

Computed tomography-based validation of abdominal adiposity measurements from ultrasonography, dual-energy X-ray absorptiometry and anthropometry

Anna M. I. Gradmark¹, Anders Rydh², Frida Renström¹, Emanuella De Lucia-Rolfe³, Alison Sleight⁴, Peter Nordström⁵, Soren Brage³ and Paul W. Franks^{1*}

¹Genetic Epidemiology and Clinical Research Group, Department of Public Health and Clinical Medicine, Division of Medicine, Umeå University Hospital, Umeå 90 187, Sweden

²Department of Radiology, Umeå University Hospital, Umeå, Sweden

³MRC Epidemiology Unit, Institute of Metabolic Science, Cambridge, UK

⁴Wolfson Brain Imaging Centre, Addenbrooke's Hospital, Cambridge, UK

⁵Department of Surgery and Perioperative Sciences, Umeå University Hospital, Umeå, Sweden

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Large-scale aetiological studies of obesity and its pathological consequences require accurate measurements of adipose mass, distribution and subtype. Here, we compared the validity of three abdominal obesity assessment methods (dual-energy X-ray absorptiometry (DXA), ultrasound and anthropometry) against the gold-standard method of computed tomography (CT) in twenty-nine non-diseased middle-aged men (BMI 26.5 (SD 3.1) kg/m²) and women (BMI 25.5 (SD 3.2) kg/m²). Assessments of adipose mass (kg) and distribution (total subcutaneous (TSAT), superficial subcutaneous (SSAT), deep subcutaneous (DSAT) and visceral (VAT)) were obtained. Spearman's correlations were performed adjusted for age and sex. VAT area that was assessed using ultrasound (r 0.79; $P < 0.0001$) and waist circumference (r 0.85; $P < 0.0001$) correlated highly with VAT from CT, as did BMI (r 0.67; $P < 0.0001$) and DXA (r 0.70; $P < 0.0001$). DXA (r 0.72; $P = 0.0004$), BMI (r 0.71; $P = 0.0003$), waist circumference (r 0.86; $P < 0.0001$) and ultrasound (r 0.52; $P = 0.015$) were less strongly correlated with CT TSAT. None of the comparison measures of DSAT was strongly correlated with CT DSAT (all r approximately 0.50; $P < 0.02$). BMI (r 0.76; $P < 0.0001$), waist circumference (r 0.65; $P = 0.002$) and DXA (r 0.75; $P < 0.0001$) were all fairly strongly correlated with the CT measure of SSAT, whereas ultrasound yielded a weaker yet statistically significant correlation (r 0.48; $P = 0.03$). Compared with CT, visceral and subcutaneous adiposity can be assessed with reasonable validity using waist circumference and BMI, respectively. Ultrasound or DXA does not generally provide substantially better measures of these traits. Highly valid assessments of DSAT do not appear to be possible with surrogate measures. These findings may help guide the selection of measures for epidemiological studies of obesity.

Computed tomography: Ultrasound: Waist circumference: Waist:height ratio: Dual-energy X-ray absorptiometry: Obesity: Adipose tissue: Validation

An abundance of adipose tissue is an established risk factor for CVD, type 2 diabetes, sleep apnoea, osteoarthritis, certain cancers, depression and early death⁽¹⁾. Several studies have suggested that the superficial and deep subcutaneous adipose compartments have different metabolic properties^(2–5). The methods available to measure abdominal adiposity vary in feasibility and economic cost, factors which are often used to justify the choice of methods in research studies. Although anthropometric methods are frequently used to assess body composition in epidemiological studies, several scanning-based methods are available which may be suitable for use in the epidemiological setting. These include dual-energy X-ray absorptiometry (DXA)

and ultrasonography; the latter can be performed with mobile equipment and is non-invasive.

Although studies exist where ultrasound and DXA have been validated for the assessment of adipose mass and distribution^(6–13), to our knowledge, no studies have been reported where the validity of ultrasound for the assessment of deep and superficial subcutaneous adipose tissue (SAT) has been ascertained and compared with DXA or computed tomography (CT).

The purpose of the present study was to compare three body composition assessment methods (ultrasound, DXA and anthropometry) against the gold-standard method of CT.

Abbreviations: CT, computed tomography; DXA, dual-energy X-ray absorptiometry; SAT, subcutaneous adipose tissue; VAT, visceral adipose tissue.

* **Corresponding author:** Paul W. Franks, fax +46 90 13 76 33, email paul.franks@medicin.umu.se

Participants and methods

Participants were white middle-aged men (n 16) and women (n 13) from the county of Västerbotten in northern Sweden. Measurements were conducted at the Clinical Research Center and Department of Radiology at the University Hospital. Before the initiation of the study protocol, the procedures and associated risks were explained in detail, and then all participants provided written informed consent. The study was conducted according to the guidelines laid down in the Declaration of Helsinki, and all procedures involving human subjects were approved by the Umeå Research Ethics Committee.

Anthropometry

Height to the nearest 0.1 cm and weight to the nearest 0.1 kg were measured using a calibrated wall-mounted stadiometer and digital scale, respectively, with participants wearing indoor clothing and no shoes. BMI was computed as weight (kg) divided by the square of height (m^2). Waist circumference was measured to the nearest 0.1 cm in duplicate using a non-stretchable, retractable nylon tape at the midpoint between the twelfth rib and the iliac crest. Waist:height ratio was calculated as waist divided by height. For all anthropometric measures, the mean of the duplicate measures was used in the analyses.

Body scans

Participants wore light clothing, free from metallic parts and lay face-up, with their arms placed alongside the body. Measurements of body composition were done using DXA (Lunar Prodigy IV, GE Lunar, WI, USA), ultrasound (Acuson Sequoia, Siemens, Mountain Woods, CA, USA) and CT (Light Speed VCT, General Electric, Milwaukee, WI, USA) scanners calibrated daily according to the manufacturer's protocols. To reduce operator bias, the ultrasound, CT and DXA measurements were performed by operators who were blind to the results from other aspects of the study.

Computed tomography and ultrasound. Greyscale ultrasound images were obtained at lumbar 2–3 by a clinical radiologist (A. R.), while the participants lay on their back and held their breath during mid-inspiration (Fig. 1(a)–(c)). For the assessment of SAT from ultrasound, a high-resolution linear probe (5–8 MHz) was used, whereas a convex probe (1–4 MHz) was used for measuring visceral adipose tissue (VAT). When measuring SAT, the probe was placed 5 cm cranial to the umbilicus. Total SAT was measured from the posterior line of dermis to the outer bowel wall. Superficial SAT was measured as the distance between the posterior line of dermis to the fascia superficialis. The deep SAT compartment was determined as the distance between the fascia and the anterior line of the rectus abdominis muscle. VAT was assessed by measuring the distance from the inside of the bowel wall to the spine. SAT is located directly beneath the skin between the dermis and fascia, whereas VAT localises to the peritoneal cavity and surrounds various organs.

When scans were performed, minimal pressure was applied to the probe to avoid displacement of the abdominal cavity. Immediately after the ultrasound scan, a single CT scan was performed at the exact location indicated during the ultrasound examination (Fig. 1(a)–(c)). This spot was marked with an angiography catheter placed on the skin. CT images were obtained in the same position as the ultrasound scans by a different radiographer who was also blind to the results of the scans. Distances (cm) were calculated on the CT and ultrasound scan images using a PACS workstation (SECTRA, Linköping, Sweden).

An upper and lower attenuation range for fat was set at -200 and -20 Hounsfield units, respectively⁽¹⁴⁾. The CT images were then thresholded at this fixed attenuation range using Analyze 7.0 (Biomedical Imaging Resource, Mayo Clinic, Rochester, MN, USA), such that all pixels sampled afterwards were those representing adipose tissue. Following extraction of the spine and posterior muscles, a region of interest was drawn that traced the transverse fascia between the abdominal cavity to provide a region that encompassed all VAT. Segmentation of the SAT into deep and superficial fat was performed manually using the methods outlined

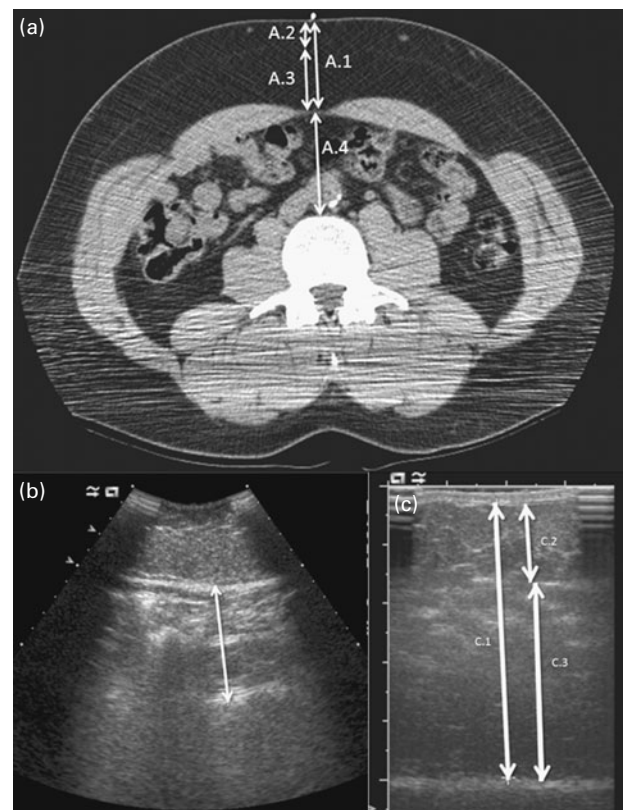


Fig. 1. Examples of the different computed tomography (CT) and ultrasound measurements. Panel (a) shows how measurements were made for the CT reference thicknesses; line A.1 shows the total subcutaneous thickness, line A.2 shows the superficial subcutaneous thickness, line A.3 shows the deep subcutaneous thickness and line A.4 shows the total visceral thickness. CT area calculations are defined in the Methods section. In panel (b), the line shows the total visceral thickness from ultrasound. In panel (c), line C.1 shows the total subcutaneous thickness, and lines C.2 and C.3 show the superficial and deep subcutaneous thicknesses, respectively.

above. Where the distinction between deep and superficial adipose tissue was indeterminable, the total subcutaneous compartment was recorded. The area for each adipose compartment (i.e. visceral, and total, deep and superficial subcutaneous) was calculated from the number of pixels in the threshold map within each of these compartments.

The abdominal region for thirteen participants extended slightly beyond the CT camera field of view. To account for the missing area, the peripheral subcutaneous region was included for at least one side of the body, and this information was used to estimate the area of the missing region within the same individual, with the assumption that subcutaneous fat distribution is symmetrical at the level of the abdomen. This method has been shown to be valid when using DXA scans performed in morbidly obese persons⁽¹⁵⁾.

Dual-energy X-ray absorptiometry scans. The DXA scans were performed using a GE-Lunar Prodigy DEXA Scanner. Adipose areas were defined using the region of interest programme as described previously⁽¹⁶⁾.

All measurements were performed on the same day, and participants fasted before undergoing the scans. None of the study participants was on weight-loss prescription medications. As with most Western populations, dieting is common in Sweden; thus, it is possible that some of our participants may have been dieting at the time of the study. However, we did not collect such information.

Statistical analysis

Analyses were performed using the Statistical Analysis Systems software v9.1 (SAS Institute, Cary, NC, USA).

Correlations between pairs of variables were calculated using Spearman's rank order statistic (*r*) for the comparisons involving measures with different scales, and Lin's concordance correlation (ρ) was used for pairs of variables with the same scales (i.e. CT adipose distances *v.* US adipose distances). Generalised linear models were used to derive β -coefficients, and to calculate explained variances (R^2). All analyses were adjusted for age and sex. Agreement between ultrasound and CT measures on the same scale was assessed using the Bland–Altman technique⁽¹⁷⁾. A *P* value < 0.05 was considered statistically significant.

Results

Participant characteristics are shown in Table 1 for men and women separately.

We initially tested whether any associations differed in magnitude by sex by fitting interaction terms (sex \times each independent variable) to linear regression models. None of these terms was significant ($P > 0.1$); therefore, remaining analyses were conducted in men and women combined, adjusted for age and sex (Tables 2 and 3).

Comparisons against computed tomography-derived adipose areas (cm²)

Subcutaneous adipose tissue. As shown in Table 2, waist circumference (*r* 0.86; $P < 0.0001$), waist:height ratio (*r* 0.74; $P < 0.0001$), DXA total adipose mass (kg) (*r* 0.72; $P = 0.0004$) and BMI (*r* 0.71; $P = 0.0003$) were strongly and comparably correlated with CT total subcutaneous adipose tissue. The ultrasound measure of total subcutaneous adipose tissue was the

Table 1. Participant characteristics (Mean values and standard deviations with their ranges)

Variable	Women (n 13)				Men (n 16)				P-comparison*
	Mean	SD	Range		Mean	SD	Range		
			Min	Max			Min	Max	
Age (years)	53.0	8.6	42.2	62.5	49.1	7.9	41.9	62.3	0.21
Height (m)	1.65	0.04	1.59	1.72	1.82	0.05	1.75	1.92	0.0001
Weight (kg)	68.7	8.5	53.0	82.0	87.5	10.0	72.4	107.0	0.0001
BMI (kg/m ²)	25.5	3.2	21.4	32.0	26.5	3.1	21.3	32.0	0.41
Waist circumference (cm)	84.7	9.2	75.0	100.0	94.1	7.5	84.0	107.0	0.005
Waist:height ratio	0.31	0.03	0.28	0.38	0.29	0.03	0.24	0.34	0.02
CT visceral (cm ²)	120.4	61.5	42.9	225.8	165.7	89.5	57.3	327.4	0.14
CT total subcutaneous (cm ²)	243.0	78.5	125.2	388.4	187.0	62.6	120.7	325.2	0.05
CT superficial subcutaneous (cm ²)	146.5	50.0	81.2	254.0	103.5	33.7	69.0	175.9	0.03
CT deep subcutaneous (cm ²)	97.0	37.6	44.0	158.9	73.8	30.6	41.2	149.4	0.12
CT visceral (cm)	6.97	2.01	3.30	10.81	8.47	2.38	5.06	11.84	0.08
CT total subcutaneous (cm)	3.03	0.92	1.83	4.43	2.76	1.05	1.69	5.20	0.47
CT superficial subcutaneous (cm)	1.53	0.49	1.13	2.44	1.07	0.33	0.63	1.83	0.01
CT deep subcutaneous (cm)	1.61	0.70	0.63	2.67	1.75	0.76	0.92	3.73	0.64
Ultrasound visceral (cm)	6.77	1.49	3.96	9.56	7.88	2.14	4.98	11.34	0.13
Ultrasound total subcutaneous (cm)	2.95	0.88	1.77	4.52	2.89	0.97	1.96	4.81	0.87
Ultrasound superficial subcutaneous (cm)	1.54	0.48	0.81	2.33	1.23	0.13	0.95	1.48	0.04
Ultrasound deep subcutaneous (cm)	1.73	0.63	0.54	2.70	1.65	0.94	0.66	3.48	0.79
DXA abdominal adipose (kg)	1.75	0.69	0.81	2.71	2.07	0.78	0.88	3.13	< 0.0001
DXA total adipose (kg)	25.9	8.1	14.6	40.5	22.4	6.9	11.0	31.1	0.21

Min, minimum; Max, maximum; CT, computed tomography; DXA, dual-energy X-ray absorptiometry.

* *P* values for the comparison of men and women using an independent (two-side) Student's *t* test. Ultrasound scans were performed in only twenty-two participants.

Table 2. Spearman's correlation coefficients for ultrasound, dual-energy X-ray absorptiometry (DXA) and anthropometric measures of adiposity compared with computed tomography (CT) measures of adipose areas (*n* 22)

	CT measure			
	Visceral (cm ²)	Subcutaneous (total, cm ²)	Subcutaneous (superficial, cm ²)	Subcutaneous (deep, cm ²)
Comparative measure				
BMI (kg/m ²)	0.67***	0.71***	0.76****†	0.53*
Waist circumference (cm)	0.85****†	0.86****†	0.65**	0.54*
Waist:height ratio	0.81****	0.74***	0.69***	0.66**†
Ultrasound visceral (cm)	0.79****	0.54*	0.56**	0.43
Ultrasound subcutaneous (total, cm)	0.24	0.52*	0.47*	0.40*
Ultrasound subcutaneous (superficial, cm)	0.62**	0.49*	0.48*	0.36
Ultrasound subcutaneous (deep, cm)	0.15	0.51*	0.47*	0.49*
DXA (abdominal fat, kg)	0.72***	0.58**	0.73***	0.51*
DXA (total fat mass, kg)	0.70***	0.72***	0.75****	0.50*

Data are Spearman, rank-ordered correlations (*r*) adjusted for age and sex. Correlation *P* value: * < 0.05, ** < 0.01, *** < 0.001, **** < 0.0001.

† The strongest correlation for each CT measure.

weakest correlate of the CT measure, although this relationship was statistically significant (*r* 0.52; *P*=0.015).

Most comparison measures of deep subcutaneous adipose tissue were generally weakly correlated with the CT deep subcutaneous adipose tissue measure, although all were statistically significant (all *r* approximately 0.50; *P*<0.02). The exception was waist:height ratio, which yielded a fairly strong correlation with CT deep subcutaneous adipose tissue (*r* 0.66; *P*=0.002).

BMI (*r* 0.76; *P*<0.0001), waist:height ratio (*r* 0.69; *P*=0.0001), waist circumference (*r* 0.65; *P*=0.002) and DXA (*r* 0.75; *P*<0.0001) were all fairly strongly correlated with the CT measure of superficial subcutaneous adipose tissue, whereas ultrasound yielded a weaker, yet statistically significant, correlation (*r* 0.48; *P*=0.03).

Visceral adipose tissue. VAT assessed using ultrasound (*r* 0.79; *P*<0.0001), waist circumference (*r* 0.85; *P*<0.0001) and waist:height ratio (*r* 0.81; *P*<0.0001) was strongly correlated with VAT from CT. BMI (*r* 0.67; *P*<0.0001) and DXA (kg) (*r* 0.70; *P*<0.0001) were also strong correlates of the CT-derived measure of VAT.

Comparisons of ultrasound and computed tomography adipose thicknesses (cm)

Here, we present the correlations for adipose thicknesses as this is the most direct comparison of methods when comparing CT and ultrasound, and may be of value for studies focused specifically on adipose thickness (e.g. surgical interventions). These results also illustrate the extent to which comparisons of thicknesses might lead to an overestimation of the magnitude of the correlations between ultrasound and abdominal adipose area, if one were to mistakenly assume that adipose thicknesses and areas are synonymous.

Table 3 shows the comparison of measures with CT-assessed adipose thicknesses. The ultrasound-derived VAT measure was strongly correlated with the CT-derived measure (ρ 0.89; *P*<0.0001). The ultrasound measure of total SAT was strongly correlated with CT-derived SAT (ρ 0.93; *P*<0.0001). Moderate correlations between the ultrasound and CT measures of superficial SAT were observed (ρ 0.56; *P*=0.007). The deep SAT compartment was accurately assessed using the corresponding ultrasound measure

Table 3. Correlation coefficients for ultrasound, dual-energy X-ray absorptiometry (DXA) and anthropometric measures of adiposity compared with computed tomography (CT) measures of adipose thicknesses (*n* 29)

	CT measure			
	Visceral (cm)	Subcutaneous (total, cm)	Subcutaneous (superficial, cm)	Subcutaneous (deep, cm)
Comparative measure				
BMI (kg/m ²)	0.61**	0.67**	0.70***	0.72****
Waist circumference (cm)	0.67**	0.61**	0.66***	0.74****
Waist:height ratio	0.64**	0.68**	0.66**	0.74***
Ultrasound visceral (cm)	0.89****†	0.50*	0.50*	0.58**
Ultrasound subcutaneous (total, cm)	0.33	0.93****†	0.79****	0.82****
Ultrasound subcutaneous (superficial, cm)	0.50*	0.67**	0.56*	0.73****
Ultrasound subcutaneous (deep, cm)	0.21	0.90****	0.84****†	0.87****†
DXA (abdominal fat, kg)	0.79****	0.58**	0.64***	0.65**
DXA (total fat mass, kg)	0.68**	0.72***	0.76****	0.78****

Lin's concordance correlations (ρ) were used to compare ultrasound and CT measures adjusted for age and sex. Remaining comparisons were made using Spearman's rank-ordered correlations (*r*) adjusted for age and sex. Correlation *P* value: * < 0.05, ** < 0.01, *** < 0.001, **** < 0.0001.

† The strongest correlation for each CT measure.

(ρ 0.87; $P < 0.0001$). None of the Lin's concordance correlations (ρ) differed markedly from the coefficients derived using Spearman's correlation statistic.

Table 4 shows the β -coefficients, intercepts and R^2 for the different combination of variables described above.

Assessment of measurement bias

The analysis of absolute agreement between the ultrasound and CT distance measures revealed a significant mean positive bias for VAT of 0.423 (95 % CI 0.079, 0.767 cm; $P = 0.018$; 95 % limits of agreement: -1.386 – 2.232 cm; RMSE: 0.98 cm). The corresponding analysis for SAT revealed a small and non-significant mean bias of -0.034 (95 % CI -0.173 , 0.104 cm; $P = 0.616$; 95 % limits of agreement: -0.764 – 0.695 cm; RMSE: 0.36 cm). The RMSE values for these two main adipose compartments amount to 12–14 % of the population mean and to about one-half and one-third of a population SD, respectively.

The subdivision of the SAT compartment was less accurately estimated by ultrasound; ultrasound measured superficial SAT with a non-significant mean bias of -0.098 (95 % CI -0.265 , 0.070 cm; $P = 0.240$; 95 % limits of agreement: -0.891 – 0.695 cm; RMSE: 0.40 cm), whereas the ultrasound-derived deep SAT had a non-significant mean bias of -0.009 (95 % CI -0.165 , 0.147 cm; $P = 0.904$; 95 % limits of agreement: -0.749 – 0.731 cm; RMSE: 0.36 cm). The last two RMSE values amount to 25 % of the population mean and to about one and one-half population SD, respectively.

Discussion

Here, we compared several body composition assessment methods against CT. The present results agree with previous

findings⁽¹⁸⁾ that indicate that a measure of waist circumference can provide an accurate estimate of visceral and subcutaneous adipose areas. For superficial subcutaneous area, BMI yielded the strongest estimate relative to CT. Although waist:height ratio is increasing in popularity⁽¹⁹⁾, this method does not appear to be any better than waist circumference when estimating total subcutaneous or visceral adipose areas. It may, however, provide a better estimate of deep subcutaneous adipose area, which may be relevant to investigators focused on the metabolic or cardiovascular sequelae of abdominal obesity^(2–5). In all comparisons, DXA, which is generally considered to be a more accurate method than anthropometry, was either comparably or less strongly correlated with CT-derived adipose areas relative to waist circumference or BMI. This observation may explain why recent studies of obesity genetics have produced disappointing results when using DXA-derived measures of adiposity^(16,19).

Several existing studies have sought to derive equations to predict subcutaneous^(20,21), intra-abdominal or total abdominal fat mass using ultrasound measurements^(21–23). Other studies focusing on absolute validity have reported strong correlations ($r > 0.70$) between ultrasound and intra-abdominal adipose thicknesses when compared with CT and MRI measurements⁽²⁴⁾. Elsewhere weight:height ratio and ultrasound measures of subcutaneous sagittal diameter adjusted for subcutaneous thickness and intra-abdominal adiposity have been shown to be highly correlated with visceral adipose mass from CT (r 0.63–0.72)^(25,26). Studies have also been conducted comparing a range of anthropometric measurements (e.g. weight and body circumferences), and they have concluded that sagittal diameter at lumbar 3–5 correlated most strongly with total and visceral adipose volumes assessed by CT⁽¹⁸⁾.

Table 4. Relationship between computed tomography-assessed adipose compartments (criterion) and measures of basic anthropometry, dual-energy X-ray absorptiometry (DXA) or ultrasound

	Equation	R^2	RMSE
Visceral adipose (cm²)			
BMI	10.7 BMI – 132	0.16	73.9
WC	6.6 WC – 443	0.56	53.9
DXA (total FM)	4.4 FM _{tot} + 41	0.18	73.3
DXA (abd FM)	94.9 FM _{abd} – 29	0.70	45.9
Ultrasound	37.3 Visceral adipose _{US} – 125	0.78	37.7
Total subcutaneous adipose (cm²)			
BMI	18.2 BMI – 257	0.54	52.1
WC	3.5 WC – 94	0.17	69.6
DXA (total FM)	7.8 FM _{tot} + 30	0.63	46.5
DXA (abd FM)	60.7 FM _{abd} + 105	0.32	65.0
Ultrasound	60.2 Subcutaneous adipose _{US} + 43.9	0.48	54.9
Deep subcutaneous adipose (cm²)			
BMI	7.8 BMI – 113	0.43	27.6
WC	1.9 WC – 81	0.20	32.6
DXA (total FM)	3.1 FM _{tot} + 15	0.49	26.1
DXA (abd FM)	35.6 FM _{abd} + 26	0.44	28.3
Ultrasound	36.9 Subcutaneous adipose _{US} + 27	0.48	26.4
Superficial subcutaneous adipose (cm²)			
BMI	11.6 BMI – 170	0.54	32.8
WC	2.1 WC – 56	0.14	45.0
DXA (total FM)	5.0 FM _{tot} + 12	0.71	26.1
DXA (abd FM)	41.7 FM _{abd} + 55	0.34	41.0
Ultrasound	69.8 Subcutaneous adipose _{US} + 30	0.35	39.1

R^2 , explained variance; RMSE, root mean square error; FM, fat mass; abd, abdominal; WC, waist circumference.

Several previous studies have examined the validity of ultrasound for adipose thickness quantification. The highest reported correlations emanate from studies where a standardised ultrasound technique was used to determine the distance between the peritoneum and lumbar spine^(7,10,11). Two studies have reported almost perfect correlations between ultrasound and CT for SAT and VAT thicknesses (r 0.96)^(8,27), whereas others have reported lower correlations for SAT⁽⁹⁾. As we have shown here, the impressive correlations between ultrasound and CT measures of adiposity are predicated largely on the comparison of thicknesses rather than of areas; for the latter, ultrasound yields relatively weak estimates. It is also important to highlight that the limits of agreement for VAT ranged from -1.39 to 2.23 . This wide range suggests that the methods may perform well in the setting of a cohort-based analysis, but poorly when used at the individual level. Thus, the appropriate interpretation of these results depends on the setting in which they are to be applied. For example, in studies of metabolic disease or CVD, the total amount of adipose tissue within the specific compartments is likely to be most relevant, whereas the accurate assessment of adipose thicknesses may be more relevant for surgical intervention studies.

One of the novel aims of the present study was to examine the validity of different methods for the assessment of the two subcutaneous compartments. We have shown that BMI, waist:height ratio and DXA (total adipose mass) are strongly correlated with CT-assessed superficial subcutaneous adipose area. For the deep subcutaneous compartment, we have shown that waist:height ratio is the only strong correlate of the respective CT-assessed compartment. This aim was motivated by the independent metabolic characteristics of superficial and deep SAT in the aetiology of cardiometabolic disease⁽²⁻⁵⁾, and by the corresponding need to be able to accurately measure these compartments in epidemiological studies. Although SAT is often considered a metabolically homogeneous tissue, the two subcutaneous compartments have distinct metabolic properties which may influence CVD risk in different ways. In studies of lean and obese glucose-tolerant adults, for example, amounts of visceral and deep SAT were strongly related with metabolic and vascular traits, whereas superficial SAT was not⁽²⁾. Similar observations have been reported in studies in diabetic and non-diabetic individuals of varying ethnicities⁽³⁻⁵⁾. Thus, assessment methods that are feasible for use in large studies and capable of accurately delineating deep SAT from superficial SAT may have an important role to play when investigating the pathogenesis of obesity. An additional novel aim of the present study was to compare measures of the waist:height ratio, an increasingly popular obesity metric, with other methods of adipose tissue quantification. As outlined above, we have shown that the waist:height ratio is strongly correlated with several of the adipose compartments of interest here, relative to DXA, ultrasound and other anthropometric measures.

The majority of people studied here had a BMI in the normal or overweight range, with only a few obese persons included. Therefore, it is possible that the relationships between the adiposity measures reported here may not generalise to morbidly obese cohorts. It was not possible to assess the reproducibility of the methods in the present study, as repeat measurements were not performed. A further

limitation is that only a single CT slice (at lumbar 4) was obtained, which may somewhat influence the validity of the criterion measure owing to intra-subject variability⁽²⁸⁾.

In summary, simple anthropometric measures of abdominal obesity provided reasonably valid estimates of abdominal adiposity in this population-based cohort of Swedish adults. Neither ultrasound nor DXA, which are more expensive and technically complex than anthropometry, yielded better estimates of adipose area than waist circumference or BMI. The ultrasound measures did, however, provide considerably more accurate measures of adipose thicknesses than the other methods examined here.

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