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Comparison of Differences in Bone Mineral Density Measurement With 3 Hologic Dual-Energy X-Ray Absorptiometry Scan Modes

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Abstract

Bone mineral density (BMD) measurement using dual-energy X-ray absorptiometry (DXA) is considered a diagnostic parameter for osteoporosis by the World Health Organization (WHO). DXA densitometers have different scanning modes for BMD measurements, although the specific scanning modes vary based upon the manufacturer. For DXA machines manufactured by Hologic, which are used globally, a range of scanning modes exist, including but not limited to (in order of decreasing spatial resolution) Array, Fast Array, and Express Array. Only a handful of prior studies have compared the reproducibility of BMD measurements across scan modes. The present study aimed to add to this body of literature by investigating the differences in BMD measured between 3 scanning modes in Hologic DXA machines at 19 different health centers. As part of cross-calibration activities for two multi-center studies in China measuring BMD, the European spine phantom (ESP, 1.000 g/cm^2) was scanned on 19 different Hologic DXA machines. To measure differences in BMD between the 3 scan modes most commonly found on the Hologic models available (i.e., Array, Fast Array, Express Array), the ESP measurement was performed 10 times for each scan mode on each Hologic DXA machine. One-sample *t* test was used to compare the average difference between the measured ESP results of the 3 scanning modes at each hospital and reference ESP values. Single factor analysis of variance was performed to compare

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the average differences between the pairs of scanning modes using the reference ESP. Statistically significant differences between the measured ESP results with reference ESP values were found with each scanning mode at 19 hospitals (all p values <0.05). Consistent with this finding, differences in average BMD between the Array mode and Fast Array mode were invariably the smallest compared to differences seen between the other two pairs of scan modes. Significant differences were observed between average ESP BMD for the Array and Express Array scan modes (0.971 ± 0.013 vs 0.935 ± 0.027, $p < 0.001$), and between Fast Array and Express Array scan modes (0.972 ± 0.012 vs 0.935 ± 0.027, $p < 0.001$). However, no significant difference in average ESP BMD was observed between the Array and Fast Array scan modes (0.971 ± 0.013 vs 0.972 ± 0.012, $p = 0.997$). The selection of ideal scanning mode requires a balance of scanning time, radiation exposure, and measurement accuracy. In this ex vivo study, the Fast Array scanning mode appeared to be a reasonable choice compared with Array and Express Array for BMD measurements by Hologic DXA. Future in vivo studies can help guide the clinical application of these findings.

Keywords

Bone mineral density; dual-energy X-ray absorptiometry; scan modes

Introduction

Osteoporosis is a common metabolic bone disorder and has become a global health issue of major concern with the growth in the aging population world-wide (1–3). Because of the short-term (e.g., hospitalizations, surgeries) and long-term consequences (e.g., disability, inability to work) of fracture, the economic burdens of osteoporosis are also increasing in the population (4). Since osteoporosis is asymptomatic and does not clinically manifest until a patient suffers from a fracture (5,6), early diagnosis depends mainly on screening tests, in particular bone mineral density (BMD) measurements. Among different measurement modalities, BMD measurement using dual-energy X-ray absorptiometry (DXA) is considered a suitable diagnostic parameter for osteoporosis by the World Health Organization (WHO) (7), and is incorporated widely into guidelines and position statements as part of screening algorithms for osteoporosis among older individuals, especially postmenopausal women, and other populations at increased risk for fracture (8–11).

DXA densitometers have different scanning modes for BMD measurements, each providing a different spatial resolution corresponding to scan time and radiation dose (12–14). For DXA machines manufactured by Hologic, which are used globally, a range of scanning modes exist, including but not limited to depending on the model (in order of decreasing spatial resolution) Array, Fast Array, and Express Array. Selection of the scan mode is a technical consideration when performing DXA imaging, and tangible clinical considerations such as spatial resolution and radiation exposure must be balanced to optimize patient care, only a handful of prior studies have compared the reproducibility of BMD measurements across scan modes, and to our knowledge all have been carried out in Hologic machines. Bandirali et al studied the differences in the radiation dose absorption with 3 different

scanning modes (high definition, array, and fast array) using a spine phantom from Hologic on a QDR-Discovery A densitometer (15), and also studied the in vivo differences in BMD and reproducibility of the above 3 scanning modes in a group of Italian patients receiving DXA imaging for evaluation of osteoporosis (12,13). Another recent in vitro Italian study examined the impact of simulated grades of abdominal fat on precision of BMD measures in 3 different scan modes and observed an impact of obesity on precision of BMD measures (16).

However, Hologic has different DXA scanners that use the pencil or fan beam, whole body or nonwhole body software, among other differences. Prior studies have not been able to evaluate differences between the 3 scanning modes across a range of different Hologic DXA models. Given differences in precision may influence the diagnosis and evaluation of osteoporosis, further exploration is necessary. We designed the current study to investigate the in vitro differences in BMD measured with 3 scanning modes in a range of Hologic DXA models at 19 different health centers across China. Because most Hologic DXA machines used in China have 3 different scan modes (i.e., Array, Fast Array, and Express Array), we chose to focus on these 3 scan modes for the purposes of this study.

Materials and Methods

Study Design, Sample, and Measures

This study was conducted as a cross-sectional cross-calibration quality control activity of a parent study, which was a national epidemiologic survey of Osteoporosis across the Chinese mainland carried out by the Chinese Society of Osteoporosis and Bone Mineral Research in partnership with the Chinese Center for Disease Control and Prevention in 2018 (ClinicalTrials.gov ID: NCT03916289). As well, 1 center included in the analysis was part of a concurrent national study carried out by the China AIDS Clinical Trials Network evaluating osteoporosis among patients with HIV (ClinicalTrials.gov ID: NCT03598556). Cross calibration of all DXA machines within each parent study was performed according to the International Society for Clinical Densitometry (ISCD) (17). and the European spine phantom (ESP, 1.000 g/cm^2) was used to compare different DXA machines. The current study represents data collected from all 19 sites with a Hologic DXA machine (including 4 Discovery A models, 8 Discovery Wi models, 5 Discovery W models, 1 Explorer model, and 1 QDR 4500 model). For each Hologic DXA machine, the ESP was measured 10 times, using the 3 scanning modes (i.e., Array, Fast Array, and Express Array), with repositioning of the phantom in between. All ESP BMD (g/cm^2) results from the 19 DXA scanners were recorded for comparison.

Statistical Analysis

All analyses were performed using SPSS Statistics 26.0 (International Business Machines, Armonk, NY, USA). The Shapiro-Wilk test and Q-Q plot were used to assess the normality of data. Mean, standard deviations (SD), and differences were used for descriptive statistics. One-sample *t* test was applied to compare the average difference between the scanning ESP results of the three scanning modes at each hospital and standard ESP values. Single factor analysis of variance was performed to compare the average differences between the pairs

of scanning modes using the reference ESP. For all comparisons, p values of <0.05 were considered as statistically significant.

Results

Table 1 demonstrates the mean ESP BMD results (g/cm^2) of the 3 scanning modes at each study site. Statistically significant differences between the scanning ESP BMD results with reference ESP values were found with each scanning mode at 19 hospitals (all p values <0.05). Table 2 provides the comparison of differences between the average ESP BMD results with the reference ESP value (1 g/cm^2) for each of the 3 scanning modes for each site. Although significant differences exist between average BMD results with the reference ESP value at each study site (all p values <0.05), larger differences were observed for the Express Array scan mode compared to the Array and Fast Array modes for each of the 19 sites. Consistent with this finding, differences in average BMD between the Array mode and Fast Array mode were invariably the smallest compared to differences seen between the other 2 pairs of scan modes.

Analysis of variance indicated significant between-group differences in terms of the average ESP BMD results for the 3 scan modes ($p < 0.001$). Specifically, Table 3 shows the significant differences between average ESP BMD for the Array and Express Array scan modes (0.971 ± 0.013 vs 0.935 ± 0.027, $p < 0.001$), and between Fast Array and Express Array scan modes (0.972 ± 0.012 vs 0.935 ± 0.027, $p < 0.001$). However, no significant difference in average ESP BMD was observed between the Array and Fast Array scan modes (0.971 ± 0.013 vs 0.972 ± 0.012, $p = 0.997$).

Discussion

DXA has been used worldwide for the evaluation of BMD, diagnosis of osteoporosis, and as a component of fracture risk prediction, especially in postmenopausal women. With different spatial resolution, scanning time, and radiation dose, each DXA manufacturer/model provides different scanning modes based on a subjective evaluation of the patients' anthropometric characteristics. Previous studies have primarily evaluated the differences in different scanning modes at a single hospital center using a single Hologic densitometer (12–15). However, it is unclear whether these differences are consistent across other Hologic DXA models as well. Although there are no official guidelines regarding scanning mode selection based upon radiation exposure or other parameters, and most clinical DXA scan reports currently do not mention scanning modes, it is nonetheless important to understand how differences between the different modes may influence BMD results clinically.

Three different scanning modes were evaluated in our study (i.e., Array, Fast Array, and Express Array) in 19 different Hologic DXA machines. Bandirali et al had previously studied the differences between scanning modes in vivo for 1 scanning model (12). However, it was not feasible to scan the same individuals within or across multiple centers in our study; therefore, we chose to use a phantom instead. The ESP was developed independently by the European Union organization, Comité d'Actions Concertés–BioMedical Engineering, for use in different DXA machines, and is widely accepted for

DXA cross calibration in multicenter studies (18,19). Therefore, we chose to use the ESP and followed the ISCD principle of performing 10 scans for each DXA machine for the cross-calibration activities of the parent studies and repeated this for each scan mode for the present study (17).

BMD measurements and their associated T-scores are used clinically for diagnosing osteoporosis and monitoring treatment effects. Accurate diagnosis and monitoring depend on the ability to measure the true value of the patient's BMD. However, this requires an understanding of potential technical barriers to obtaining patients' true BMD values in clinical practice (12). In our study, the mean of 10 ESP BMD measures for each machine was statistically different for each scanning mode when compared to the reference ESP value. Larger differences were found for the Express Array mode as compared to Array and Fast Array modes in each of the 19 models. However, BMD values were closer to the reference ESP when scanning with Array or Fast Array modes rather than Express Array mode. Therefore, larger differences in BMD across scanning modes may influence the accuracy of the BMD results. Furthermore, in our study, mean difference in BMD from the reference ESP value measured using the Array mode compared to the Fast Array mode was not significant. However, statistically significant differences in BMD measures between Express Array with either Array or Fast Array were found. Taken together, these findings suggest that Express Array may be incrementally less accurate than Array or Fast Array scanning modes and therefore not an optimal choice for routine BMD measurement with Hologic DXA densitometer.

Scanning time and radiation dose are other factors that need to be considered when selecting a scanning mode. After the scanning mode is chosen, the rotation speed of the X-ray tube/detector system is constant in time, i.e., it does not depend on the patient and cannot be modified by the operator (12). In general, increased scanning times are associated with greater radiation dosages for BMD measurement at the same site, with the same scanner (12,13,15). It is well known that the scanning time for the Array mode is longer than that of the Fast Array mode, and for Fast Array mode is longer than that of Express Array. In previous reports (12,13,15), scanning time was halved in the Fast Array mode, thus, the Fast Array mode may be a better choice for spinal BMD measurements from the perspective of lower radiation dose and quicker scanning time, while maintaining superior accuracy as compared with Express Array.

There are several limitations that warrant mention. One limitation is that we used ESP phantoms rather than human subjects for the comparative study, as it was not feasible for us to perform scans using human participants across so many study sites. However, we feel that our study design offered valuable advantages in terms of being able to demonstrate consistency of findings across different Hologic DXA models; the second limitation is that we did not compare differences in T- and Z-scores in our study. Because we used the ESP phantom, we felt it more appropriate to focus directly on BMD measures themselves rather than T- and Z-scores which take into account the age of the participant. We therefore acknowledge that our findings are more directly applicable to use of BMD for treatment monitoring rather than osteoporosis diagnosis, which has been studied previously (20). The third limitation is that we did not compare radiation dose and scanning time in the study.

However, this has been studied previously by Bandirali et al (12,13) and helps illustrate our conclusions. Finally, while we included a large number of sites, and 5 different Hologic models in this study, certain Hologic models such as the Horizon were not widely available yet in China at the time of this study.

Our study provides new data in an area where the literature is scarce and helps illuminate an important technical consideration when performing DXA for BMD measurement. Future studies should expand upon the models and scan modes studied, and also include in vivo measurements to guide the clinical application of these findings.

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Table 1

Average ESP BMD Results at Each Site Compared to the Reference ESP BMD Value (1 g/cm^2), by Scan Mode

Site	DXA model	Scan mode					
		Array		Fast array		Express array	
		Mean ± SD	*p* value	Mean ± SD	*p* value	Mean ± SD	*p* value
1	Discovery A	0.969 ± 0.006	0.000	0.968 ± 0.008	0.000	0.948 ± 0.010	0.000
2	Discovery Wi	0.954 ± 0.010	0.000	0.959 ± 0.008	0.000	0.909 ± 0.012	0.000
3	Discovery Wi	0.956 ± 0.002	0.000	0.955 ± 0.009	0.000	0.900 ± 0.006	0.000
4	Discovery Wi	0.963 ± 0.006	0.000	0.974 ± 0.010	0.000	0.908 ± 0.008	0.000
5	Discovery A	0.988 ± 0.007	0.000	0.989 ± 0.005	0.000	0.966 ± 0.009	0.000
6	Discovery W	0.993 ± 0.005	0.001	0.996 ± 0.005	0.041	0.946 ± 0.007	0.000
7	Discovery Wi	0.961 ± 0.010	0.000	0.971 ± 0.005	0.000	0.908 ± 0.008	0.000
8	Discovery W	0.978 ± 0.005	0.000	0.971 ± 0.010	0.000	0.956 ± 0.009	0.000
9	Discovery Wi	0.970 ± 0.005	0.000	0.971 ± 0.007	0.000	0.919 ± 0.011	0.000
10	Discovery Wi	0.967 ± 0.005	0.000	0.973 ± 0.010	0.000	0.888 ± 0.116	0.014
11	Explorer	0.992 ± 0.007	0.008	0.990 ± 0.007	0.001	0.976 ± 0.004	0.000
12	Discovery Wi	0.959 ± 0.003	0.000	0.954 ± 0.003	0.000	0.898 ± 0.004	0.000
13	QDR 4500W	0.968 ± 0.005	0.000	0.959 ± 0.009	0.000	0.925 ± 0.015	0.000
14	Discovery A	0.956 ± 0.011	0.000	0.960 ± 0.006	0.000	0.941 ± 0.012	0.000
15	Discovery W	0.969 ± 0.006	0.000	0.969 ± 0.011	0.000	0.954 ± 0.009	0.000
16	Discovery W	0.959 ± 0.007	0.000	0.961 ± 0.009	0.000	0.939 ± 0.009	0.000
17	Discovery A	0.994 ± 0.003	0.000	0.989 ± 0.007	0.001	0.973 ± 0.009	0.000
18	Discovery Wi	0.985 ± 0.004	0.000	0.981 ± 0.005	0.000	0.951 ± 0.009	0.000
19	Discovery W	0.972 ± 0.005	0.000	0.972 ± 0.004	0.000	0.960 ± 0.008	0.000

Abbr: BMD, bone mineral density; DXA, dual-energy X-ray absorptiometry; ESP, European Spine Phantom.

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Table 2

Differences Between the Average ESP BMD Results at Each Site and the Reference ESP Value (1 g/cm^2), by Scan Mode

Site	DXA model	Scan mode					
		Array		Fast array		Express array	
		ΔBMD (g/cm^2)[a]	*p* value	ΔBMD (g/cm^2)	*p* value	ΔBMD (g/cm^2)	*p* value
1	Discovery A	−0.031	0.000	−0.032	0.000	−0.052	0.000
2	Discovery Wi	−0.046	0.000	−0.041	0.000	−0.091	0.000
3	Discovery Wi	−0.044	0.000	−0.045	0.000	−0.100	0.000
4	Discovery Wi	−0.037	0.000	−0.026	0.000	−0.092	0.000
5	Discovery A	−0.012	0.000	−0.011	0.000	−0.034	0.000
6	Discovery W	−0.007	0.001	−0.004	0.041	−0.054	0.000
7	Discovery Wi	−0.039	0.000	−0.029	0.000	−0.092	0.000
8	Discovery W	−0.022	0.000	−0.029	0.000	−0.045	0.000
9	Discovery Wi	−0.030	0.000	−0.029	0.000	−0.081	0.000
10	Discovery Wi	−0.033	0.000	−0.027	0.000	−0.112	0.014
11	Explorer	−0.008	0.008	−0.010	0.001	−0.024	0.000
12	Discovery Wi	−0.041	0.000	−0.046	0.000	−0.102	0.000
13	QDR 4500W	−0.032	0.000	−0.041	0.000	−0.075	0.000
14	Discovery A	−0.044	0.000	−0.040	0.000	−0.059	0.000
15	Discovery W	−0.031	0.000	−0.031	0.000	−0.046	0.000
16	Discovery W	−0.041	0.000	−0.039	0.000	−0.061	0.000
17	Discovery A	−0.006	0.000	−0.011	0.001	−0.027	0.000
18	Discovery Wi	−0.016	0.000	−0.019	0.000	−0.049	0.000
19	Discovery W	−0.028	0.000	−0.028	0.000	−0.040	0.000

Abbr. BMD, bone mineral density; DXA, dual-energy X-ray absorptiometry; ESP, European Spine Phantom.

[a]ΔBMD = average ESP scanning BMD results – reference ESP BMD value (1 g/cm^2).

Table 3

ANOVA Analysis for the Comparison of Mean ESP BMD Measures Among the 3 Scan Modes

	Array vs fast array	Array vs express array	Fast array vs express array
BMD (g/cm^2)	0.971 ± 0.013 vs 0.972 ± 0.012	0.971 ± 0.013 vs 0.935 ± 0.027	0.972 ± 0.012 vs 0.935 ± 0.027
p value	0.997	<0.001	<0.001

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