she has no commercial associations (e.g. consultancies, stock ownership, equity interest, patent/licensing arrangement, etc.) that might pose a conflict of interest in connection with the submitted article

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Data availability: Data are available upon justifiable request.

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