Obesity Increases Precision Errors in Total Body Dual X-ray Absorptiometry Measurements.

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Abstract

Total body dual energy x-ray absorptiometry (DXA) is increasingly being used to measure body composition in research and clinical settings. This study investigated the effect of body mass index (BMI) and body fat on precision errors for total and regional total body DXA measurements of bone mineral density, fat and lean tissue using the GE Lunar Prodigy. 144 women with BMI's ranging from 18.5 to 45.9 kg/m^2 were recruited. Participants had duplicate DXA scans of the total body with repositioning between examinations. Participants were divided into three groups based on their BMI and the root mean square standard deviation (RMSSD) and the percentage coefficient of variation (%CV) calculated for each group. The RMSSD (%CV) for the normal (<25 kg/m^2) (n=76), overweight (25-30 kg/m^2) (n=36) and obese (>30 kg/m^2) (n=32) BMI groups respectively were: total BMD (g cm^{-2}): 0.009 (0.77%), 0.009 (0.69%), 0.011 (0.91%); total fat (g): 545 (2.98%), 486 (1.72%), 677 (1.55%); total lean (g): 551 (1.42%), 540 (1.34%), 781 (1.68%). These results suggest that serial measurements in obese subjects should be treated with caution since the least significant change may be larger than anticipated.

Keywords: Dual energy x-ray absorptiometry; Precision; Obesity; Bone mineral density

Introduction

Dual energy x-ray absorptiometry (DXA) has been successfully used for around 25 years for the diagnosis of osteoporosis and the prediction of fracture risk. In addition to the measurement of bone mineral density (BMD) at clinically significant fracture sites, DXA affords the ability to measure fat and lean tissue body composition using total body (TB) scans. DXA scans of the spine and hip provide a low radiation burden, with negligible increase in lifetime cancer risk, and are therefore suitable for repeat measurements where clinical indications require this [1]. Total body scans are acquired using the same low-dose technology and give a similarly small effective dose [2]. The precision errors of DXA measurements are important for characterising the ability to detect longitudinal changes [3], and changes in fat or lean tissue may be of interest in some clinical groups [4] and in elite athletes [5], particularly in decision making about their fat content and potential injury risk. Precision errors are partly dependent on quality assurance systems to detect scanner changes and on operators' training and experience [3]. The evaluation of precision errors involves repeated measurements, with the International Society of Clinical Densitometry (ISCD) recommending either duplicate scans of 30 subjects or triplicate scans of 15 subjects [6] [7]. Precision errors may vary between individuals due to differences in bone status and biological variations, such as tissue inhomogeneity, and it is therefore important to measure a representative set of subjects [8].

Total body DXA measurements are used in a range of populations [4,5], ranging from athletes with low body-fat to patients suffering from a range of obesity and non-obesity related conditions. The ability of TB DXA to accurately and precisely measure BMD, fat and lean tissue within these different populations is unlikely to be comparable [9], and a previous study demonstrated larger precision errors in spine, hip and total body BMD in obese groups [10]. As obesity becomes increasingly prevalent in the western world, DXA services are likely in future to see rising numbers of patients in the over-weight and obese groups [11]. It

is estimated that by 2012 obesity levels in England will have risen to 31.2% and 31.0% in men and women respectively [12].

Previous studies of TB DXA precision errors have investigated a range of subjects, but the only other study in an obese population focused on a small number of obese women, with no direct comparison with their normal weight counterparts [9]. To date no well-powered study has been purposely designed to investigate TB DXA precision errors on the GE Lunar Prodigy. A previous study investigating spine and hip BMD precision errors demonstrated precision errors that increased with BMI and body fat, particularly at the spine [10]. This was hypothesised to result from reduced signal to noise ratio and increased inhomogeneity in soft tissue composition. Increased soft tissue inhomogeneity is likely to occur from a greater and/or more variable amount of visceral fat surrounding the organs in overweight and obese patients.

This study investigated the effect of increasing BMI and percentage body fat on DXA precision errors at the total body for BMD, lean and fat measurements of the total body and individual sub regions using the GE Lunar Prodigy.

Materials and Methodology

Participants

The study consisted of 144 female volunteers aged between 18 and 75 years recruited from the general population via poster advertisements. The participants were allocated to one of three BMI groups <25 kg/m^2; 25-29.9kg/m^2 and ≥30kg/m^2 representing normal, overweight and obese respectively based upon the WHO criteria for body mass index classification [13]. Subjects were analysed according to BMI groups determined from the measured height and weight at their DXA scan visit. The aim of the study was to perform duplicate TB DXA scans on a minimum of 30 participants in each BMI group, yielding a sufficiently robust study to

determine differences between the groups with at least 30 degrees of freedom (df) in each group. The exclusion criteria included, aged <18 or >75 years, male, the presence of internal prosthetic implants and the inability to lie flat and hold the position for the duration of the scan. The study was approved by the Devon and Torbay Research Ethics Committee and all subjects gave written informed consent.

Methods

All participants had their height measured to the nearest 0.01m using a stadiometer (Holtain, Crymych, Dyfed, UK) and body weight measured to the nearest 0.1 kg in minimal clothing using beam balance scales (Avery, Birmingham, UK) respectively prior to their scan. BMI was calculated as weight (kg)/height^2 (m^2).

DXA scans were performed using the GE Lunar Prodigy (GE Healthcare, Bedford, UK). The participants underwent duplicate total body DXA scans with repositioning, involving the participant getting off and back onto the table between the scans. The scan modes used (standard or thick) were selected automatically by the scanner software. Scans were analysed using the GE Lunar Encore 2005 software version 9.30.044.

Statistical Analysis

Descriptive statistics (means and standard deviations) were calculated for anthropometric variables, BMD, lean and fat for the TB for participants by BMI group. Any differences between groups were tested using a one-way ANOVA using SPSS version 21.0 (IBM, Hants, UK).

The participants were grouped into three BMI categories based upon the WHO criteria for BMI classification resulting in three groups of <25 kg/m^2; 25-29.9 kg/m^2 and ≥30 kg/m^2 representing optimal, overweight and obese respectively [13]. The root mean square standard deviation (RMSSD) of the duplicate scans was calculated for TB BMD, lean and fat

for the total measurement as well as individual sub regions. The combined left and right ROI's were used rather than the individual measurements for each side. Precision errors of the DXA derived variables were also expressed as the percentage coefficient of variation (%CV) calculated by expressing the RMSSD as a percentage of mean BMD [5]. Differences between precision errors were tested for statistical significance using the F-test. In a secondary analysis the women were also classified based on their DXA derived total body fat expressed as a percentage of total body weight. Four body fat groups were examined representing <30%, 30-39.9%, 40-44.9% and ≥45% fat respectively [13].

The women were grouped by both BMI and % body fat as described above. The least significant change (LSC) was calculated by multiplying the precision error by 2.77 [14]. Finally, the influence of scan mode on precision error was examined by computing the %CV for the subjects scanned in thick mode (n=15) compared with a group of participants matched for body fatness scanned in standard mode (n=15) from individuals with >40% fat. Differences between the anthropometric characteristics of these two groups were tested using an unpaired t-test. Significant differences in precision errors were reported using a significance level of $p \leq 0.05$.

Results

The participant characteristics for each BMI group are shown in Table 1. No statistically significant differences were found between the groups for height, while statistically significant differences were found between the groups for age, weight, total BMD, total lean and total fat as would be expected based on the criteria for inclusion within the groups.

The precision errors with the women categorised by BMI group are shown in Table 2, which lists the RMSSD and the %CVs from the lowest to the highest BMI group for total body BMD, lean and fat and for all the subregions. A trend for precision errors to increase with increasing BMI is seen, with the differences between the optimal BMI, overweight and obese

groups reaching statistical significance for a number of BMD, lean and fat regions of interest. It should be noted that compared with the RMSSD the %CV's for the lean and fat measurements are influenced by the increasing size of the denominator in the equation.

Table 3 shows the patient characteristics when the participants were subdivided based on percentage body fat. Statistically significant differences were found between the groups for all measurements except height, where no difference was demonstrated.

Table 4 shows the precision errors when the women were divided based on their percentage body fat measured by their total body DXA scans. The results demonstrate a trend for precision errors to increase with increasing %fat mass, with many differences between groups reaching statistical significance. As for the BMI groups, the %CV understates the increases in precision error because of the larger denominator in the higher % body fat groups.

Table 5 outlines the participant characteristics when similar fat groups were compared for those scanned on standard versus thick mode and Table 6 demonstrates the precision errors for the same groups for the BMD, fat and lean tissue ROI's. When the precision errors for the women with > 40% body fat scanned in "thick" and "standard" modes were compared there were small reductions in %CV using the "thick" scan mode compared to the "standard" scan mode for many of the regions of interest, some of which reach statistical significance. A clear anomaly here was the arms subregion, and it is believed that breast tissue overlying the arms in a number of the patients resulted in larger precision errors for this region (Figure 1).

Table 7 outlines the LSC's for BMD, fat and lean tissue for the different BMI groups. The LSC generally increases with BMI and range from 2.5% to 9.4% for BMD; 4.3% to 28.7% for

fat and 4.7% to 22.6% for lean tissue in the obese group. The largest errors were in the smaller regions of interest, particularly the arms, where as noted above overlying breast tissue confounded these measurements in some subjects.

Discussion

These results demonstrate increasing precision errors with increasing BMI and higher percentage body fat for TB DXA BMD, lean tissue and fat measurements. This is in keeping with previous research, which has reported increasing precision errors in BMD at the lumbar spine and proximal femur with increasing BMI and percentage fat [10]. These results are generally similar in the optimal BMI group to those reported by Kiebak et al in their group which was reflective of the general population, but the overweight and obese groups in our study yielded higher precision errors [15]. The results of this study yielded similar results in the obese group to that by Cordero-MacIntyre et al in their study of 20 obese women [9]. The relationship between increasing body fat and increasing precision errors was generally stronger than that for increasing BMI and precision. This is likely to be due to participants in the optimum and overweight groups being dispersed across the body fat groups since BMI does not accurately represent body fat content [16].

The increasing incidence of obesity in the population [12,17] and the link of obesity with diseases such as heart disease and type 2 diabetes, means that TB DXA is becoming an attractive low dose, cost-effective option for evaluating those at risk [4]. However, the increased precision errors in obese populations demonstrated in this study are an important consideration for measurements in obese populations.

The BMI groups were well matched, with no significant differences for mean height or total body BMD, demonstrating that the differences in precision errors expressed as the %CV were not explained by different mean BMD between the groups for the BMD data. However,

the groups were not matched for weight, BMI, fat and lean tissue, meaning the %CV results are confounded by the larger denominators used to calculate %CV in the overweight and obese groups, thus masking to a degree the true increase in the size of the errors. The RMSSD provides a more accurate indication of the magnitude of the increases and is therefore reported in the tables alongside the %CV [18].

Although the results demonstrate a trend for precision errors to increase with increasing BMI, the relationship with % fat was typically greater. The most likely reason for the effect of increasing fat on precision errors is the greater body thickness. Soft tissue in the abdominal cavity is also not held in a fixed position and therefore has the ability to move from scan to scan, resulting in inherent errors in measurements made in this area. This is of particular importance when using DXA to measure visceral adipose tissue, which is of clinical interest and importance, particularly in obese populations [19].

The arms yielded particularly poor results for %CV, especially in the overweight and obese groups and in those with the higher % body fat. As demonstrated in Figure 1, in some participants breast tissue overlay the arms when they were lying supine on the scanner. This tended to occur more in participants with higher BMI's and % body fat due to their greater volume of breast tissue. The breast tissue may alter its position when the subject is rescanned generating the potential for larger errors due to inhomogenieties in soft tissue composition. This is a similar scenario to that found in hip DXA, when in obese patients the femoral neck ROI is frequently overlain by a fat panniculus [25]. It is therefore recommended that if results for the arms are of particular interest, breast tissue is kept clear of this area. This may be achieved by using metal-free sports bras or other support. However, in many clinical indications for TB DXA, the arms are of less interest, so in the general population, this limitation may not be of great concern. When the effect of scan mode was investigated in two groups with similar high fat mass, there were reductions in the total body results with thick scan mode, but this relationship did not hold for all of the measurements.

This may be due to the small numbers in this sub-analysis and these results should be treated with caution.

The impact of obesity on the LSC was also investigated and these increased in line with the increasing precision errors as expected. The LSC's for the >45% fat group ranged from 3.8% to 8.7% for BMD, 6.6% to 31.9% for fat and 6.8 to 26.2% for lean tissue, meaning that significant changes in body composition would be required in this population to demonstrate a true change. The best results were for the TB, while the worst were for the arms, which is likely to be a result of breast tissue overlaying this region of interest. Long-term precision has been reported to be 50% greater than short-term precision [20]. Therefore with this in mind, the LSC and thus scanning intervals are likely to be even greater than reported above. In practice, patients in the obese range are also more likely to exhibit large weight changes between scans, which might further confound repeat measurements.

There are some limitations to this study. This study was conducted using a GE Lunar Prodigy and these results should not be generalised to other manufacturers' DXA scanners or to other GE Lunar bone densitometers. The participants were drawn from a volunteer population, which may not reflect the typical clinical population. A volunteer population was more appropriate for this study due to the DXA scanner used being based in a research centre where clinical studies are not performed. It was felt inappropriate to approach a clinical population from a local service, since the volunteers would be undergoing duplicate scans as part of the study and there would be no benefit to the women undertaking the study if they had already been scanned by the local service. The subjects in this study underwent duplicate scans on the same day, which has been reported as yielding lower precision errors than when duplicate scans are performed on different days [21]. However, scanning on different days was not feasible for this study because of potential attrition based on the large geographical area from which participants were drawn. This is mitigated to an extent by

ensuring that all participants were asked to get up from the table between scans so that repositioning was performed.

In conclusion, increased BMI and % body fat have a clinically significant effect on precision errors, with larger precision errors in those in higher BMI and body fat groups. This was most marked for the subregional measurements, with the lowest precision errors generally in the total body. The impact of increased BMI and % body fat resulted in high LSC estimates, leading to an increased time interval or larger body composition changes required between scans in obese populations.

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Table 1: Descriptive statistics (Mean (SD)) of women by BMI group

	Whole Group Mean (SD)	<25kg/m^2 Mean (SD)	25-29.9 kg/m^2 Mean (SD)	≥30 kg/m^2 Mean (SD)
N	144	76	36	32
Age (y)	41.0 (15.3)	37.2 (15.2)*	43.4 (15.6)*	47.6 (12.9)*
Height (m)	1.65 (0.07)	1.66 (0.06)	1.63 (0.07)	1.66 (0.07)
Weight (kg)	71.2 (16.5)	60.5 (6.5)**	72.5 (7.3)**	95.0 (15.3)**
BMI (kg/m^2)	26.1 (5.6)	22.1 (1.7)**	27.1 (1.4)**	34.5 (4.4)**
Total BMD (g/cm^2)	1.19 (0.09)	1.17 (0.08)**	1.20 (0.08)**	1.23 (0.08)**
Total fat (kg)	26.5 (11.9)	18.4 (5.4)**	28.4 (4.4)**	43.8 (9.0)**
Total lean (kg)	40.8 (5.6)	38.7 (4.2)**	40.2 (3.8)**	43.5 (6.6)**

* p=≤0.05; **p=≤0.001: all inter-group comparisons significant

Table 2: Precision errors (CV%)by BMI group

	<25 kg/m^2		25-29.9 kg/m^2		≥30 kg/m^2	
	RMSSD	RMS CV%	RMSSD	RMS CV%	RMSSD	RMS CV%
BMD						
Head	0.036	1.6	0.040	1.6	0.049	†2.1
Arms	0.015	1.7	0.024	*2.6	0.025	2.6
Legs	0.018	1.4	0.015	*1.1	0.016	1.2
Trunk	0.008	0.8	0.011	*1.2	0.012	1.2
Ribs	0.010	1.5	0.019	**2.9	0.018	2.5
Pelvis	0.017	1.5	0.021	*1.8	0.026	2.1
Spine	0.023	2.2	0.035	*3.2	0.030	3.3
Total BMD	0.009	0.8	0.009	0.7	0.011	†0.9
Fat						
Arms	120.8	6.8	240.4	*8.6	443.9	†10.4
Legs	442.7	6.2	357.9	**3.6	760.3	5.5
Trunk	290.2	3.3	667.7	**4.5	1009.5	4.1
Android	41.8	3.0	73.0	2.9	122.4	2.8
Gynoid	197.2	4.9	135.1	**2.5	185.8	2.5
Total Fat	545.4	3.0	486.4	**1.7	676.6	1.6
Lean						
Arms	92.9	2.3	201.9	**4.7	390.6	††8.5
Legs	472.4	3.7	490.7	3.7	633.2	4.2
Trunk	337.4	1.8	753.7	**3.8	931.8	3.9

Android	53.5	2.8	74.0	2.7	123.1	†3.5
Gynoid	183.4	3.3	96.4	**1.6	123.6	1.8
Total Lean	550.9	1.5	540.2	*1.3	780.9	††1.7

* p=<0.05, ** p=<0.001 when compared to optimal BMI group

† p=<0.05, †† p=<0.001 when compared to overweight BMI group

Table 3

Participant Characteristics – Fat subgroups

	<30% Mean (SD)	30-39.9% Mean (SD)	40-44.9% Mean (SD)	>45% Mean (SD)
N	35	57	26	26
Age (y)	31.0 (12.9)**	42.7 (14.5)**	43.2 (15.2)**	48.9 (14.2)**
Height (m)	1.66 (0.06)	1.64 (0.07)	1.66 (0.07)	1.64 (0.07)
Weight (kg)	57.5 (5.2)**	65.6 (7.4)**	79.6 (12.9)**	93.4 (17.9)**
BMI (kg/m^2)	20.8 (1.4)**	24.3 (2.2)**	28.6 (3.1)**	34.4 (5.3)**
Total BMD (g/cm^2)	1.18 (0.09)	1.17 (0.08)	1.20 (0.07)	1.20 (0.09)
Total fat (kg)	13.9 (3.4)**	23.2 (3.6)**	33.3 (6.1)**	44.3. (9.9)**
Total lean (kg)	40.3 (4.1)**	38.8 (4.0)**	42.3 (6.6)**	44.5 (7.3)**
% fat	24.4 (5.0)**	35.8 (2.5)**	42.3 (1.8)**	48.2 (2.2)**

* p=≤0.05 across the four subgroups; **p=≤0.001 across the four subgroups.

Table 4: Precision errors RMSSD and CV% by % fat group

	<30%		30-39.9%		40-44.9%		>45%	
	RMSSD	RMS CV%	RMSSD	RMS CV%	RMSSD	RMS CV%	RMSSD	RMS CV%
BMD								
Head	0.040	1.7	0.035	1.5	0.037	1.5	0.054	◊◊2.3
Arms	0.015	1.7	0.020	2.2	0.020	2.1	0.026	◊2.7
Legs	0.015	1.1	0.014	1.1	0.011	0.9	0.026	◊◊2.0
Trunk	0.007	0.8	0.009	1.0	0.010	1.0	0.013	◊1.4
Ribs	0.009	1.3	0.015	**2.3	0.016	2.3	0.018	2.6
Pelvis	0.016	1.4	0.018	1.6	0.024	†2.0	0.025	2.1
Spine	0.024	2.3	0.024	2.3	0.042	††3.7	0.035	3.2
Total BMD	0.007	0.6	0.008	0.7	0.008	0.7	0.014	◊◊1.2
Fat								
Arms	76.9	6.1	190.8	*8.3	195.5	†5.8	489.0	◊◊11.5
Legs	137.2	2.4	289.7	*3.5	321.5	†2.8	1071.9	◊◊7.5
Trunk	207.7	3.3	423.3	3.6	672.3	3.8	1102.2	4.5
Android	39.3	4.4	46.3	**2.4	90.2	3.0	126.6	2.9
Gynoid	86.1	2.5	127.2	2.7	145.6	2.5	338.9	◊◊4.5
Total Fat	217.1	1.6	311.8	*1.4	620.1	††1.9	1048.5	2.4
Lean								

Arms	117.6	2.9	164.3	**4.0	95.9	††2.1	427.2	◊◊9.5
Legs	252.1	1.9	385.2	**3.0	317.2	†2.2	983.8	◊◊7.0
Trunk	352.3	1.8	585.8	**3.1	649.5	3.2	920.1	4.0
Android	53.3	2.0	47.9	1.8	98.9	††3.3	126.3	3.7
Gynoid	68.8	1.2	90.0	*1.6	100.3	1.6	309.6	◊◊4.7
Total	236.9	0.6	342.6	*0.9	718.7	††1.7	1092.0	◊2.4
Lean								

* p=<0.05, ** p=<0.001 when compared to <30% fat group

† p=<0.05, †† p=<0.001 when compared to 30-39.9% fat group

◊ p=<0.05, ◊◊ p=<0.001 when compared to 40-44.9% fat group

Table 5: Descriptive statistics for the similar body fat groups scanned on standard or thick mode

	Standard Mode Mean (SD)	Thick Mode Mean (SD)
N	15	15
Age (y)	52.1 (16.1)	43.5 (9.1)
Height (m)	1.62 (0.07)	*1.69 (0.06)
Weight (kg)	80.8 (7.4)	**108.1 (11.6)
BMI (kg/m^2)	30.8 (2.7)	*37.9 (4.1)
Total BMD (g/cm^2)	1.17 (0.1)	*1.25 (0.1)
Total fat (kg)	37.4 (3.8)	**50.8 (8.1)
Total lean (kg)	39.3 (3.4)	*52.1 (4.2)
% fat	47.2 (1.3)	47.8 (3.7)

*p≤ 0.05, **p<0.001 when compared to standard mode group

Table 6: Precision errors RMSSD and CV% for standard and thick mode on similar fat-containing groups.

	Standard mode		Thick mode	
	RMSSD	RMS CV%	RMSSD	RMS CV%
BMD				
Head	0.051	2.2	0.050	2.1
Arms	0.013	1.4	0.034	**3.4
Legs	0.030	2.4	0.017	*1.3
Trunk	0.013	1.4	0.013	1.3
Ribs	0.016	2.3	0.020	2.7
Pelvis	0.024	2.1	0.024	1.9
Spine	0.035	3.1	0.030	2.7
Total BMD	0.013	1.1	0.014	1.1
Fat				
Arms	349.6	9.1	544.9	11.6
Legs	1039.4	8.5	975.7	*6.0
Trunk	874.8	4.3	1161.5	4.0
Android	74.8	2.2	156.1	2.9
Gynoid	415.2	6.3	168.8	**2.0
Total Fat	1299.7	3.5	497.1	**1.0
Lean				
Arms	186.9	4.3	536.7	**10.6
Legs	1054.7	8.4	754.1	*4.5

Trunk	809.5	4.9	932.3	3.4
Android	67.7	2.3	152.3	3.8
Gynoid	387.5	6.5	132.3	**1.7
Total Lean	1361.0	3.4	506.7	**1.0

*p≤ 0.05, **p<0.001 when compared to standard mode group

Table 7: Least significant change for the bone, lean tissue and fat measurements based on body fat percentage

	<30% LSC%	30-39.9%	40-44.9%	>45%
BMD				
Arms	4.7	6.1	5.8	7.5
Legs	3.0	3.0	2.5	5.5
Trunk	2.2	2.8	2.8	3.9
Ribs	3.6	6.4	6.4	7.2
Pelvis	3.9	4.4	5.5	5.8
Spine	6.4	6.4	10.2	8.9
Total BMD	1.7	1.9	1.9	3.3
Fat				
Arms	16.9	23.0	16.1	31.9
Legs	6.6	9.7	7.8	20.8
Trunk	9.1	10.0	10.5	12.5
Android	12.2	6.6	8.3	8.0
Gynoid	6.9	7.5	6.9	12.5
Total Fat	4.4	3.9	5.3	6.6
Lean				
Arms	8.0	11.1	5.8	26.3
Legs	5.3	8.3	6.1	19.4
Trunk	5.0	8.6	8.9	11.1
Android	5.5	5.0	9.1	10.2
Gynoid	3.3	4.4	4.4	13.0

Total Lean	1.7	2.5	4.7	6.6

Figure 1 Breast tissue overlaying the arms on a TB DXA scan