

CROSS-CALIBRATION OF GE LUNAR iDXA AND PRODIGY DENSITOMETER FOR MEASUREMENT OF BONE MINERAL DENSITY IN YOUNG ADULTS

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Submitted May 2020; Accepted in final form August 2020

Ramirez EA, et. al. The assessment of bone mineral density (BMD) is essential to skeletal health, and dual-energy x-ray absorptiometry (DXA) is a type of bone densitometer that is extensively used in both clinical and research settings. When changing a DXA system during longitudinal monitoring or multicenter studies, it is important to conduct cross-calibration between the new and reference scanners to ensure that BMD values measured by the two systems are as close as possible. Purpose: To properly cross calibrate between the GE Lunar iDXA and Prodigy in healthy young adults. Methods: Thirty college students, ten males and twenty females, participated in the study. The BMD at the lumbar spine and dual femurs were measured using the GE iDXA and Prodigy by the same licensed technician on the same day. A paired sample t-test and linear regression analysis were utilized to compare the BMD values between the two systems. Limits of agreement were obtained by Bland-Altman analyses. Results: Although strong correlations were found between the two systems ($r = 0.985 - 0.998$), the iDXA had significantly higher lumbar spine (1.54%) and dual femur (1.28 - 1.56%) BMD values compared to the Prodigy. Conclusion: Our results suggest that calibration equations should be considered to examine data across densitometers to reduce system differences in the young adult population.

Key Words: cross-calibration, DXA, bone mineral density

INTRODUCTION

Bone mineral density (BMD) and bone strength are important parameters of skeletal health. Currently, dual-energy x-ray absorptiometry (DXA) is the gold standard to measure BMD and it has been widely used in the clinical and research settings (Shuhart et al., 2019). The diagnosis of osteoporosis or low bone mass highly relies on BMD measurement. According to the World Health Organization (WHO, 2004), osteoporosis in postmenopausal women or older men is defined as BMD being ≥ 2.5 SD below the mean for healthy young adults (Baim et al., 2005). Furthermore, research has shown that a decrease of one standard deviation (SD) in BMD is associated with a 1.5 - 2.6-fold increase risk of fracture (Marshall,

Johnell, & Wedel, 1996). Therefore, DXA measurements on femoral neck BMD are used in conjunction with the WHO Fracture Risk Assessment (FRAX) to estimate an individual's 10-year risk of hip and major osteoporotic fractures (Kanis et al., 2000; Kanis et al., 2011).

Although the measurement of BMD is typically performed in older adults, it is a valuable assessment for individuals at any age. Peak bone mass, which is the maximum density and strength an individual's bone can attain, is associated with the risk of osteoporotic fracture (Heaney et al., 2000) and is established between the ages of 20 and 30 (Hendrickx, Boudin, & Van Hul, 2015). Thus, performing BMD measurements to assess skeletal health during young adulthood can provide important

information to young adults so they can invest time in building up their skeletal health sooner rather than later. In addition, there are sex and ethnicity differences in bone density and risk of fractures. Males generally have a higher BMD than females at any given age due to their larger body mass and lean mass (Makovey, Naganathan, & Sambrook, 2005; Zhu, Briffa, Smith, Mountain, & Briggs, 2014). Research indicates that black women and men have the lowest risk of fractures, Mexicans and Caucasians are the intermediates, and Asians have the highest risk of fractures (Ishii et al., 2011).

DXA technology has been evolving over time transitioning from pencil beam (Lunar DPXL) to fan beam scanners (Lunar Prodigy and iDXA), followed by hardware and software renovation (Blake, Harrison, & Adams, 2004; Gagnon, McLean, Hannan, & Cupples, 2010). With several DXA manufacturers in the field, the GE Lunar Prodigy is one of the most widely used models worldwide. More recently, GE introduced the iDXA model, a modernized fan beam system with powerful X-ray tubes, more detectors, and a higher resolution (Choi, Lee, Lim, & Chung, 2009; Hull et al., 2009). Current literature shows significant differences in BMD assessments between manufacturers and densitometers despite high levels of precision (Choi et al., 2010; Hind, Oldroyd & Truscott, 2010; Shepherd et al., 2006). This could be an issue when upgrading DXA densitometers in longitudinal or multicenter studies. The International Society of Densitometry (ISCD) recommends performing cross-calibration at commonly measured anatomical sites when changing hardware or systems to reduce systematic errors (Shuhart et al., 2019).

The GE Lunar Prodigy has been utilized in our research laboratory for over 10 years. Recently, a GE Lunar iDXA was installed to replace the older unit. Therefore, a group of college students were recruited and scanned at the lumbar spine and dual femur sites to cross-calibrate between the two devices.

METHODS

Participants

Thirty healthy participants, 20 to 30 years of age, completed the study. Exclusion criteria were individuals who: 1) were currently smoking, 2) had any metal implants in the body; 3) had fractures

within the last 12 months; 4) took medications known to affect bone metabolism (i.e. glucocorticoids, antidepressant medication, etc.). In addition, pregnant women were excluded. The study was approved by California State University San Bernardino (CSUSB) Institutional Review Board (IRB-FY2019-20). The participant's characteristics are shown in Table 1. There were ten males and twenty females, and their ethnicity were as follows: Asian (7), Black (4), and Hispanic (15).

Table 1

Participant Characteristics (n=30, Mean ± SD)

Sex	Age (years)	Height (cm)	Weight (kg)
Male (n=10)	23.7 ± 1.9	171.9 ± 6.7	81.8 ± 11.4
Female (n=20)	23.1 ± 1.9	161.8 ± 6.1	64.9 ± 1.3

Research Design

Two visits were required for this study. During the first visit, participants signed a written informed consent, filled out the Physical Activity Readiness Questionnaire (PAR-Q), and the Health History Questionnaire (HHQ). If the participants met the criteria for the study, they were scanned on the iDXA (GE Healthcare, Madison, WI) (new scanner) followed by the Prodigy (GE Healthcare, Madison, WI) (reference scanner) at common clinical sites for BMD measurements. Prior to the scans, height and weight were measured using a portable stadiometer (Seca 213, Seca North America, Hamburg, Germany) and digital electric scale (Tanita BWB-800S, Tanita Corporation of America Inc., IL), respectively. During the second visit, the same bone scans were repeated on the iDXA only.

Bone Mineral Density Measurements

All participants were scanned at the lumbar spine (L1-L4) and dual femurs on the iDXA first and then on the Prodigy. Standard positioning was conducted following the manufacturer's recommendation on both devices. Prior to DXA

scans, participants were asked to take off shoes, wear minimal clothing and remove all metal. The participants were positioned supine on the table with their head approximately 2-3 cm below the horizontal line at the top of the table. A foam block was placed under their legs with knees bent at 60-90 degrees and the scanner arm was adjusted to 2 finger widths below the navel. Participants then held their arms upright so that the lumbar spine was scanned. Once the scan was completed, the block was removed and the feet were placed onto each side of the foot brace using the provided straps. The left leg was positioned straight so that the left hip was scanned first and then the same procedure was conducted with the right leg.

A quality assurance test was performed at the beginning of each testing day prior to data collection. EnCORE software version 17 for the iDXA and version 11 for the Prodigy were used for analysis, respectively. The same licensed DXA technician performed and analyzed all the scans. BMD Z-scores were used in this study since it is reflective to the population of the participants. ISCD states that Z-scores, not T-scores, are preferred for BMD reporting in females prior to menopause and in males younger than age 50. A Z-score of -2.0 or lower is defined as “below the expected range for age”, and a Z-score above -2.0 is “within the expected range for age” (Shepherd et al., 2015). In addition, a precision assessment was performed in standard routine following ISCD recommendation as this is a new device in our laboratory (Baim et al., 2005; Hind et al., 2010; Shepherd et al., 2015). All participants were scanned on the iDXA again at the lumbar spine and dual femurs during the second visit within a week of their first visit.

Statistical Analysis

Data were analyzed using SPSS version 24 (SPSS Inc., Chicago, IL). All descriptive data were reported as mean \pm standard deviation (SD). Paired sample t-tests and correlation analyses were used to compare BMD values between iDXA and Prodigy. Linear regression was used to establish calibration equations between the two scanners based on the slope and intercept. Per the manufacturer’s instruction, if the slope was not statistically significant, paired sample t-tests were further used to

determine if the intercept was equal to 0. If both the slope and the intercept were not statistically significant, a calibration equation was not needed. Bland-Altman analysis was used to reveal any agreement to evaluate the bias in the devices. Low bone mass was determined using the BMD Z-scores ≤ -2 at lumbar spine, femoral neck, or total hip. The level of significance was set at $p \leq 0.05$.

Table 2

Comparison of BMD between Prodigy and iDXA (n=30, Mean \pm SD)

BMD (g/cm ²)	Prodigy	iDXA	% Diff	p
AP Spine	1.26 \pm	1.27 \pm	1.54%	.000
L1-L4	.15	.15***		
Left Femoral Neck	1.10 \pm	1.12 \pm	1.28%	.002
	.18	.19**		
Right Femoral Neck	1.12 \pm	1.14 \pm	1.56%	.007
	.18	.19**		
Left Total Hip	1.11 \pm	1.13 \pm	1.38%	.000
	.17	.18***		
Right Total Hip	1.12 \pm	1.14 \pm	1.42%	.000
	.17	.18***		

Notes. %Difference = (iDXA - Prodigy)/Prodigy; ** $p < 0.01$, *** $p < 0.001$ between iDXA and Prodigy

RESULTS

The in-vivo precision (CV%) of iDXA for our population was determined in the study: 1.07% in lumbar spine (L1-L4), 1.31% in left femoral neck, 1.20% in right femoral neck, 0.97% in left total hip, and 0.81% in right total hip. The CV% was within the minimum acceptable precision according to the ISCD Position Stand (Shuhart et al., 2019).

All participants had normal BMD based on Z-scores. Strong correlations were found between all BMD measurements in the two scanners (Figure 1) ($r = 0.985 - 0.998$). However, the BMD values derived from the iDXA were significantly higher at all

measured sites compared to the Prodigy ($p < 0.01$) (Table 2.), ranging from 1.28% to 1.54% at each site for the same participant.

Table 3 demonstrates the results of the linear regression. At the lumbar spine, left femoral neck and right femoral neck, only the intercepts and not the slopes were statistically significant ($p < 0.01$). Whereas at the left and right total hip, both the slopes and intercepts were statistically significant ($p < 0.05$).

Calibration equations derived from linear regression analysis were also reported in Figure 1. Additionally, a positive bias of 0.015 to 0.019 g/cm² in BMD values were found in the iDXA as illustrated in the Bland-Altman analysis in Figure 2. Limits of agreements (mean \pm 1.96 SD) were also presented. Since there were no differences in BMD values between the right and left side of the femoral neck and total hip, only the right side was shown in the figure.

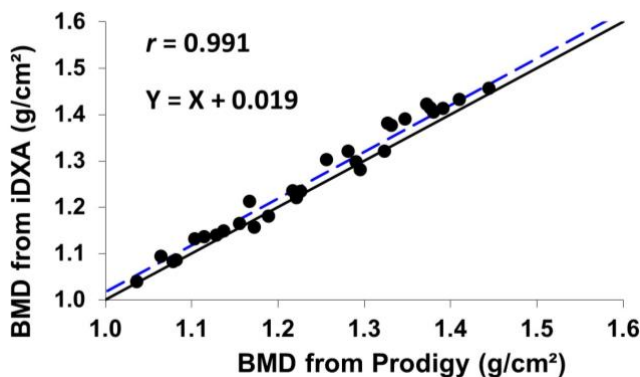
Table 3

Linear Regression between iDXA and Prodigy in BMD Measurement

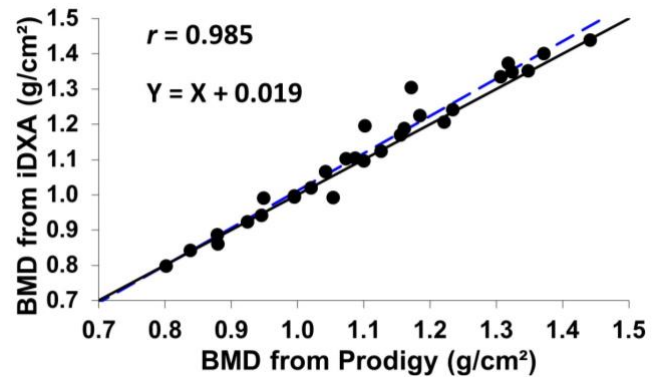
BMD Sites	Intercept 95%CI	Slope 95% CI	R2	SEE
AP Spine L1-L4	0.010 (-0.002, 0.021)###	1.008 (0.998, 1.017)	0.982	0.021
Left Femoral Neck	-0.036 (-0.045, 0.026)##	1.046 (1.038, 1.055)	0.986	0.023
Right Femoral Neck	-0.047 (-0.061, -0.033)##	1.059 (1.046, 1.072)	0.969	0.034
Left Total Hip	-0.025 (-0.032, -0.017)###	1.037 (1.030, 1.043)*	0.992	0.016
Right Total Hip	-0.048 (-0.053, -0.042)###	1.058 (1.053, 1.063)***	0.995	0.013

Notes. ## $p < 0.01$, ### $p < 0.001$ significant from 0; * $p < 0.05$, *** $p < 0.001$ significantly from 1

1A



1B



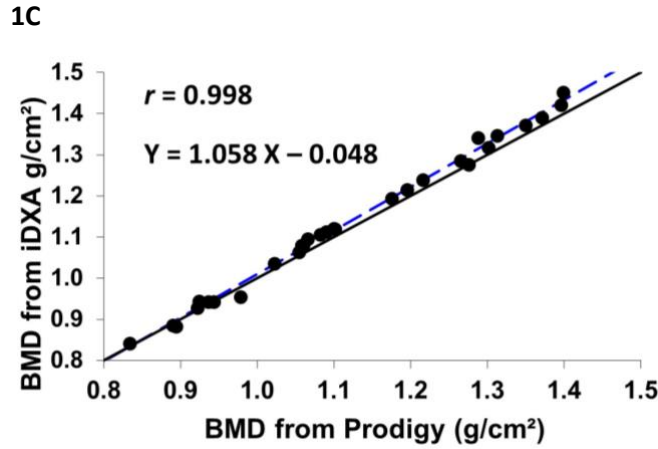
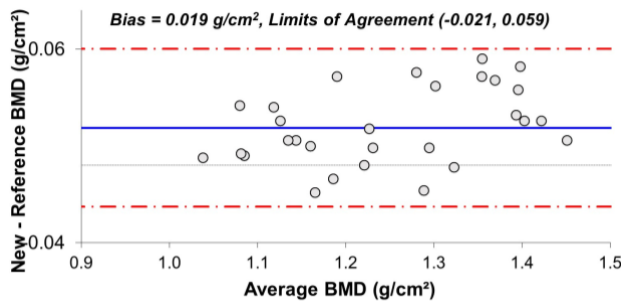
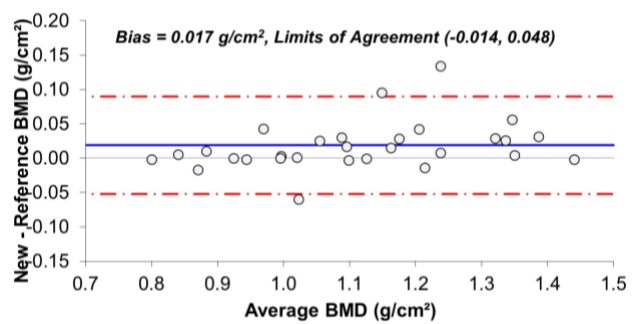


Figure 1. Correlations in the two DXA scanners at (A) lumbar spine (L1-L4), (B) right femoral neck, (C) right total hip (n = 30).

2A



2B



2C

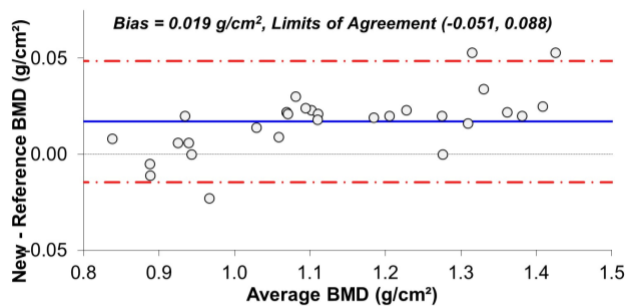


Figure 2. Bland-Altman analysis at (a) lumbar spine (L1-L4), (b) right femoral neck, (c) right total hip. Mean difference (d) = blue line, limits of agreement (d ± 1.96 x SD) = dashed lines.

DISCUSSION

In our present study, the iDXA had significantly higher BMD values than Prodigy at all measured sites despite strong correlations between the two devices. This holds true for several other studies. Saarelainen et al. (2016) measured a cohort of women (21-72 years old, $n = 72$) and reported that BMD values were significantly higher in iDXA than Prodigy. Specifically, they found iDXA results were 1.5% higher at the lumbar spine (L2–L4), 0.5% higher at the femoral neck, and 0.9% higher at the total hip, which was greater than our results at lumbar spine but lower at hips. Choi et al. (2009) scanned 100 Korean participants (66 women and 34 men) and found iDXA to have a higher mean difference of 2.3% in lumbar spine, 2.4% in femoral neck and 1.4% in total hip when compared to Prodigy, which were greater in comparison to our findings. The discrepancy might be due to their participants' older age (average 50 yrs) and ethnicity (Asian only). Similar to our results, Choi et al. (2009) and Krueger, Vallarta-Ast, Checovich, Gemar, and Binkley (2012) both found a high level of agreement ($r^2 \geq 0.98$) in lumbar spine and dual femurs BMD measurements between the iDXA and Prodigy in a large cohort of participants (202 women and 143 men).

However, some other studies have reported that GE iDXA BMD values were lower than Prodigy BMD values at the total hip (ranging from -0.1% to -0.2%), femoral neck (ranging from -0.7% to -2.0%), and lumbar spine (ranging from -0.25% to -1.2%) (Hind, Cooper, Oldroyd, Davies, & Rhodes, 2015; Hull et al., 2009). Hull et al. (2009) reported a total body BMD mean difference of -0.0197 g/cm^2 in males ($n = 47$) and -0.0403 g/cm^2 in females ($n = 52$) between iDXA and Prodigy in a group aged 18 to 81 years old. To the contrary, we found that the BMD mean values of iDXA were 0.015 to 0.019 g/cm^2 higher than the Prodigy. It is necessary to note that our study measured and examined all five common clinical sites as oppose to analyzing the total body BMD only. Hind et al. (2015) found that the lumbar spine BMD ($p < 0.05$) and femoral neck BMD ($p < 0.01$) were significantly lower in iDXA than the Prodigy. Interestingly, total hip BMD values between the two densitometers had no significant difference in their cohort.

According to the ISCD, cross-calibration between devices is essential as the mean systematic differences between instruments may exceed the annual biological BMD changes (Shepherd et al., 2015). Differences of below 1% have been typically observed in past studies between similar and different instruments from the same manufacturer (Blake et al., 2004; Shepherd et al., 2008). In our study, we observed a 1.28-1.58% difference between the densitometers. Greater percent differences may be attributed by the greater average BMD values obtained from individuals, the younger age of our participants, and the implementation of an upgraded software in GE iDXA.

Limitations of this present study may lead to differences in results of previous studies. A wide range of BMD values would be ideal for cross-calibration; however, all the participants are healthy young adults who had a smaller range of BMD values (Shuhart et al., 2019). Sex also plays a role as we see differences in past studies that examined cross calibration of the spine and hip (Ganda, Nguyen, & Pockock, 2014; Krueger et al., 2012). In one study, separate calibration equations for total bone mineral content between the GE iDXA and Prodigy were derived for female and male participants (Hull et al., 2009). However, The ICSD position stand does not state any comment whether gender should be implemented during cross-calibration studies (Shepherd et al., 2015; Shuhart et al., 2019). As anthropometrical parameters and BMD values differ between ethnicities (Ishii et al., 2011; Liang et al., 2007; Makovey et al., 2005), calibration equations of multiethnic participants were not employed in this study. Furthermore, the difference in software programs between scanners (enCORE version 11 versus version 17) should also be noted as the radiation detection and resolution of the iDXA is superior to the Prodigy. Lastly, body composition could potentially influence BMD measurements. Blake et al. (2004) found that 40% of the variance between the Prodigy and DPX-L spine BMD was explained by systematic errors associated with patient body weight and the difference in soft tissue composition measured on the two systems. A further analysis on the effects of age, sex, and body composition on BMD between the two scanners is needed in the future.

CONCLUSION

The GE Lunar iDXA had significantly higher BMD values than the Prodigy at all measured sites in healthy young adults. Cross-calibration equations should be implemented to examine data across densitometers to reduce system differences in longitudinal or multicenter studies.

ACKNOWLEDGMENTS

N/A

FUNDING

No funding declared to complete this research.

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