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ORIGINAL RESEARCH

Characteristics of the DXA Measurements in Patients Undergoing Lumbar Fusion for Lumbar Degenerative Diseases: A Retrospective Analysis of Over 1000 Patients

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Purpose: To explore the characteristics and reliability of dual-energy x-ray absorptiometry (DXA) measurements in patients undergoing lumbar fusion for lumbar degenerative diseases (LDD).

Patients and Methods: A total of 1041 patients aged ≥50 years undergoing lumbar fusion for LDD were reviewed. The BMDs and T-scores of DXA were retrospectively analysed. The diagnosis of osteoporosis was in accordance with World Health Organization (WHO) criteria. Based on the guidelines of International Society for Clinical Densitometry (ISCD), an abnormal lumbar segment is identified as having unreliable T-scores when there is more than a 1.0 T-score difference between two adjacent vertebrae.

Results: The prevalence of osteoporosis diagnosed on DXA was 42.3%, and it was higher in women than in men (50.2% vs 31.8%, $P < 0.001$). Increasing age resulted in higher prevalence of osteoporosis in females. The prevalence of osteoporosis significantly declined with increasing BMI. The lowest lumbar T-score was mostly found at L1. Unreliable T-scores were mostly seen in the lower lumbar segment (L3–L4) and were the least common in L1–L2. The average amount of abnormal lumbar segments increased with age ($P = 0.003$) and BMI ($P = 0.021$). Furthermore, those with degenerative lumbar scoliosis had more abnormal segments ($P < 0.001$). Of the 95 patients with at least one fractured vertebra, 39 (41.1%) were not diagnosed as having osteoporosis on lumbar DXA.

Conclusion: Female, older age and low BMI are the risk factors for osteoporosis in patients undergoing lumbar fusion for LDD. Lower lumbar segments, such as L3–L4, are more likely to have unreliable T-scores. Patients with older age, higher BMI or degenerative scoliosis have more abnormal segments with unreliable T-scores. Lumbar DXA measurements are not sensitive enough to identify patients with vertebral fracture.

Keywords: dual-energy x-ray absorptiometry, lumbar degeneration diseases, osteoporosis, body mass index, T-score

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Introduction

Lumbar degenerative diseases (LDD) are a group of diseases caused by structural degeneration of the lumbar spine, including lumbar spinal stenosis (LSS), degenerative lumbar spondylolisthesis, lumbar disc herniation and degenerative lumbar scoliosis.[1,2] Presently, increasing number of elderly patients with LDD are faced with the need to alleviate symptoms and improve life quality by receiving lumbar

fusion surgery. Osteoporosis is a common disease among aging people, affecting nearly one-third of geriatric population in China.[3] In addition, the prevalence of osteoporosis in patients aged ≥50 years undergoing lumbar fusion for LDD is 48.9% and 27.1% among women and men, respectively,[1] which is higher than that in the general population.[3,4] Such a high rate of osteoporosis has posed major challenges for surgeons because several postoperative osteoporosis-related complications, such as pedicle screw loosening, adjacent segment fracture, cage subsidence and nonunion, often lead to implant failure and reoperations.[5–7] Hence, preoperative bone mineral density (BMD) assessment and osteoporosis identification is of vital importance for spinal surgeons to take necessary preventive measures for improving the efficacy of lumbar fusion.

Dual-energy X-ray absorptiometry (DXA) of the lumbar vertebrae (L1–L4) and hips (femoral neck and total hips) is recommended as the gold standard method for assessing BMD and diagnosing osteoporosis by World Health Organization (WHO). In addition, based on the WHO classification, osteoporosis is defined as the lowest T-score of less than −2.5 on DXA.[8] This technique operates simply with low radiation exposure and relatively low cost.[9] Whereas degenerative structures in patients with severe LDD can falsely elevate the DXA measurements (BMD and T-scores), leading to an underestimation of the severity of osteoporosis.[9–11] Among the patients with vertebral compression fracture, about 50% had either osteopenic or normal DXA measurements.[12–14]

Nevertheless, no research with a large sample size has been conducted to analysed DXA measurements in degenerative lumbar spine. This retrospective study aimed to explore the characteristics and reliability of DXA measurements in over 1000 patients undergoing lumbar fusion for LDD. We hope our results would help spine surgeons better understand the DXA measurements in clinical practice.

Patients and Methods

Patients Cohort

This study was approved by the Ethical Committee of the Peking University Third Hospital (IRB00006761-M2018012). All data collection and analysis conducted in this study were in accordance with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. Formal consent was waived because this was a retrospective study. We reviewed the patients who underwent lumbar surgery operated by senior spine surgeons at our spine centre from July 2015 to June 2017. Inclusion criteria were (1) patients aged ≥50 years, (2) patients undergoing lumbar fusion for LDD and (3) patients having DXA reports within 3 months before the index operation. Exclusion criteria were patients with spinal tuberculosis, bone tumour, ankylosing spondylitis, diffuse idiopathic skeletal hyperostosis and a history of prior lumbar spinal surgery.

According to the guidelines of International Society for Clinical Densitometry (ISCD), an abnormal lumbar segment is identified as having unreliable T-scores when there is more than a 1.0 T-score difference between the two adjacent vertebrae.[15] The abnormal lumbar segments are identified from L1 to L4 because the lumbar DXA only measures the T-scores of L1–L4.

Body mass index (BMI) was calculated as a ratio of weight to height squared (kg/m^2). According to the BMI value of men and women, the subjects were divided into three subgroups: underweight or normal (BMI < 24.0), overweight (24.0 ≤ BMI < 28.0) and obese (BMI ≥ 28.0) based on the criteria proposed by the Department of Disease Control Ministry of Health in China.[16]

BMD Evaluation

DXA scans (Hologic Inc, Discover A densitometers, Bedford, MA, USA) were performed for the lumbar spine (L1–L4) and two hips (femoral neck and total hips) to obtain bone quality information including BMD (measured in g/cm^2) and T-score of all subjects. Lumbar T-scores were derived using the database provided by the manufacturer, and femoral neck and total hip T-scores were determined using the NHANES III database. According to the WHO criterion, patients were categorised as having osteoporosis (T-score ≤ −2.5), osteopenia (T-score between −1.0 and −2.5) or normal BMD (T-score at −1.0 and above) using the lowest T-score.

Vertebral Fracture Assessment

We assessed the presence of vertebral fractures on sagittal CT images or lateral X-ray images of the lumbar spine by applying the Genant semiquantitative visual approach.[12] When the lumbar compression deformities were moderate (grade 2, 25% to 40% loss of height) or severe (grade 3, >40% loss of height), we determined that there were fractured vertebrae.

Statistical Analysis

Statistical analysis was conducted using SPSS software (ver. 26) for Windows (SPSS, USA). Continuous variables are reported as mean ± standard deviation (SD). The chi-squared test was used to compare the incidence rate between different groups. Independent sample *t*-tests were carried out for between-group comparisons. In addition, we used analysis of variance (ANOVA) to compare the mean values of three different groups. A *P* value of <0.05 was considered statistically significant.

Results

A total of 1041 patients were finally included in the analysis, with an average age of 62.6 years (range, 50–84 years), including 594 women (57.1%). Their general information and bone density measured by DXA are summarised in Table 1.

The prevalence of osteoporosis, osteopenia, and normal BMD was 42.3% (440/1041), 44.6% (464/1041), 13.2% (137/1041), respectively. Furthermore, 298/594 (50.2%) female patients had osteoporosis, whereas the incidence in men was much lower, affecting 142/447 (31.8%) men with osteoporosis ($P < 0.001$). The prevalence of osteoporosis in women appeared to increase with age and was 29.5%, 58.1% and 72.0% in the age groups of 50–59, 60–69 and ≥70 years, respectively ($P < 0.001$). Conversely, among male patients, the prevalence of osteoporosis among the three age groups did not significantly differ (26.0%, 34.1% and 36.5%, respectively; $P = 0.150$), as shown in Table 2. Furthermore, the BMI- and gender-related distribution of osteoporosis diagnosed on DXA scan was shown in Table 3.

Table 1 General Information and Bone Density

	Total	Male	Female
n	1041	447	594
Age (years)	62.6±7.04	62.9±7.39	62.3±6.77
BMI (kg/m^2)	26.0±3.45	25.6±2.98	26.3±3.74
L1 BMD (g/cm^2)	0.858±0.162	0.927±0.154	0.806±0.148
L2 BMD (g/cm^2)	0.918±0.182	0.995±0.172	0.860±0.168
L3 BMD (g/cm^2)	0.995±0.200	1.065±0.192	0.943±0.189
L4 BMD (g/cm^2)	1.049±0.222	1.121±0.224	0.995±0.206
Femoral neck BMD (g/cm^2)	0.676±0.121	0.726±0.115	0.639±0.112
Total hip BMD (g/cm^2)	0.830±0.135	0.890±0.122	0.784±0.126
L1 T-score	−1.53±1.38	−1.33±1.40	−1.68±1.35
L2 T-score	−1.25±1.58	−0.89±1.57	−1.53±1.53
L3 T-score	−0.87±1.79	−0.34±1.75	−1.28±1.72
L4 T-score	−0.22±2.01	0.28±2.03	−0.59±1.90
Femoral neck T-score	−1.72±0.97	−1.50±0.86	−1.89±1.01
Total hip T-score	−1.14±0.96	−0.94±0.81	−1.29±1.03

Abbreviations: BMI, body mass index; BMD, bone mineral density.

Of the 1041 patients who underwent lumbar fusion surgery for LDD, the prevalence of osteoporosis in patients with vertebral compression fracture was evidently higher than in those without (70.5% vs 39.4%, $P < 0.001$), and patients with degenerative scoliosis had significantly higher prevalence of osteoporosis than those without (47.8% vs 38.2%, $P = 0.002$). Nevertheless, there was no significant difference between the incidence of osteoporosis in patients diagnosed with and without lumbar spondylolisthesis (45.7% vs 40.0%, $P = 0.070$).

The lumbar vertebral body with the lowest T-score was L1 for 601 patients (57.7%), L2 for 219 patients, L3 for 158 patients, and L4 for 63 patients. Meanwhile, we observed that 142, 189 and 338 patients had unreliable T-scores at L1–L2, L2–L3 and L3–L4, respectively. There were 407 patients with one abnormal segment, 110 with two abnormal segments and 14 with three abnormal segments. The average number of abnormal segments was similar in men and women (0.68 vs 0.61, $P = 0.147$). A tendency towards having more abnormal segments was seen with increasing age (50–59 years: 0.54, 60–69 years: 0.69, ≥70 years: 0.73; $P = 0.003$) and higher BMI (<24.0: 0.56, 24.0–27.9: 0.64 and ≥28.0: 0.74; $P = 0.021$). In addition, patients with degenerative scoliosis had more unreliable segments than those without (0.76 vs 0.56, $P < 0.001$); however, patients with lumbar compression fractures or spondylolisthesis had a similar number as those without.

The prevalence of lumbar osteoporosis diagnosed on lumbar DXA (L1–L4) was 34.1% (355/1041), and the prevalence of hip osteoporosis diagnosed on hip DXA (femoral neck and total hips) was 22.9% (238/1041). Only 50.6% (527/1041) of patients had concordant diagnostic results for lumbar DXA and hip DXA (Table 4).

Ninety-five patients had at least one fractured vertebra (35 had fractures at multiple vertebral levels), 28 (29.5%) of whom were diagnosed with osteopenia or normal BMD

Table 2 The Prevalence of Osteoporosis or Osteopenia in Different Age Groups

Age (Years)		Total	50–59	60–69	≥70 (70–84)	*P* [a]
Male	**Osteoporosis (%)**	31.8 (142/447)	26.0 (40/154)	34.1 (71/208)	36.5 (31/85)	0.150
	Osteopenia (%)	51.9 (232/447)	61.0 (94/154)	45.7 (95/208)	50.6 (43/85)	0.015
Female	**Osteoporosis (%)**	50.2 (298/594)	29.5 (62/210)	58.1 (169/291)	72.0 (67/93)	< 0.001
	Osteopenia (%)	39.1 (232/594)	51.0 (107/210)	34.4 (100/291)	26.9 (25/93)	< 0.001

Notes: [a]The chi-squared test was used to compare the prevalence between the three age groups. $P < 0.05$ was considered statistically significant.

Table 3 BMI- and Gender-Related Distribution of Osteoporosis Diagnosed on DXA

BMI (kg/m^2)		< 24.0	24.0–27.9	≥28.0	*P* [a]
Male	**n**	130	232	85	
	Osteoporosis (%)	43.1 (56/130)	31.0 (72/232)	16.5 (14/85)	< 0.001
Female	**n**	159	259	176	
	Osteoporosis (%)	60.4 (96/159)	50.2 (130/259)	40.9 (72/176)	0.002
Total	**n**	289	491	261	
	Osteoporosis (%)	52.6 (152/289)	41.1 (202/491)	33.0 (86/261)	< 0.001

Notes: [a]The chi-squared test was used to compare the prevalence between the three BMI groups. $P < 0.05$ was considered statistically significant.
Abbreviation: BMI, body mass index.

by DXA scan. When considering osteoporosis diagnosed on the basis of lumbar DXA, 39 patients (41.1%) had either osteopenic or normal T-scores, and 52 patients (54.7%) were not diagnosed with osteoporosis on hip DXA.

Discussion

In recent times, LDD are receiving greater attention with the increase in aging population, which experience significant pain, lower limb radiation pain and decreased quality of life. Consequently, it has been reported that LDD predispose patients to osteoporosis, and the results of the current study were in line with those of prior studies.[1,4,17] Among patients aged ≥50 years undergoing lumbar fusion for LDD, 42.3% had osteoporosis, and women were more susceptive to osteoporosis than men. The prevalence of osteoporosis in these patients was significantly higher than in the general population in Chinese mainland, affecting about 29.1% women and 6.5% men.[3] When stratifying these subjects into different age groups, we found a remarkable increase in the prevalence of osteoporosis with age in females. These differences between both sexs could be attributed to low levels of oestrogen and subsequently a rapid decrease of BMD in postmenopausal women.

Table 4 Diagnosis According to Lumbar DXA and Hip DXA

Lumbar DXA	Hip DXA		
	Osteoporosis	**Osteopenia**	**Normal**
Osteoporosis	153	194	8
Osteopenia	75	237	68
Normal	10	159	137

Abbreviation: DXA, dual-energy X-ray absorptiometry.

We also reported that most LDD patients were diagnosed as having osteoporosis based on DXA measurements of the vertebrae L1. Among the lumbar vertebrae L1–L4, approximately 60% of the cases had the lowest T-scores at L1. Besides, if the absolute value of T-score differences is greater than 1.0 between the adjacent vertebral segments, at least one of the two bodies has unreliable T-score. Unreliable lumbar T-scores were more common in the lower lumbar spinal segments, namely the L3–L4 segment, which also confirms the notion that lower segments have more severe lumbar degenerative changes, and therefore have more unreliable T-scores.[18] As is well known, the lumbar spine mainly plays

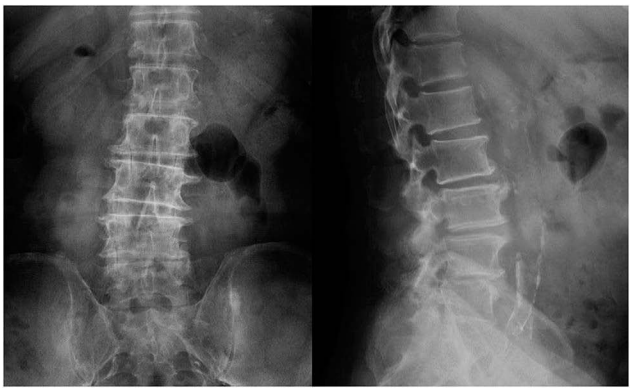

Figure 1 The anteroposterior and lateral X-ray images of a 68-year-old woman diagnosed with lumbar spinal stenosis. The T-scores of L1-L4 in the 68-year-old woman were −0.8, 0.4, 1.9 and 3.4, respectively. She had 3 abnormal segments with unreliable T-scores whose absolute value of T-score differences were all more than 1.0. From the anteroposterior and lateral X-ray images of the patient, we could observe obvious degenerative changes such as vertebral osteophytes and abdominal aortic calcifications, especially at lower segments.

a significant role in weight bearing, which suggests that lower lumbar vertebrae being under more mechanical load causes reactive hyperplasia and degenerative changes of the vertebral bone; as a result, DXA measurements of these vertebrae cannot reflect accurate bone density. This may also explain lumbar disc herniation and spondylolisthesis being the most common at L4/L5 levels in both men and women.[19,20] In agreement with prior studies,[21] greater variation in T-scores is frequently seen in patients with more severe lumbar degeneration (Figure 1), particularly in the elderly aged ≥70 years, obese individuals and patients with degenerative scoliosis. Blake et al[21] also found that T-score differences can be seen in younger women, which is likely to be caused by measurement errors related to soft tissue distribution in the scan field. Moreover, DXA is insufficient in evaluating bone strength and fracture risk in patients with LDD;[22] this is because nearly one-third of patients with vertebral compression fracture are not diagnosed as having osteoporosis, and T-scores measured by lumbar or hip DXA for about 40–50% of patients with a lumbar fragility fracture show them in the osteopenic or normal range. It further indicates the questionable credibility of DXA scans in LDD patients.

When lumbar and hip DXA measurements were separately used to identify osteoporosis, the diagnostic results of both were concordant only in 50% of patients. This discordance between lumbar and hip DXA measurements has also been pointed out in previous cross-sectional studies.[23,24] It is most likely because lumbar degenerative changes mainly affect lumbar DXA measurements.[23,24] Pappou et al[24] suggested that lumbar BMD values were less sensitive for monitoring osteoporosis than hip values in aging patients, whereas our study showed that among patients with LDD, hip DXA identified fewer osteoporotic patients than lumbar DXA.

To date, several studies have reported that higher BMI plays a crucial role in increasing BMD.[25–28] An increase in BMI may cause greater mechanical load on the lumbar spine, which activates bone formation, thus increasing BMD and consequently delaying the occurrence of osteoporosis.[25,28] A higher BMI means more adipose tissue where oestrogen is mostly produced in men and postmenopausal women, resulting in an increase in BMD.[25,27] Alternatively, low BMI indicates poor nutritional status, directly causing decreased bone density.[27,28] Furthermore, individuals with higher BMI are more likely to have hyperinsulinemia, resulting in increased IGF-1 to promote osteogenesis.[28] The reasons mentioned above may illustrate why BMD increases with BMI. However, to our knowledge, previous conclusions about the correlation between BMI and BMD have been derived from healthy population without lumbar degeneration. Therefore, our study focused on the relationship between the two parameters in patients with LDD. Among patients with LDD, higher BMI is believed to exert a protective effect against osteoporosis as diagnosed on DXA regardless of the sex of the patients. The underlying association may be that higher BMI increases the mechanical load on the lumbar spine and causes more severe lumbar degenerative changes. However, higher BMI may also falsely increase the lumbar BMD value measured by DXA. The hypothesis is consistent with numerous prior studies, wherein the increase in BMI was correlated with a lower trabecular bone score (TBS) that reflects the microarchitecture of trabecular bone[26,27] and is less affected by degenerative-changes in the spine.[11,22]

As previously mentioned, LDD are a set of disorders characterised by the deterioration of the bony structure, morphological changes and subsequently the appearance of symptoms in the lumbar vertebrae, including LSS, degenerative lumbar scoliosis, lumbar disc herniation and lumbar spondylolisthesis.[1,2] These diseases do not exist in isolation. Frequently, they could present together in one patient, or may even be related to each other.[2,29] In addition, osteoporosis has been implicated in the development of vertebral compression fracture and degenerative scoliosis. Our findings corroborate Xu et al's retrospective study,

where they suggested that degenerative scoliosis patients may be predisposed to lower T-scores.[30] Meanwhile, Wang et al reported BMD < −1.85 g/cm^2 as a potential risk factor for the formation of degenerative scoliosis based on LSS.[2] From the above discussion, we detected that osteoporosis and LDD are associated with each other. Patients with LDD are predisposed to osteoporosis due to lack of exercise, and osteoporosis may lead to degenerative scoliosis.

In clinical practice, there are alternatives to DXA scan for evaluating osteoporosis, with the most common ones being quantitative computed tomography (QCT) and lumbar computed tomography (CT) which have been studied more recently. Vertebral volumetric BMD measured by QCT[31,32] and bone density of trabecular bone reflected by the CT value[33] can provide more accurate BMD values by avoiding cortical bone and degenerative structure. However, it is difficult to implement QCT in most hospitals because of its high radiation exposure and particular requirement of software,[31] and the use of CT value is hindered by the lack of common standards. Therefore, we still need to use DXA scan to diagnose osteoporosis, but we have to be very cautious about interpreting DXA measurements, particularly for L3–L4. Moreover, the combination of DXA and CT value of the lumbar vertebral body has been recommended to reduce the missed diagnosis of osteoporosis in degenerative lumbar spine.[1]

There are some limitations in this study. First, the patients undergoing lumbar fusion for LDD in present study mostly came from Beijing and its surrounding areas, and their prevalence of osteoporosis could not represent that of all the patients in Chinese mainland. Second, this is a retrospective, single-centre analysis and a multicentre study may be needed to obtain more information about the prevalence of osteoporosis in patients with LDD.

Conclusion

In conclusion, female, older age and low BMI are the risk factors for osteoporosis in patients undergoing lumbar fusion for LDD. Osteoporosis apparently increases the risk of degenerative scoliosis in patients with LDD. Lower lumbar segments, such as L3–L4, are more likely to have unreliable T-scores. Patients with older age, higher BMI or degenerative scoliosis have more abnormal segments with unreliable T-scores. Lumbar DXA measurements are not sensitive enough to identify patients with vertebral fracture.

Abbreviations

DXA, dual-energy X-ray absorptiometry; LDD, lumbar degeneration diseases; LSS, lumbar spinal stenosis; BMD, bone mineral density; BMI, body mass index; WHO, World Health Organization; ISCD, International Society for Clinical Densitometry; SD, standard deviation; ANOVA, analysis of variance; TBS, trabecular bone score; IGF-1, insulin-like growth factors-1; QCT, quantitative computed tomography; CT, computed tomography.

Disclosure

The authors report no conflicts of interest in this work.

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