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Original Article

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The Precision of Lumbar Spine BMD and TBS on Different Vertebral Combinations

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ABSTRACT

OBJECTIVE The objective of this study is to compute the precision and LSC of BMD and TBS at the lumbar spine using dual-energy X-ray absorptiometry in different vertebral combinations.

METHODS Thirty female participants (age 58.8 ± 4.0 years, height: 155.0 ± 5.2 cm, weight: 57.4 ± 8.6 kg and BMI: 23.9 ± 3.6) were scanned at the lumbar spine twice in the same day using DXA. The precision and LSC of BMD and TBS were computed in terms of the RMS-SD and %CV using the ISCD Advanced Precision Calculation Tool.

RESULTS The precision and LSC of BMD of the 4 vertebrae combinations showed the best precision and also showed a similar trend (0.005 g/cm^2 and 0.62%, 0.013 g/cm^2 and 1.71%), respectively. For TBS, the precision and LSC followed a similar pattern as BMD but was inferior to those of BMD. The %CV LSC of BMD for all vertebrae combinations did not exceed 5.3% as recommended by ISCD (15). The %CV LSC of TBS for 2-4 vertebrae combinations were within 5.8% with the exception of the individual vertebra which was unacceptable (%CV range 6.17-8.98).

CONCLUSIONS All vertebrae combinations had an acceptable level of precision and LSC for BMD monitoring. However, the precision and LSC of TBS were inferior to those of BMD, and individual vertebra were not appropriate for TBS monitoring.

KEYWORDS precision, least significant change (LSC), bone mineral density (BMD), trabecular bone score (TBS)

INTRODUCTION

Dual-energy X-ray absorptiometry (DXA) is the current gold standard for the clinical diagnosis of osteoporosis based on the measurement of bone mineral density (BMD) for the diagnosis of osteoporosis and monitoring of changes in BMD over time (1, 2). DXA measurements at the central skeletal site (lumbar spine and proximal femur) are recommended for diagnosis of osteoporosis. Lumbar spine measurements can provide BMD values, which quantify the amount of minerals in specific volumes of bone (3). The lumbar spine is effective for monitoring treatment response due to its higher proportion of trabecular bone in the vertebral bodies and it also adheres to the World Health Organization (WHO) operational definition of osteoporosis and osteopenia (4). DXA measurements of the lumbar spine also provide trabecular bone score (TBS) values that are derived from the same region of interest (ROI). TBS is a non-invasive technique that evaluates bone quality by analyzing gray-level variations in lumbar spine images to project a 2-dimensional image of the 3-dimensional (3D) structure (5). TBS holds the potential to monitor the effects of anabolic therapy involving drugs such as teriparatide and abaloparatide (6).

Because DXA measurements are useful for monitoring changes over time of disease progression and treatment response, reproducibility and precision are essential. To determine whether a difference between measurements is statistically significant (indicative of a true change) or falls within the examination's range of error, the ISCD has recommended the use of precision and least significant change (LSC) values. The precision of DXA measurements is expressed as root mean square standard deviation of BMD and TBS in absolute terms (g/cm^2). It is sometimes expressed as CV or %CV, but this is less desirable due to variation in these values over a range of measured BMD (7). The LSC represents the smallest difference between successive measurements. This threshold value is set equal to the upper limit of the 95% confidence range for the mean value of the differences between measurements and can be mathematically calculated (8). The difference is normally considered to be statistically significant when it exceeds the LSC.

When performing DXA measurements on the lumbar spine, the image should be clear and devoid of artifacts. Artifacts can be inside or outside of patients and both can impact BMD interpretation. While external artifacts such as jewelry or the type of clothing textiles can be avoided through careful pre-scan questions and perceptive observation by technologists, internal artifacts such as vertebral fractures, aortic calcification, peacemakers and surgical clips cannot be removed (9, 10). In cases where the lumbar spine image is compromised by internal artifacts or when it displays a T-score discrepancy greater than 1.0 compared to adjacent vertebrae, the International Society for Clinical Densitometry (ISCD) recommends excluding the affected individual vertebra from the analysis based on specific criteria. However, diagnostic classification requires a minimum of two vertebrae (11).

The aim of this study is to evaluate the precision and LSC values of BMD and TBS at the lumbar spine using DXA measurements for different vertebral combinations of excluded vertebrae. These values assist physicians in making more accurate interpretation of results, thereby facilitating informed decision-making.

METHODS

Study participants

In this study, 30 female volunteers aged between 56 and 67 years were recruited from the staff of our hospital. To help ensure reliable and accurate measurements, participants with any anatomical abnormalities that could interfere with the interpretation of spine images, e.g., lumbar spine fixators, a history of lumbar spine fractures, severe lumbar scoliosis, oral contrast administration within the past 7 days, or the possibility of pregnancy, were excluded. All participants provided signed informed consent before participating in the study. The demographic characteristics of the participants are shown in Table 1. This study received approval from the Institutional Review Board (IRB) of the Faculty of Medicine Ramathibodi Hospital, Mahidol University (Research Ethics Code COA. MURA 2022/677).

DXA measurement

All participants underwent a scan of the lumbar spine (L1-L4) twice using a Hologic Horizon A DXA machine (Figure 1). Apex Software version 13.6.0.7 (Hologic, Inc., Bedford, MA, USA) was used for acquisition and analysis. To help ensure accurate measurements, participants were requested to change into hospital light clothing and to remove any metal or plastic artifacts that could potentially affect the BMD and TBS values. Following the first scan, participants were instructed to stand up and walk around the room for approximately 10-15 minutes before the second scan to help ensure that the measurements closely reflected actual conditions. The positioning of participants during the scans adhered to the manufacturer's recommended guidelines (12). After image acquisition, the lumbar spine image underwent analysis by

Table 1. Demographic data of participants (n=30)

	Mean ± SD	Range
Age (yrs)	58.8±4.0	56.0-67.0
Height (cm)	155.0±5.2	158.0-167.0
Weight (kg)	57.4±8.6	59.8-80.0
BMI (kg/m^2)	23.9±3.6	16.8-32.0

placing the ROI at L1-L4 to compute the BMD value (Figure 2). The same lumbar spine image ROI were employed to calculate the TBS values for various combinations of vertebrae using TBS insight software version 3.0.2.0 (Medimaps, Geneva, Switzerland) (Figure 3). All measurements were conducted using the same scanning mode (fast array), positioned and analyzed by same technologist, a ISCD-certified technologist with over 10 years' experience in DXA, and passed the precision test to avoid variation between measurements. A daily quality control test was conducted prior to scanning and consistently met the required standards. A spine phantom was scanned 10 times daily without repositioning, and the variation in BMD, BMC, and area values remained within 0.2%. No significant drift or shift in calibration was observed throughout the study period, which encompassed all participant measurements.

Figure 1. Positioning of lumbar spine scan by DXA

Statistical analysis

Descriptive statistics, including mean ± standard deviation (SD), were calculated using Microsoft Excel 2019 for all participant data.

Determination of precision error of BMD and TBS equivalent to the root mean square standard deviation (RMS-SD) or percent coefficient of variation (CV%), was performed using equations (1) and (2), respectively (13). The LSC of BMD and TBS were determined at a 95% confidence level using RMS-SD and (%CV) as 2.77 times of the precision, represented in equation (3). Precision error and LSC were computed using the ISCD Advanced Precision Calculation Tool (14). The levels of LSC of BMD and TBS were considered acceptable with a %CV of ≤ 5.3% and ≤ 5.8%, respectively (3, 15).

$$RMS\ SD = \sqrt{\frac{\sum_{i=1}^{m}(SD_i)^2}{m}} \quad (1)$$

Where: m = number of subjects
SD = standard deviation

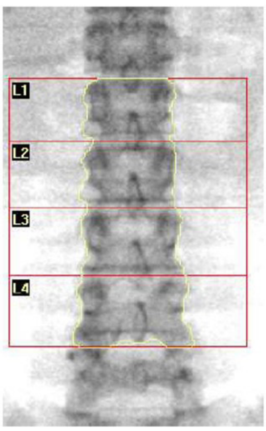
$$RMS\ \%CV = \sqrt{\frac{\sum_{i=1}^{m}(CV_i)^2}{m}} \times 100 \quad (2)$$

Where: m = number of subjects
CV = coefficient of variation

LSC=2.77 (precision error) (3)

RESULTS

The descriptive results for lumbar spine BMD and TBS in different vertebrae combinations are given in Table 2, while Table 3 presents the precision values for lumbar spine BMD and TBS across different vertebrae combinations.



Region	Area (cm²)	BMC (g)	BMD (g/cm²)	T - score	Z - score
L1	12.86	11.67	0.907	-0.5	1.0
L2	14.23	12.79	0.899	-0.7	1.0
L3	15.63	14.24	0.911	-1.0	0.8
L4	18.34	16.17	0.882	-1.2	0.8
L1-L2	27.08	24.45	0.903	-0.3	1.3
L1,L3	28.48	25.91	0.910	-0.5	1.2
L1,L4	31.19	27.83	0.892	-0.9	0.9
L2-L3	29.85	27.03	0.905	-0.9	0.9
L2,L4	32.56	28.95	0.889	-1.2	0.7
L3-L4	33.97	30.41	0.895	-1.4	0.6
L1-L3	42.71	38.70	0.906	-0.6	1.1
L1-L2,L4	45.42	40.62	0.894	-0.8	1.0
L1,L3-L4	46.82	42.08	0.899	-0.9	0.9
L2-L4	48.19	43.20	0.896	-1.2	0.7
L1-L4	61.05	54.87	0.899	-0.9	0.9

Figure 2. An example of analysis and results of BMD of vertebrae combinations

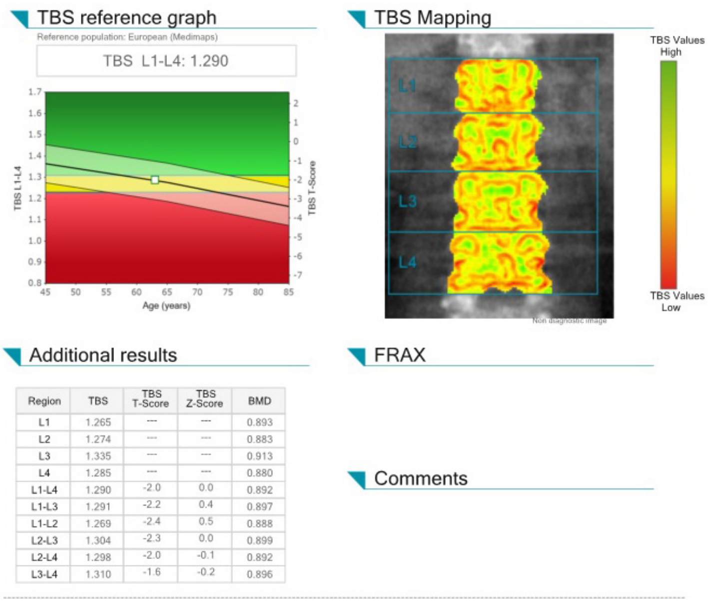


Figure 3. An example of analysis and results of TBS vertebrae combinations

The precision and LSC for 4 vertebrae combinations showed smallest value. The combination of 3 and 2 vertebrae exhibited larger values than the 4 vertebrae combinations, and individual vertebra demonstrating the greatest values. None of the lumbar spine vertebrae combinations exceeded acceptable levels (LSC value of BMD and TBS were within 5.3% and 5.8%, respectively), except individual vertebra combinations of TBS, which exhibited significantly lower precision.

DISCUSSION

Precision and LSC function as vital clinical tools for determining the minimum change in DXA serial measurements which can be considered a statistically significant change. Computation of precision and LSC at each DXA facility, as recommended by the ISCD, assists physicians in report interpretation and facilitates monitoring of response to treatment and disease progression (16).

In this study, we determined the precision and LSC for BMD and TBS in the lumbar spine, by considering both individual vertebra and various combinations of vertebrae of volunteer participants aged between 56 and 67. The age and physical condition of the participants was representative of the patient population undergoing BMD measurement in our department and followed the ISCD recommendations for BMD measurement (17). The determination of precision and LSC for BMD and TBS in younger participants may not be a good representative because the reproducibility of BMD measurements in younger patients might be higher due to more ease in repositioning than elderly participants (18).

Table 2. Mean and SD of lumbar spine BMD and TBS in different vertebrae combinations

Vertebrae combinations of lumbar spine (L1-L4)	Mean±SD	
	BMD	**TBS**
L1L2L3L4	0.857±0.158	1.359±0.068
L1L2L3	0.846±0.152	1.353±0.075
L2L3L4	0.871±0.164	1.375±0.710
L1L2L4	0.845±0.157	1.346±0.069
L1L3L4	0.862±0.161	1.349±0.067
L1L2	0.821±0.150	1.337±0.078
L1L3	0.850±0.153	1.344±0.075
L1L4	0.850±0.163	1.335±0.069
L2L3	0.864±0.156	1.378±0.082
L2L4	0.863±0.166	1.369±0.071
L3L4	0.886±0.173	1.376±0.074
L1	0.805±0.153	1.301±0.085
L2	0.838±0.153	1.373±0.082
L3	0.888±0.163	1.386±0.094
L4	0.884±0.187	1.366±0.085

BMD, bone mineral density; TBS: trabecular bone score; SD, standard deviation

The precision of the BMD 4 vertebrae combination showed the greatest precision (%CV = 0.62). The precision trend was declined for the 3 vertebrae combination (%CV range 0.65-0.81), the 2 vertebrae combination (%CV range 0.75-1.03), and individual vertebra (%CV range 0.94-1.32). The LSC of BMD with the 4 vertebrae combination (%CV = 1.71), the 3 vertebrae combination (%CV range 1.86-2.24), the 2 vertebrae combination

Table 3. Lumbar spine precision and LSC of BMD and TBS in different vertebrae combinations

Vertebrae combinations of lumbar spine (L1-L4)	Precision				LSC			
	BMD		TBS		BMD		TBS	
	RMS-SD	%CV	RMS-SD	%CV	RMS-SD	%CV	RMS-SD	%CV
L1L2L3L4	0.005	0.62	0.017	1.22	0.013	1.71	0.046	3.38
L1L2L3	0.006	0.81	0.210	1.56	0.018	2.24	0.059	4.31
L2L3L4	0.005	0.67	0.021	1.55	0.015	1.86	0.057	4.28
L1L2L4	0.005	0.65	0.019	1.43	0.014	1.79	0.053	3.96
L1L3L4	0.006	0.68	0.018	1.31	0.015	1.87	0.049	3.62
L1L2	0.007	0.93	0.024	1.81	0.020	2.59	0.067	5.00
L1L3	0.008	0.97	0.025	1.81	0.022	2.69	0.069	5.03
L1L4	0.006	0.78	0.024	1.85	0.017	2.15	0.066	5.11
L2L3	0.008	1.03	0.029	2.13	0.022	2.86	0.080	5.61
L2L4	0.006	0.75	0.023	1.73	0.017	2.08	0.064	4.78
L3L4	0.006	0.77	0.021	1.54	0.017	2.12	0.058	4.27
L1	0.012	1.44	0.041	3.24	0.032	3.54	0.114	8.98
L2	0.009	1.11	0.036	2.70	0.024	4.00	0.100	7.48
L3	0.011	1.32	0.034	2.49	0.030	3.67	0.094	6.91
L4	0.008	0.94	0.030	2.23	0.021	2.60	0.084	6.17

BMD, bone mineral density; TBS, trabecular bone score; RMS SD, root-mean-square deviation; %CV, % coefficient of variation; LSC, least significant change

(%CV range 2.08-2.86), and the individual vertebra (%CV range 2.60-4.00) are shown in Table 3. Nevertheless, none of the %CV values for BMD in any of the combinations exceeded 5.3%, the maximum level recommended by ISCD (17). Comparing the precision and LSC of RMS-SD and the %CV for BMD in our study with those of previous studies by Whittaker et al. (19), McNamara et al. (20), and Hind and Oldroyd (10), found noteworthy similarities.

For TBS, the precision and LSC followed a similar pattern to those of BMD. However, the precision and LSC of TBS were inferior to those of BMD. Moreover, the LSC of an individual vertebra was unacceptable (%CV range 6.17-8.98 (Table 3), while the threshold recognized by ISCD for monitoring TBS changes is %CV=5.8) (15).

Our findings indicate that all combinations of vertebrae can be utilized for monitoring changes in BMD. However, to gain further insights beyond BMD and bone turnover markers, it is advisable to monitor changes in TBS, specifically in 2-4 vertebrae combinations, but not in individual vertebra. This recommendation is particularly relevant for patients undergoing anabolic therapy (teriparatide and abaloparatide).

It is essential to also acknowledge the limitations of this study. First, all participants in this study were females. Although the ISCD does not offer specific recommendations regarding gender-based precision studies (11) and Krueger et al. found no significant difference in BMD precision between females and males (21), further study of precision and LSC for lumbar spine BMD and TBS in male populations are necessary. Additionally, it should be noted that the results of this study were obtained using specific manufacturers and models of DXA machines (Hologic, Horizon A) and thus may not be generalizable to all manufacturers and models. Finally, all participants enrolled in this study were staff of our hospital, not patients. The precision and LSC values of BMD and TBS of our staff may be superior to those of general patients.

CONCLUSIONS

All vertebrae combinations can provide an acceptable level of precision and LSC for BMD monitoring. However, the precision and LSC of TBS are inferior to those of BMD, and individual vertebra are not appropriate for use in TBS monitoring.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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