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Lumbar Vertebrae Morphological Analysis and an Additional Approach for Vertebrae Identification in Lumbar Spine DXA Images

Wenmin Guan¹, Wei Yu, MD^{1,*}, Qiang Lin¹, Zaizhu Zhang¹, Guiying Du², Junping Tian¹, Ying Xu¹, Evelyn Hsieh³

¹Department of Radiology, Peking Union Medical College Hospital, Chinese Academy of Medicine Sciences and Peking Union Medical College, Beijing, China

²Department of Radiology, TEDA International Cardiovascular Hospital, Tianjin, China

³Section of Rheumatology, Department of Internal Medicine, Yale School of Medicine, New Haven, CT, USA

Abstract

Introduction: Bone mineral density measured by dual-energy X-ray absorptiometry (DXA) is the gold standard for diagnosis of osteoporosis. However, DXA interpretation can be influenced by analytic errors which can, in turn, interfere with diagnostic accuracy. One such source of potential error is the accurate identification of specific lumbar vertebrae on lumbar spine DXA images. Although the International Society for Clinical Densitometry has introduced several approaches to aid with this process, there remain individuals whose lumbar vertebrae cannot be labeled with certainty using these approaches. We designed the present study to systematically evaluate lumbar spine DXA images among a large cohort of Chinese patients and present an additional simple strategy for identifying L5 named the “em dash”-shaped L5 or “—”-shaped L5, based upon the two-dimensional relationship between the bilateral pedicles with the central spinous process on DXA images.

Methodology: Lumbar spine posteroanterior DXA images from adult patients receiving care at a large tertiary hospital in Beijing, China from May to August 2016 were retrospectively reviewed. For each patient, data were collected regarding key anatomic features seen on DXA (positions of the most superior portions of the iliac crests, the lowest vertebra with ribs, and the longest transverse processes) and the proportion of patients presenting with “H”-shaped L4 and “—”-shaped L5. Chi-squared analyses were used to compare proportions across age strata.

Results: DXA images from 1125 patients (79.6% female) were evaluated. The mean age of patients was 52.5 ± 14.8 yr (range: 19–90 yr). A horizontal line drawn across the superior-most portions of the iliac crests crossed the disk space between L4 and L5 among 78.3% of patients. The lowest ribs were most frequently (83.9%) observed at T12. Almost 80% of individuals had the longest transverse processes at L3. L4 was predominantly “H”-shaped (73.3%), however we found that the proportion of individuals with “H”-shaped L4 decreased steadily after 50 yr of age ($p <$

* Address correspondence to: Wei Yu MD Department of Radiology, Peking Union Medical College Hospital, Chinese Academy of Medicine Sciences and Peking Union Medical College, Beijing 100730, China. weiyu5508@yahoo.com.

0.001). By contrast we observed that L5 was predominantly “—”-shaped (80.3%), with no significant differences in proportions across all age strata ($p = 0.063$).

Conclusions: The “—”-shaped L5 can be incorporated as an additional reference tool for lumbar spine DXA image analysis and may be particularly helpful for lumbar vertebrae identification among patients over 50 yr of age.

Keywords

Dual energy X-ray absorptiometry; lumbar spine; morphology; osteoporosis

Introduction

Osteoporosis is a systemic bone disease characterized by decreased bone mineral density (BMD) and degeneration of bone microstructure that significantly impacts older individuals, and in particular postmenopausal women (1). Timely diagnosis and treatment of osteoporosis can improve prognosis and reduce the socioeconomic burden resulting from osteoporosis-related fractures (2–4). Dual-energy X-ray absorptiometry (DXA) is considered the gold-standard approach to quantitative measurement of BMD (5). DXA measurements are used to diagnose osteoporosis (6), monitor changes in BMD over time (7) and estimate fracture risk (8), and is often an integral component of therapeutic guidelines (5). Indeed, the World Health Organization (WHO) has recommended global diagnostic criteria for osteoporosis based upon DXA measurements (6,9).

Both standardized technician and clinician training is key to ensuring proper acquisition and interpretation of DXA images, and poor-quality DXA analysis may result in unnecessary diagnostic testing or inappropriate treatment. Such errors in clinical practice can be costly, and potentially harmful to patients (10,11). Many factors can affect lumbar spine DXA analysis; one of which is uncertainty regarding the identifier of specific vertebrae due to natural variation in anatomy (12,13). The International Society for Clinical Densitometry (ISCD) has introduced several approaches to guide vertebrae identifier in lumbar spine DXA posteroanterior (PA) images, including identifying the L4 and L5 disk space by drawing a straight line across the superior-most portions of the iliac crests, identifying T12 as the vertebra with the lowest ribs, L3 as the vertebra with the longest transverse processes, L4 as the vertebra morphologically shaped like a letter “H,” and L5 as the vertebra morphologically shaped like a “block I on its side” (14–17). However, even when the above approaches are used in combination, there are still individuals for whom specific identifier of lumbar vertebrae remains difficult

To our knowledge, no study has systematically assessed the full range of variability on DXA image in lumbar vertebrae location among individuals using the aforementioned methods. We therefore designed a large study to address this gap among Chinese men and women across all age strata, and in the process, identified an additional approach for lumbar vertebrae identification, which we call the “em dash”-shaped L5.

Materials and Methods

Study Design

This was a retrospective cross-sectional analysis of DXA images performed among adult patients seen at Peking Union Medical College Hospital (PUMCH), a large tertiary hospital in Beijing, China. The study was exempt from review by the PUMCH Institutional Review Board as all DXA imaging data was collected and analyzed without patient identifiers and no additional patient-related data was collected during the study.

Study Population

All DXA images obtained from inpatients and outpatients seen at PUMCH between May and August 2016 were eligible for inclusion. The exclusion criteria were as follows: (1) age <18 yr; (2) evidence of lumbar spine surgery on DXA; (3) evidence of vertebral fracture on DXA; (4) evidence of scoliosis on DXA; (5) poor-quality lumbar spine DXA images or presence of foreign artifacts influencing interpretation.

Lumbar Spine DXA Images

Two experienced radiologists (W.Y. and W.G.) visually analyzed lumbar spine DXA images independently in a randomized order. Readers were blinded to participant information, such as age, sex, and any external information that could potentially identify L4 and L5. Differences of opinion were resolved by discussion and consensus.

For each patient, the DXA PA image of the lumbar spine was collected and L1–L5 were identified. Morphological characteristics of L1–L5 were recorded, including the position of the most superior portions of the iliac crests, the positions of the lowest vertebra with ribs and the longest transverse processes, and the proportion of patients presenting with an “H”-shaped versus “non-H”-shaped L4.

For most patients, a straight line was drawn across the most superior portions of the iliac crests and the disk space crossed by this line was identified as the L4 and L5 disk space (5,12). This was used as the primary method to locate lumbar vertebrae in our study. If the patient’s anatomy did not allow for determination using this approach, the lumbar vertebrae were confirmed by anatomic identification of other supporting landmarks, such as the lowest ribs and the longest transverse processes.

Furthermore, we observed that for L1–L5, if a virtual line is drawn from the bilateral pedicles inwards toward the central spinous process, the angle formed at the vertex of the two connection lines increases progressively from L1 to L5 on lumbar spine **PA DXA** images, such that by L5, the angle between the lines of connection is 180°. In other words, the two connection lines form a flat angle. We called this phenomenon the “em dash”-shaped L5 (hereafter called the “—”-shaped L5) and recorded the proportion of patients presenting with an “—”-shaped L5. Those with different anatomic variants whose angles between the lines of connection are larger or smaller than 180° were categorized as having a non-“—”-shaped L5, or, “ ”-shaped, and “ ”-shaped L5, respectively.

All DXA studies were performed on the same GE Lunar Prodigy Advance DXA scanner (GE Healthcare, Madison, WI), using the same software (enCORE version 10.50.086) for both scan acquisition and analysis.

Statistical Analyses

All statistical analyses were performed using SPSS20.0 software (International Business Machines, Armonk, NY). Data regarding the location and characteristics of lumbar vertebrae are reported using descriptive analyses. Inter-reader agreement for analysis of lumbar spine DXA images was obtained by using Kappa statistics. Intragroup differences in proportions of both “H”-shaped L4 and “—”-shaped L5 across 7 age strata were analyzed using chi-squared analysis. Age strata were grouped by 10-yr intervals, with the exception of the youngest stratum (ages 19–29) and the oldest stratum (ages 80 and above). Intergroup differences between the “H”-shaped L4 approach and “—”-shaped L5 approach were also compared using chi-squared analysis. For all analyses, $p < 0.05$ was considered statistically significant.

Results

DXA images from a total of 1125 patients were included in this analysis. The mean age of the overall sample was 52.5 ± 14.8 yr (range: 19–90 yr), including 229 (20.4%) men with an average age of 45.8 ± 18.2 yr (range: 19–86 yr), and 896 (79.6%) women with an average age of 54.2 ± 13.2 yr (range: 19–90 yr). The overall inter-reader agreement for analysis of lumbar spine DXA images was $\kappa = 0.82$.

The Position of the Most Superior Portions of the Iliac Crests

A virtual line drawn across the most superior portions of the iliac crests crossed the intervertebral space between L4 and L5 for 881/1125 (78.3%) individuals (Fig. 1A). Among the remaining patients, there were 38 (5.3%) for whom this virtual line crossed the L4 vertebral body (Fig. 1B), and 198 (17.6%) for whom the line intersected the L5 vertebral body (Fig. 1C). Only in rare cases [8/1125 (0.7%)] did the line intersect the intervertebral space between L5 and S1 (Fig. 1D).

The Position of the Lowest Vertebra With Ribs

In our study population, the lowest vertebrae with ribs included T11, T12, and L1, with T12 being the most common vertebra (944/1125 [83.9%]), T11 was the second most common vertebra (130/1125 [11.6%]), and L1 was the least common (51/1125 [4.5%]) vertebra.

The Position of the Longest Transverse Processes

The longest transverse processes could be observed clearly for 896 (79.6%) patients. Among those, the longest transverse processes were most commonly seen at L3 (721/1125 [64.1%]) (Fig. 2A), next most commonly seen at L4 [125/1125 (11.1%)] (Fig. 2B), and least commonly seen at L2 (50/1125 [4.4%]) (Fig. 2C).

The “H”-Shaped L4

We observed both “H”-shaped (825/1125 [73.3%]) (Fig. 3A) and “non-H”-shaped L4 (300/1125 [26.7%]) (Fig. 3B) morphology in the lumbar spine PA DXA images reviewed.

For each age stratum, the proportions of “H”-shaped L4 and non-“H”-shaped L4 were calculated and significant differences were found in the proportion of “H”-shaped L4 across increasing age strata ($p < 0.001$) (Fig. 4A). Notably, the proportion of “H”-shaped L4 decreased significantly after 50 yr of age, with a corresponding increase in the proportion of non-“H”-shaped L4 observed.

The Progressively Widening “V”-Shape of L1–L4 and “—”-Shaped L5

Figure 5 demonstrates the progressive increase in the angle at the vertex of the two virtual lines connecting the central spinal process with the bilateral pedicles of each lumbar vertebra. These two connection lines form a “V”-shape at L1–L4 and the angle progressively becomes wider until L5 where it becomes a straight line, or “—”-shape (Fig. 5A and B). Due to natural anatomic variation, we also described non-“—”-shaped variants including the “ ”-shaped L5 (Fig. 5C) and “ ”-shaped L5 (Fig. 5D).

In our sample, we observed the “—”-shaped L5 most commonly (903/1125 [80.3%]) followed by “ ”-shaped L5 (201/1125 [17.9%]), and least common was the “ ”-shaped L5 (21/1125 [1.9%]).

For each age stratum, the proportions of “—”-shaped L5 versus non-“—”-shaped L5 were calculated and no significant differences in proportions were found across increasing age strata ($p = 0.063$), as shown in Fig. 4B.

Comparison of the “H”-Shaped L4 and “—”-Shaped L5

Chi-squared analyses showed that statistically significant intergroup differences exist between the proportions of “H”-shaped versus “non-H”-shaped L4 and proportions of “—”-shaped versus non-“—”-shaped L5 in this study population ($p < 0.001$).

Discussion

DXA-based measurements remain the internationally recognized gold standard for diagnosis of osteoporosis. However, these measures are susceptible to analytic errors as a result of inaccurate labeling of lumbar vertebrae, despite the existence of several approaches to aid in this process. Our study is the first to systematically evaluate anatomic features of lumbar spine DXA images from a large cohort of Chinese adults, and identifies an additional method of DXA-based lumbar vertebrae identification, named the “—”-shaped L5.

The unique feature of the “—”-shaped L5 approach is that it employs a technically straightforward concept whereby the angles formed at the vertex of two virtual lines drawn from the bilateral pedicles to the center point of the lumbar spinous processes are examined in series. In L1–L4, we observed that the two virtual lines form progressively widening “V”-shapes, and at L5 they create a straight or approximately straight line. We believe there are two main reasons accounting for this pattern. First, the anatomical distance between bilateral

pedicles increases from L1 to L5, which results in increasing distance of two outer starting points of the connecting lines. Second, the lumbar vertebrae are arranged in an arc, forming a physiological lumbar lordosis. A normal lumbar curvature has upward sloping vertebral bodies and downward sloping posterior elements at L1-L4. The inclination angles become progressively smaller from L1-L4, and at the level of L5, the body and its posterior elements are close to the horizontal position. Therefore, the distance between the pedicle level and spinous process level in L1-L5 decreases gradually. These two reasons result in the gradual decrease in height of the “V” in L1-L4, and the gradual increase in degree of the vertex on the two-dimensional lumbar spine DXA image, leading to an “—” at L5.

Observing the straight shape of the L5 vertebral body, Bonnick had previously put forth the “Block I on its side” characterization of L5 (16). However, this description is based on the visual appearance of the vertebral body itself (similar to the morphological approach used to identify the “H”-shaped L4). Therefore, it is more susceptible to error as radiologists may not have the same subjective impression regarding vertebral body shape. By contrast, the “—” shape or “non —” shape, which is described by the pattern of virtual lines drawn between easily identified anatomic points on DXA images, is comparatively more convenient for the identification of L5.

The “H”-shaped L4 has also been classically used as a reference point in vertebrae location (5,16). But in our study, the proportion of “—”-shaped L5 was higher than that of “H”-shaped L4. In addition, there was no significant change across age strata in the proportion of “—”-shaped L5 versus “non —”-shaped L5, while the proportion of “H”-shaped L4 decreased across age strata, especially after 50 yr. One reason accounting for the proportion of “H”-shaped L4 decreased across age strata may be the appearance of lumbar osteoarthritis with age. Hyperostosis changes the morphology of lumbar vertebrae, which may lead to the appearance of “non-H”-shaped L4. Further studies are needed to confirm this or identify other etiologies behind the age-related differences observed.

Given osteoporosis occurs most commonly among older individuals, and postmenopausal women in particular (1), the age-associated findings presented here are of clinical relevance. The increased prevalence of non-“H”-shaped L4 with increasing age adds an additional source of potential error for identification of lumbar vertebrae on DXA images in this age group. Given the “—”-shaped L5 appears less susceptible to age-related changes; we believe this approach provides important supplemental information. Therefore, we recommend inclusion of L5, or at least the top two-thirds of the L5 vertebral body on lumbar spine DXA images to enable application of this technique for vertebrae location. It is important to note as well that using the described approach, progressively obtuse “V”-shaped angles were observed from L1-L4 for all patients. Therefore, even “—”-shaped and “—”-shaped L5 may be used to accurately identify L5 based upon comparison with the “V”-shaped angles of L1-L4 in the same individual.

With regards to using anatomic landmarks to guide lumbar vertebrae identification, a straight line drawn across the most superior portions of the iliac crests was used as the primary method for locating the L4 and L5 disk space (5,12). There is limited data regarding the consistency with which this approach identifies this space. In 21.7% of the images

reviewed in our study, the line drawn across the most superior portions of the iliac crests did not cross the intervertebral space between L4 and L5, but rather crossed the L4 or L5 body, or the L5 and S1 disk space, which could lead to potential error in DXA analysis. In terms of using the lowest ribs as an anatomic land-mark, consistent with prior studies by Peel (12), Bardeen CR (14), and Bornstein and Peterson (15) we found that the lowest ribs were located on T12 in approximately 84% of individuals. Finally, L3 is generally recognized as having the longest transverse processes, and our findings were consistent that of with prior studies (5,17). However, 15.5% of individuals in our study had the longest transverse processes at L2 or L4. In addition, we found that in about 20.4% individuals, the longest transverse processes cannot be seen clearly even after adjusting the grayscale. This may be attributable to obesity or visual obstruction by other intra-abdominal contents, however further study is necessary to explore this. To our knowledge our study is the first to systematically characterize each of these anatomic landmarks in a large population.

Limitations

This study has some limitations. First, we recognize that the “—”-shaped L5 method, like the other existing methods described, can only provide an indirect means of lumbar vertebrae identification, whereas the gold standard for proper identification of lumbar vertebrae is the total spine X-ray examination. However, in clinical practice total spine radiographs are not routinely obtained simultaneously with DXA images, as they would place an unnecessary burden on the patient in terms of cost and radiation exposure. Furthermore, due to the retrospective nature of our study, we were unable to obtain total spine X-rays for our study population. Future prospective studies of approaches to evaluated approaches to lumbar vertebrae identification would benefit from concurrent comparison to total spine X-ray. Second, while large in size, we acknowledge our study represents data from a single tertiary care hospital in China. Therefore, this approach requires validation, and whether the progressively widening “V”-shapes of L1-L4, and the “—”-shaped L5 approach can be generalized to other populations requires further study in non-Chinese populations.

In conclusions, we present a simple additional approach for lumbar spine vertebrae identification in DXA images, named the “—”-shaped L5. This approach was robust in our study population and stable across age strata, therefore addition of the “—”-shaped L5 approach to other approaches used in routine DXA analysis can potentially improve the accuracy of osteoporosis diagnosis, particularly among older adults.

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Fig. 1.

Lumbar spine DXA images with white dashed lines are drawn across the most superior portions of the iliac crests. (A) A 51-yr-old female, with the dashed line crossing the intervertebral space between L4 and L5; (B) A 41-yr-old male, with the dashed line crossing L4; (C) A 42-yr-old male, with the dashed line crossing L5; (D) A 41-yr-old male, with the dashed line crossing the intervertebral space between L5 and S1.

Fig. 2. Lumbar spine DXA images with yellow dashed lines trace the outline of each transverse process and arrows indicate the longest transverse process in each image. (A) A 48-yr-old female with the longest transverse process at L3; A 45-yr-old female, with the longest transverse process at L4; (C) A 45-yr-old female, with the longest transverse process at L2. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Fig. 3. Lumbar spine DXA images demonstrating different L4 morphologies in the study population. The arrows indicate the L4 vertebra in each image. (A) A 48-yr-old female with an “H”-shaped L4; (B) A 46-yr-old female with a “non-H”-shaped L4.

Fig. 4.

(A) The lines indicate proportions of "H"-shaped L4 and "non-H"-shaped L4 across age strata; (B) The lines indicate proportions of "—" -shaped L5 and non—"—" -shaped L5 across age strata.

Fig. 5.

(A) Lumbar spine DXA image from a 51-yr-old female showing the progressive “V”-shaped L1-L4 and “—”-shaped L5 (indicated by the arrow), consisting of two dashed lines from the bilateral pedicles connecting at the center of the spinous process for each vertebra, with the angles of the vertex increasing progressively from L1 to L4; (B) An illustration of this concept; (C) Lumbar spine DXA image from a 39-yr-old female. The arrow indicates the “—”-shaped L5; (D) Lumbar spine DXA image from a 45-yr-old female. The arrow indicates the “—”-shaped L5