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Cross calibration of the GE-Prodigy and iDXA for the measurement of total and regional body composition in adults

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Abstract

Introduction: Dual energy X-ray absorptiometry (DXA) body composition measurements are widely performed in both clinical and research settings, and enable the rapid and non-invasive estimation of total and regional fat and lean mass tissue. DXA upgrading can occur during longitudinal monitoring or study, therefore cross calibration of old and new absorptiometers is required. We compared soft tissue estimations from the GE Prodigy with the more recent iDXA, and developed translational equations to enable Prodigy values to be converted to iDXA values.

Methodology: Eighty three men and women aged 20.1 to 63.3 years and with a BMI range of 17.0 to 34.4 kg.m^{-2} were recruited to the study. Fifty nine participants (41 women: 18 men) comprised the cross calibration group and 24 (14 women: 10 men) comprised the validation group. Total body Prodigy and iDXA scans were performed on each subject within 24 hours. Predictive equations for total and regional soft tissue parameters were derived from linear regression of the data.

Results: Measures of lean and fat tissue were highly correlated (R^2=0.95-0.99) but significant differences and variability between machines were identified. Bland Altman analysis revealed significant biases for most measures, particularly for arm, android and gynoid fat mass (12.3 to 22.7%). The derived translational equations reduced biases and differences for most parameters, although limits of agreement exceeded iDXA least significant change.

Conclusion: Variability in soft tissue estimates between the Prodigy and iDXA were detected, supporting the need for translational equations in longitudinal monitoring. The derived equations are suitable for group but not individual analysis.

Keywords: calibration; agreement; DXA; lean mass, fat mass; least significant change.

Introduction

Dual energy X-ray absorptiometry (DXA) is a non-invasive, low radiation medical imaging device that measures bone and body composition with high precision (1-3). It estimates body weight by deriving a three compartment body composition analysis consisting of lean mass (LM), fat mass (FM) and bone mineral content (BMC). DXA also performs a regional body composition analysis of the same parameters for the arms, legs and trunk, and provides estimates of android (abdominal) and gynoid (femoral-gluteal) fat mass, which can be useful for the evaluation of cardiovascular disease risk and obesity characterisation. Over the last few decades there have been advances in densitometer technology, including the replacement of pencil beam with fan beam, higher output X-ray tubes, reduced pixel size, multiple detectors, wider transverse scan widths, faster scan times, improved precision and scanning beds to accommodate higher patient body weights (up to 200 kg).

In recent years, there has also been a marked increase in the use of DXA for measuring total and regional body composition, for example when investigating the effects of aging (4), treatments (5) and exercise training and competition (6-8). Recent regional body composition longitudinal studies have also been conducted in clinical patients (6) and in athletes (7-9). To accurately evaluate total and regional body composition changes, it is important that DXA has low precision error for all regions. Reducing the precision error reduces the least significant change (LSC) and time to detect significant changes. It is also essential that in longitudinal studies, precision is measured in the study group of interest (10). This is important because for example, different precision and hence different LSC for the same machine may occur between normal adults (1, 3) and athletes (12). It is also important to ensure that follow-up scans are conducted on the same DXA system and if this is not possible, cross calibration of the initial and subsequent DXA, should be performed. This may occur if a system malfunctions and needs to to be replaced, and cross calibration is also required when different systems are used in multi-centre research studies. Currently, there is no whole body phantom that can be used for body composition cross calibration of different machines. Therefore, an in-vivo cross-calibration study between the absorptiometers is necessary to determine if systematic differences exist (13). If differences are found to exist, cross calibration predictive equations can be derived from a cross calibration study group. These equations should then be applied to a validation group to observe how these predictive values compare with the measured values (13).

The aim of this study was to compare total and regional LM, FM and %FM between two fan beam absorptiometers from the same manufacturer: GE-iDXA and Prodigy. Cross calibration predictive equations were then developed and applied to a validation group in order to compare iDXA measured values with iDXA predicted values, and to determine if any observed differences were outside the LSC range of the iDXA.

Materials and Methods

Study group

Eighty three healthy adults were recruited via an intra-university email invitation. The exclusion criteria were having had a DXA scan within the previous 12 months or pregnancy. Participants were sub-divided into a cross calibration group (n=59): females = 41 / males = 18 and a validation group (n=24): females = 14 / males = 10: and in accordance with International Society for Clinical Densitometry (ISCD) recommendations (10), these groups are representative of those normally scanned at our iDXA facility. The groups were Caucasian except for two Asian males, one in the cross calibration group and one in the validation group**.** Ethical approval for the study was provided by the University Faculty Research Ethics Committee and informed signed consent was attained before scans, from all volunteers. All activities performed in this study were in accordance with The Declaration of Helsinki.

DXA measurements

For on each system, participants wore the same light clothing with all metal and plastic artefacts removed. Height was measured on a stadiometer and recorded to the nearest millimeter and body mass was measured on calibrated electronic scales to the nearest gram (both SECA, Birmingham, UK). Total body scans were conducted for each participant on the Prodigy and on the iDXA. The two systems were not situated at the same site therefore participants could not be scanned on the same day. However, scans were conducted at the same time of day (24 hours apart). Each participant was also asked to avoid exercise, refrain from a heavy meal (within 12 hours) and arrive hydrated (and bladder void) for each scan. The scan mode (standard or thick) was machine-selected and dependant on an estimate of body thickness. For the Prodigy, the standard scan mode is based on an estimated body thickness of 13 to 25cm and for the iDXA, an estimated body thickness of 16 to 25cm. The thick scan mode is based on an estimated body thickness of >25cm for both the Prodigy and iDXA. For both GE machines, the estimate of body thickness and hence criterion for scan selection is based on the weight/height ratio, if this ratio is ≥0.545 the thick scan mode is selected. The same scan mode was used on both machines. Three participants were scanned in thick mode, two in the cross calibration group and one in the validation group.

Participants were centrally positioned on the scanning bed, within the transverse scan width of the densitometer and with the legs supported together by a velcro strap. On the scanning bed, maximum separation between arm and trunk was set and the palm of the hand was placed on the bed. If there was a possibility of the arm being outside of the scan region, the palm of the hand was placed in the mid-prone position. This ensured that all scan images were within the scan fields of the densitometers and accurate adjustment of the regions of interest could be made. If part of an arm is outside the designated scan region, the iDXA software will apply the analysis from the arm which is within the scan region to the arm which has a part outside the region. These scans can be identified by both arms having identical analyses. Therefore, in this study it was ensured that participant positioning was consistent and within the scan dimensions of both systems.

To validate the total body in-vivo %FM cross calibration, a Variable Composition Phantom (VCP) was also used. This phantom consists of four acrylic blocks, two thin PVC sheets and four vinyl sheets. The sheets are used in various combinations to simulate five %FM values from 16.0 to 44.0 % (14).

Image analysis

Scans were analysed using Encore software version 12.5 for the Prodigy and 13.5 for the iDXA, and adjustment of the cuts which define regional analysis made. The arms and trunk were separated by lines through the glenohumeral joints and the trunk and legs by lines obliquely through the hip joint at 45^o to the sagittal plane of the body image. The head was excluded from the trunk region by a transverse line below the mandible. The trunk includes the thorax, abdomen, pelvis and a portion of the medial thigh. The android region of interest (ROI) is at the lower boundary of the pelvis cut and the upper boundary above the pelvis cut 20% of the distance between pelvis and neck cuts. Lateral boundaries are the arm cuts. The gynoid ROI upper boundary is below the pelvis cut by 1.5 times the height of the android ROI, and the gynoid ROI height is equal to two times the height of the android ROI. The lateral boundaries are the outer leg cuts. For consistency, manual ROI analysis of each scan was performed by the same experienced and ISCD certified clinical densitometrist. Quality assurance tests of each machine were performed using their respective GE block calibration phantoms and no drifts in calibration were observed throughout the study.

The GE range of DXA absorptiometers are utilised globally both clinically and for research. GE iDXA (GE Healthcare) is the most recent model, advancing on the older Prodigy model. The iDXA uses a higher output x-ray tube than the Prodigy, an identical narrow angle (4.5^{o}) fan beam with 64 high definition CZT detectors and a staggered element array. This improves the image resolution by reducing the dead space between the detectors, giving a near radiographic image and improved spatial resolution, pixel sizes iDXA: 2.40 x 3.04mm compared to Prodigy = 4.80 x 13.0mm, but with a higher radiation dose (Table 1).

Table 1. Comparison of GE Lunar iDXA and Prodigy scan parameters

	Prodigy	**iDXA**
Scan mode	Standard	Standard
Voltage (kV)	76	100
Current (mA)	0.150	0.188
Reference counts: High	131902	170911
Reference counts: Low	159964	263860
Scan dimensions (cm)	197.6 x 60.0	196.8 x 65.5
Pixel size (mm)	4.8 x 13.0	2.4 x 3.04
Pixel area (mm^2)	62.4	7.3
Scan time (min)	6.0	7.0
Dose (uGy)	0.4	3.0
Weight limit (kg)	160	204

Statistical analysis

All statistical analyses were performed using Analyse-It (Leeds UK) and IBM SPSS Version 19.0. Descriptive statistics are presented as the mean and the standard deviation of the mean

(SD). Two tailed paired t-tests were applied to test for significant differences between study groups and body composition parameters derived by the two absorptiometers. In this study, measured Prodigy values ($Prodigy_m$) were converted into predicted iDXA values ($iDXA_p$) and compared to the measured iDXA values ($iDXA_m$) for each subject. The differences were then compared to the iDXA least significant change (LSC) for the particular body composition parameter. The LSC is the smallest change between two measurements on the same densitometer over time that must be exceeded before a change can be considered to be significant. LSC is derived from the precision of the parameter and to be confident at the 95% level = 2.77*Precision. The precision and LSC values of the iDXA for the sites measured in this study are given in Table 2. The total body precision values RMS-SD of the Prodigy used in the study were: LM = 0.41kg, FM = 0.41kg, with corresponding LSC for LM = 1.13kg and FM = 1.13kg (15).

Linear regression analysis was used to derive the cross calibration equations; the iDXA measurement was the dependant variable and the Prodigy was the independent variable. The standard error of estimate (SEE) was used as an indicator of the accuracy of the prediction equation. The agreement between the absorptiometers was analysed using Bland-Altman analysis (Bland Altman 1986). The differences in the measurements ($iDXA_m$ – $Prodigy_m$) and ($iDXA_m$ – $iDXA_p$) were plotted against the mean value of the measurements. The mean difference (bias) was derived and also expressed as a percentage (%) of the mean value. The limits of agreement (LOA), an indication of the range of random error, were derived from the standard deviation (SD) of the mean difference, LOA = ±1.96*SD, and 95% of the differences should lie between these limits. The observed differences between measured and predicted values guide decisions as to whether or not the cross calibrations equations can be applied to individual subjects.

The correlations of the differences and mean values were derived to determine if the observed differences were dependent on the magnitude of the measurement and to determine if the bias was systematic: non-significant slope, proportional: significant slope or heteroscedastic: differences dependant on the magnitude of the mean. Independent paired two tailed t-tests were used to compare cross calibration and validation groups physical characteristics. Paired t-tests were used to compare body composition parameters between the two machines and to compare the Bland Altman bias against zero. The level of significance for all statistical tests was $p<0.05$.

Table 2. GE Lunar iDXA: In-vivo precision and least significant change (LSC) (3, 20)

	RMS-SD	**LSC (95%CI)**
Total lean mass (kg)	0.24	0.68
Total fat mass (kg)	0.19	0.52
Arm lean mass (kg)	0.07	0.20
Leg lean mass (kg)	0.20	0.54
Arm fat mass (kg)	0.05	0.13
Leg fat mass (kg)	0.09	0.25

Results

There were no significant differences in physical characteristics between the two study groups. The DXA derived body weight for the Prodigy and iDXA for both study groups were in close agreement indicating that the 24 hour time interval between scans had not resulted in any significant weight changes.(Table 3).

Table 3. GE Lunar iDXA – Prodigy cross calibration : physical characteristics of study groups

	Cross-Calibration n=59 (41f / 18m)		Validation n=24 (14f / 10m)	
	Mean(sd)	**Range**	**Mean(sd)**	**Range**
Age (yr)	45.3(12.8)	21.0 – 63.3	40.5(11.5)	20.1 - 59.7
Height (cm)	168.8(9.6)	151.5 – 188.0	169.5(7.9)	154.0 - 183.0
Weight (kg)	72.3 (12.1)	43.8 – 103.1	72.0(10.4)	58.0 - 99.7
Prodigy weight (kg)	72.8(12.3)	43.7 – 104.8	72.1(10.5)	57.8 – 100.1
iDXA weight (kg)	72.7(12.0)	44.7 – 103.5	72.4(10.4)	58.3 – 99.4
BMI (kg/m^2)	25.6(3.7)	17.0 – 34.4	25.7(3.5)	22.1 - 33.1
Weight/Height (kg/cm)	0.427(0.060)	0.273 – 0.575	0.423(0.053)	0.353 – 0.546

For the cross calibration group, no significant differences between systems were observed for total body composition parameters LM, FM and %FM. However, for regional analysis, highly significant differences were observed between systems. LM from the iDXA was significantly lower in the arms but significantly higher in the legs, android and gynoid regions ($p < 0.001$). FM from the iDXA was higher in the arms ($p < 0.0001$) and legs ($p < 0.05$) but significantly lower in the trunk, android and gynoid regions ($p < 0.0001$). %FM from the iDXA was significantly higher in the arms but lower in the trunk, android and gynoid regions ($p < 0.0001$) with no significant difference in the leg region (Table 4).

Table 4. Cross calibration group (n = 59): Comparison of total and regional body composition parameters from the GE Lunar Prodigy and iDXA

		Lean mass, kg	**Range**	**Fat mass, kg**	**Range**	**%fat**	**Range**
Total body	iDXA	45.07(9.23)	31.18-66.79	25.02(7.92)	11.50-45.78	34.2(8.3)	17.3-49.8
	Prodigy	45.00(10.15)	30.48-69.60	25.05(9.03)	10.83-46.24	34.2(9.8)	13.8-50.3
Arm	iDXA	4.61(1.46)††	2.79-7.93	2.61(0.82)**	1.33-4.50	35.2(10.3)**	16.3-51.3
	Prodigy	4.79(1.50)	2.83-8.55	2.18(0.92)	0.69-4.31	30.2(11.4)	8.1-47.6
Leg	iDXA	15.90(3.52)**	10.23-24.95	9.31(3.12)*	3.99-17.21	35.4(9.4)	16.3-50.3
	Prodigy	15.45(3.76)	9.40-24.63	9.15(3.63)	3.29-18.27	35.5(11.3)	13.7-53.6
Trunk	iDXA	21.56(4.21)	15.65-32.09	12.28(4.90)††	3.73-27.03	34.7(9.3)††	16.6-54.2
	Prodigy	21.46(4.65)	15.34-33.53	12.99(5.14)	4.89-26.75	36.1(9.9)	15.5-53.1
Android	iDXA	3.33(0.66)**	2.45-5.02	2.01(1.01)††	0.45-5.42	36.0(11.2)††	13.1-59.2
	Prodigy	3.15(0.73)	2.17-5.42	2.26(1.02)	0.55-5.55	40.5(11.0)	17.4-58.5
Gynoid	iDXA	7.27(1.55)**	4.68-11.30	4.40(1.52)††	1.89-8.18	37.5(9.8)††	17.2-52.5
	Prodigy	6.80(1.66)	4.32-10.97	4.90(1.66)	2.03-8.96	41.7(10.7)	18.5-56.9

mean(sd)

*p<0.05

**p<0.0001 iDXA significantly higher than Prodigy

†† p<0.0001 iDXA significantly lower than Prodigy

Total body cross calibration equations

The in-vitro derived %FM cross calibration equation using the VCP phantom had a different intercept and slope compared to the in-vivo %FM cross calibration, -8.6 and 1.20 compared to 5.7 and 0.83 respectively. Results of the in-vivo linear regression analysis are shown in Figures 1-3. Although a high degree of correlation was observed (r = 0.97 to 0.98), the derived equations all had significant intercepts and slopes different from unity.

To validate the sex- independent derived regression equations for total FM and LM, Sex-specific regression equations were generated for the complete study group (cross calibration + validation) of 55 females and 28 males (n = 83) and compared with the derived cross calibration regression equations. Using 95% confidence intervals, no significant differences were observed between the intercepts and slopes for the sex-specific and sex-independent regression equations. For FM, the intercepts varied between 2.27 to 3.15 and slopes 0.87 to 0.89. For LM, the intercepts varied between -1.01 to 4.97 and slopes between 0.90 to 1.05.

Bland Altman analysis of the total body composition parameters showed no significant differences in bias, but highly significant negative slopes, r = - 0.49 to - 0.75 ($p < 0.0001$) indicating that differences were proportional to the mean values. It was observed that the Prodigy underestimated at low FM values (mainly males) and overestimated at high values of FM (mainly females) compared to the iDXA. This results in an overestimation of LM at low values (mainly females) and an under estimation at higher values of LM (mainly males). (Figures 4 - 6).

Regional cross calibration

A high degree of correlation was observed from linear regression analysis of the arms, legs and trunk (R^2 = 0.95 to 0.99). For LM, only the arms had no significant intercept and all slopes were significantly different from unity. For FM, only the trunk and gynoid regions did not have a significant intercept and all slopes, except android FM, were less than unity. No significant intercepts were observed for the android / gynoid regions %FM and the android %FM slope (0.99) was close to unity (Table 5).

Table 5. Regional body composition linear regression analysis: cross calibration group

	Intercept	**95%CI**	**Slope**	**95%CI**	**r^2**	**SEE**
Arm lean mass (kg)	0.005	-0.18 to 0.19	0.96	0.92 to 0.99	0.98	0.21
Arm fat mass (kg)	0.69	0.60 to 0.79	0.88	0.83 to 0.92	0.97	0.14
Leg lean mass (kg)	1.81	0.91 to 2.71	0.91	0.85 to 0.97	0.95	0.81
Leg fat mass (kg)	1.48	1.26 to 1.70	0.85	0.83 to 0.88	0.99	0.31
Trunk lean mass (kg)	2.57	1.44 to 3.69	0.88	0.83 to 0.94	0.95	0.91
Trunk fat mass (kg)	0.07	-0.54 to 0.69	0.94	0.89 to 0.98	0.97	0.86
Android %fat	-4.2	-6.6 to 1.7	0.99	0.93 to 1.05	0.95	2.5
Android fat mass (kg)	-0.22	-0.31 to -0.13	0.99	0.95 to 1.03	0.98	0.14
Gynoid %fat	-0.1	-1.6 to 1.4	0.90	0.87 to 0.93	0.98	1.4
Gynoid fat mass (kg)	-0.03	-0.18 to 0.12	0.90	0.97 to 0.93	0.98	0.18

Bland Altman analysis indicated a significant negative bias -0.18 kg ($p < 0.0001$) in arm LM and a significant positive bias 0.46 kg ($p < 0.0001$) in leg LM. No significant bias was observed for trunk LM. A negative proportional relationship for LM at the legs and trunk $r = -0.27$ ($p = 0.05$) and $R = -0.42$ ($p < 0.0001$) respectively, was observed.

FM had a positive bias at the arm: 0.43 kg ($p < 0.0001$) and leg: 0.16 kg ($p < 0.05$) and a negative bias at the trunk: - 0.71 kg ($p < 0.0001$). FM had a negative proportional relationship at all three sites, arms $r = -0.55$: leg $r = -0.84$ (both $p < 0.0001$) and trunk $r = -0.26$($p < 0.05$). Android FM and %FM had significant negative biases of -0.25 kg and -4.5 % ($p < 0.0001$) respectively but had no proportional relationships. Gynoid FM and %FM had significant negative biases of -0.49 kg and -4.1% ($p < 0.0001$) and negative proportional relationships, $r = -0.61$ and - 0.55, both $p < 0.0001$ (Table 6).

Table 6. Bland Altman Analysis : Cross calibration of the Prodigy and iDXA for regional body composition

	Bias (%)	Limits of Agreement	Regression slope (r)
Arm lean mass (kg)	-0.18 (0.4%)††	-0.61 to 0.26	ns
Arm fat mass (kg)	0.43 (18.0%)††	0.06 to 0.79	-0.55**
Leg lean mass (kg)	0.46 (2.9%)††	-1.28 to 2.19	-0.27*
Leg fat mass (kg)	0.16 (1.7%)†	-1.06 to 1.38	-0.84**
Trunk lean mass (kg)	0.10 (0.5%)	-1.99 to 2.189	-0.42**
Trunk fat mass (kg)	-0.71 (5.6%)††	-2.53 to 1.10	-0.26*
Android %fat	-4.5 (11.8%)††	-9.3 to 0.3	ns
Android fat mass(kg)	-0.25 (11.7%)††	-0.53 to 0.03	ns
Gynoid %fat	-4.1 (10.3%)††	-7.6 to -0.8	-0.55**
Gynoid fat mass (kg)	-0.49 (10.5%)††	-0.97 to -0.01	-0.61**

*† p=0.05, †† p<0.0001, significant*ly different from zero; *p= 0.05, ** p <0.0001.

Validation of the cross calibration equations

The derived regression equations were applied to the measured Prodigy body composition parameters of the validation group (n = 24). For Bland Altman analysis of total LM, FM and %FM, the comparison of $iDXA_m$ - $iDXA_p$ with $iDXA_m$ - $Prodigy_m$, indicated a small increase in bias but the LOA were reduced and the proportional relationships were eliminated. For regional analysis comparison of LM, arm and leg bias were reduced, no changes were observed in the LOA and the proportional relationship of leg LM eliminated. For FM, the significant bias observed at the arm and trunk were eliminated but a significant bias remained at the leg: -0.38 p = 0.001. The LOA were comparable and the proportional relationships at the arm and leg were eliminated. For comparison of android FM and %FM regions, the significant biases were eliminated and LOA were comparable. Although both FM and %FM for the gynoid region had reduced biases, both were still significant: -0.10 kg

(2.5%) and 1.1% (3.2%) both $p = 0.001$. LOA were similar and the gynoid proportional relationship eliminated (Table 7).

Comparison of Bland Altman analysis of $iDXA_m$ - $iDXA_p$ for LM and FMof the total body and regions, were made with the LSC for the iDXA (Table 9). LOA for total body LM was ±3.46 kg compared to a LSC of ±0.68 kg. The LOA for FM was ±2.18 kg compared to a LSC of ±0.52 kg. Bland Altman plots indicate a random distribution of the differences with fourteen participants outside the LSC range for both LM and FM. (Figures 7 and 8).

The LOA for arm LM was ±0.28 kg compared to a LSC of 0.20 kg, and with only four particiants outside the LSC range. The LOA for leg LM was ±2.14 kg compared to a LSC of ±0.54 kg, with thirteen participants outside of the LSC range (Figures 9 and 10). For arm FM, the LOA was ±0.30 kg and LSC was ±0.14 kg, with eight participants outside of the LSC range. For leg FM, the LOA was ±1.00 kg and the LSC was ±0.25 kg, with fifteen participants outside of the LSC range (Figures 11 and 12).

Table 7. Validation group: Bland Altman analysis (Prodigy - iDXA) of total and regional body composition

	iDXAm, kg	iDXAp, kg	Prodigym, kg	$iDXA_m$ – $Prodigy_m$			$iDXA_m$ – $iDXA_p$		
				Bias, kg (%)	LOA	R	Bias, kg (%)	LOA	R
Total lean mass	47.35 (8.25)	46.67 (8.17)	46.77 (9.12)	0.59 (1.2%)	± 4.06	-0.43*	0.69 (1.5%)	± 3.46	-0.05
Total fat mass	22.38 (7.54)	22.82 (7.66)	22.54 (8.79)	-0.15(0.7%)	± 3.42	-0.73***	-0.44 (2.0%) †	± 2.18	-0.10
Total % fat mass	31.3 (8.4)	31.9 (8.3)	31.6 (10.0)	-0.35 (1.1%)	± 4.6	-0.69***	-0.7 (2.2%)	± 3.0	0.07
Arm lean mass	4.84 (1.45)	4.89 (1.41)	5.00 (1.47)	-0.17 (3.4%)††	± 0.28	-0.12	0.02 (0.4%)	±0.28	0.28
Leg lean mass	17.14 (3.09)	17.16 (3.20)	16.84 (3.51)	0.31(1.8%)*	± 2.38	-0.47	-0.02 (0.1%)	± 2.14	0.17
Trunk lean mass	22.34 (3.69)	22.03 (3.42)	21.90 (3.82)	0.44 (2.0%)	± 2.46	-0.11	0.50 (2.2%)	± 2.38	0.28
Arm fat mass	2.32 (0.85)	2.31 (0.87)	1.84 (0.99)	0.47 (22.7%) †††	± 0.42	0.69***	0.005 (0.2%)	± 0.30	-0.16
Leg fat mass	8.53 (2.51)	8.91 (2.58)	8.69 (3.02)	0.16 (1.8%)	± 1.48	-0.69***	-0.38 (4.3%) ††	± 1.00	0.14
Trunk fat mass	10.75 (4.89)	11.10 (5.13)	11.35 (5.22)	-0.59 (5.3%)††	± 1.78	-0.37	0.01(0.1%)	± 1.60	-0.02
Android fat mass	1.71 (0.91)	1.70 (0.93)	1.94 (0.94)	-0.23 (12.5%)†††	± 0.26	-0.20	0.015(0.9%)	± 0.24	0.13
Gynoid fat mass	3.96 (1.32)	4.06 (1.30)	4.55 (1.45)	-0.60 (13.8%)†††	± 0.44	-0.58**	-0.10 (2.5%) ††	± 0.34	0.10
Android (%fat)	31.9 (11.6)	31.6 (11.1)	36.1 (11.2)	-4.2 (12.3%)†††	± 4.60	0.19	0.3(1.0%)	± 4.60	0.24
Gynoid (%fat)	33.1 (9.8)	34.1 (9.7)	38.9 (10.7)	-5. 1 (14.0%)†††	± 3.40	-0.47**	-1.1 (3.2%) ††	± 3.00	0.16

† p *<0.05* *††* p < *0.001* *††† p* < 0.0001 significantly different from zero;

* p < 0.05, **p < 0.01 ***p < 0.0001;

iDXA(m) = measured iDXA ; iDXA(p) = predicted iDXA : Prodigy(m) = measured Prodigy.

Discussion

This study aimed to cross calibrate the GE Prodigy and iDXA for measurements of lean and fat mass in adults, and to derive translational equations. To our knowledge, this study is also the first to cross calibrate Prodigy and iDXA measurements of soft tissue within the android and gynoid regions. We found marked differences between systems for all measurements of soft tissue, and although the translational equations were effective in reducing bias, the differences continued to exceed LSC.

We found no significant differences between Prodigy and iDXA total body soft tissue measurements. Regional analysis of the arms indicated that iDXA measured FM was significantly higher than Prodigy measured FM, with a corresponding significantly lower iDXA LM . The same trends for iDXA-Prodigy measured arm FM and LM have been observed elsewhere (17,18). Analysis of the leg region from our study indicated that both iDXA FM and LM were significantly higher than Prodigy FM and LM. Similarly, Hull et al (2009) and Morrison et al (2016) both reported higher iDXA measured leg LM compared to Prodigy values (17, 18). Malouf et al (2013) found that leg FM was greater when measured by the iDXA compared to the Prodigy (19). At the trunk, iDXA FM measurements were significantly lower than FM measured by the Prodigy, with no significant difference observed for LM measurements. Hull et al reported similar results, but only for measurements of women and not men (17). The same study also reported significantly lower iDXA trunk LM compared to the Prodigy, although the current and two further studies have reported no differences between machines in LM measurements at this region (20, 21). In summary, regional analysis indicates that compared to the Prodigy, iDXA FM tends to be greater at the arms, and iDXA LM, greater at the legs, but no clear tendency for trunk measurements. These results may indicate a possible relationship with the thickness of the region, which should be a focus of investigation in future cross calibration studies.

Despite excellent agreement between machines for total body and regional FM and LM measurements, a number of the intercepts and slopes differed from zero and unity. We therefore developed translational equations in order to enable the conversion of Prodigy values to iDXA values. To date, four studies have provided translational equations for Prodigy and iDXA body composition measurements (17-20). Hull et al (2009) cross calibrated three DXA absorptiometers: the GE Lunar DPXL, Prodigy and iDXA in a USA, multi-ethnic study group (52 women and 47 men) and reported significantly higher Prodigy FM values at the total body, legs and trunk in women (17). In men, the authors reported significantly higher iDXA FM for the total body and arms (17). Sex-specific regression equations were published as follows: females: FM iDXA(kg) = 1.17 + (0.944*FM Prodigy); LM iDXA(kg) = 0.40 + (1.00*LM Prodigy). Males: FM iDXA(kg) = 1.83 + (0.944*FM Prodigy); LM iDXA(kg) = 0.40 + (0.98*LM Prodigy). The only sex-differences reported for the FM regression equations between the Prodigy and iDXA were for the arms, with different slopes, and for the total body, a different intercept. All the LM sex-specific regression equations had significant differences in both slopes and intercepts. In the current study, we compared sex-specific regression equations to the sex-independent regression equation and found no significant differences.

Malouf et al (2013) cross calibrated three fan beam absorptiometers: the GE iDXA, Prodigy Advance and Hologic Discovery for FM only (19). The Spanish study group consisted of 51 women and 40 men. The iDXA range of FM was 8.4 to 52.4 kg and the iDXA provided higher mean values of FM at the total body, arms, legs and trunk regions compared to the Prodigy. The derived total body regression equation for converting FM iDXA from the FM Prodigy was: FM iDXA(gm) = 11337 + (0.78*FM Prodigy) + (118*Wt) – (85.7*Ht) + (19.6*Age). Watson et al (2015) cross calibrated the GE Prodigy and iDXA for total body FM and LM with a UK study group of 36 women and 33 men, ranging in body weight from

49.1 to 129.6 kg and with FM ranging between 6 and 68.6 kg (20). Using a four compartment model, the authors identified significant differences in Prodigy measurements at higher values of FM (20). This is relevant given that DXA examinations may be performed for the management of obesity. The total body FM and LM iDXA regression equations were: FM iDXA(kg) = 1.42 + (0.91*FM Prodigy); LM iDXA(kg) = 4.12 + (0.94*LM Prodigy) (24). Morrison et al (2016) cross calibrated the two densitometers using a USA multi-ethnic group (56 women and 36 men) and reported a significant negative proportional bias for total body, arm and leg FM. The authors derived regression equations for total body, arms, legs and trunk regions: FM iDXA (kg) = 2.25 + (0.908*FM Prodigy); LM iDXA(kg) = 3.03 + (0.939*LM Prodigy) (18).

As in previous studies (17, 19), variability between the Prodigy and iDXA was greatest for measures of regional composition, with the iDXA measuring lower for LM and FM on some, but not all regions. Our regression equations for regional lean mass differed from those published by Hull et al (2009) who reported negative intercepts for arm lean mass and trunk fat mass (17). All derived equations in the current study were effective in reducing the bias for all parameters (from 0.7 - 22.7% to 0.1 - 4.5%) and application of the equations also reduced LOA for all parameters except arm lean mass and android % fat. Never-the-less, for all parameters, LOA continued to exceed iDXA LSC.

Advancements in technology, such as which leads to improved precision, may explain the differences in outcomes between the two densitometers. Elsewhere, Kaminsky et al (2014) report that the iDXA absorptiometer has improved total body and regional %FM precision compared to the Prodigy (21). The precision of the iDXA densitometer (RMS-SD) for %fat of the total body, arm, leg and trunk was 0.26, 0.62, 0.37 and 0.43 kg compared to the Prodigy precision values of 0.60, 1.13, 0.56 and 1.00 kg respectively. There have also been reports concerning potential limitations of the Prodigy for the estimation of FM.

Williams et al (2006) compared body composition from the Prodigy with a four-component criterion method for measuring body composition (22). The authors reported that the Prodigy overestimates FM and %FM in non-obese adults and obese women (22). Similarly, Knapp et al (2012) recently reported that the effect of increasing BMI and %FM resulted in higher precision errors with the Prodigy (23).

Published GE Lunar cross calibration studies to date have used varying combinations of Encore software versions for Prodigy / iDXA analysis (Hull 8.80 / 10.40; Malouf 12.3 / 12.3; Watson 12.3 / 15.0; Morrison 6.0 / 12.3) (17-20). In the current study, the Encore software was 12.5 for the Prodigy and 13.5 for the iDXA. It should also be considered that we did not include individuals with a body weight that was over 103 kg, and that most participants were scanned in standard mode. For this reason, our equations are valid only for the standard scan mode and within the group weight range.

In conclusion, clear differences exist in soft tissue estimates between the GE Prodigy and iDXA absorptiometers. Although these differences were more pronounced at regional sites, our findings support the need for translational equations for all parameters. The equations generated in this study are effective at reducing bias and LOA, but given that the LOA continued to exceed LSC, it is recommended that the equations are more suited to group rather than individual analysis.

Conflict of Interest

The authors declare that there is no conflict of interest associated with this research or the production of the manuscript.

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