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CORRELATION BETWEEN DEGENERATIVE LUMBER SPINE DISEASES (SPONDYLOLISTHESIS, RETROLISTHESIS AND SPINAL STENOSIS) WITH BONE MINERAL DENSITY AND TRABECULAR BONE SCORE: CASE-CONTROL STUDY

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ABSTRACT

Background: Degenerative lumbar spine diseases are among the leading causes of low back pain and disability worldwide. Bone mineral density and trabecular bone score are important indicators of bone quantity and microarchitecture, respectively. However, the correlation between individual degenerative lumbar spine diseases and these bone health parameters remains controversial because previous studies have reported inconsistent findings. **Objectives:** To investigate the correlation between lumber spinal degenerative diseases with bone mineral density and trabecular bone score, specifically degenerative spondylolisthesis, retrolisthesis, and lumbar spinal stenosis. **Patients and methods:** A hospital-based case-control study was conducted at Al-Basrah Teaching Hospital, Basrah, Iraq, between June 2025 to June 2026. Demographic and clinical data were collected, and lumbar spine radiographs, computed tomography, and magnetic resonance imaging were used to identify degenerative spinal disorders. Bone mineral density and trabecular bone score were assessed using dual-energy X-ray absorptiometry. Statistical analysis was performed using the Statistical Package for the Social Sciences version 31, and a probability value of less than 0.05 was considered statistically significant. **Results:** A total of 781 participants were included, including 521 patients with degenerative lumbar spine diseases and 260 healthy controls. The majority of participants were females 649 (83.1%), while males accounted for 132 (16.9%). Lumbar spinal stenosis was the most common degenerative disorder, affecting 289 (37.0%) participants, followed by degenerative spondylolisthesis 223 (28.6%), and retrolisthesis 9 (1.15%). The L4–L5 level was the most frequently affected spinal segment, occurring in 258 (33.0%) cases. Degenerative spondylolisthesis demonstrated significant negative correlations with both bone mineral density ($r = -0.336$, $P < 0.001$) and trabecular bone score ($r = -0.385$, $P < 0.001$) and was significantly associated with BMD and TBS categories. Lumbar spinal stenosis showed a significant negative correlation with trabecular bone score ($r = -0.230$, $P = 0.009$) and significant associations with both BMD and TBS categories. Retrolisthesis showed no significant correlations or associations with either bone mineral density or trabecular bone score. There was no significant association between the affected spinal level and BMD ($P = 0.220$) or TBS ($P = 0.378$). **Conclusions**: Degenerative spondylolisthesis demonstrated the strongest relationship with bone health, showing significant correlations and associations with both bone mineral density and trabecular bone score. Lumbar spinal stenosis showed a weaker but significant relationship with bone health, including significant associations with both bone mineral density and trabecular bone score categories and a significant negative correlation with trabecular bone score, whereas retrolisthesis was not significantly related to either parameter. Trabecular bone score provided complementary information to bone mineral density in assessing bone quality in patients with degenerative lumbar spine diseases. The reasons behind this study are that osteoporosis and osteopenia can contribute to chronic back pain.

Therefore, when decompression surgery is performed for a patient with spinal stenosis, and the patient continues to complain of pain after surgery, the pain may be related to weakened vertebrae due to reduced bone mineral density rather than the surgery itself. The second reason is that when spinal fixation is performed, bone quality must be taken into consideration. In patients with poor bone quality, the surgeon may need to use larger screws, modify the screw trajectory, or use bone cement augmentation to achieve better fixation and adequate bone purchase, thereby improving the stability of the instrumentation. Therefore, patients with degenerative spinal diseases, particularly those with spondylolisthesis and spinal stenosis, should be considered for screening for osteoporosis and osteopenia to facilitate early identification and appropriate management.

KEYWORDS: Bone mineral density; Lumbar spine; Osteoporosis; Retrolisthesis; Spondylolisthesis; Stenosis; Trabecular bone score.

1-INTRODUCTION

The term osteoporosis, meaning “porous bone”, was initially used by the French doctor Jean Lobstein in the early 19th century. It is derived from the Greek terms osteon (bone) and poros (pore or tiny hole), and was first used to describe the porous aspect of bone detected during pathological examination. The word had been used for many years, but osteoporosis was not recognized as a separate clinical condition until the twentieth century, when advances in bone biology and imaging enhanced knowledge of its aetiology and diagnosis.[1]

Osteoporosis is a serious health problem characterized by decreased bone strength and an increased risk of fragility fractures. The condition is generally asymptomatic until a fracture develops, therefore it goes undiagnosed and untreated, especially in low- and middle-income countries. In Iraq, lack of awareness among healthcare professionals and the general public leads to delayed diagnosis and inadequate treatment. Furthermore, undiagnosed osteoporosis has been linked to poor outcomes in orthopedic and spinal surgery, such as implant failure, delayed bone healing, and revision procedures. These results emphasize the need of early detection, regular screening of high-risk people, and enhanced osteoporosis education for medical staffs and patients.[1-2]

The strength of bones is dependent upon both bone mineral density and bone microarchitecture. Estrogen is essential for the development of maximal bone mass during adolescence and the subsequent preservation of skeletal integrity in maturity. Bone mass progressively decreases in both genders after the age of 30, with postmenopausal women experiencing accelerated bone loss due to estrogen deficiency.[2-3]

Dual-energy X-ray absorptiometry (DXA) continues to be the standard method used for evaluating bone mineral density, whereas the Trabecular Bone Score (TBS) is an indirect evaluation of trabecular microarchitecture based on lumbar spine DXA images. Lower TBS values suggest decline in trabecular bone quality, which is related with lower T-scores and an increased risk of fragility fractures, especially in postmenopausal women. As a result, TBS complements bone mineral density evaluation by enhancing fracture risk assessment.[3-4]

Osteoporosis and degenerative diseases of the spine are regarded discrete disorders with different pathophysiological mechanisms. However, the link between bone mineral density and degenerative spinal disorders like spondylolisthesis, retrolisthesis and spinal stenosis remains questionable. Conflicting results have been observed in previous studies, with some reporting decreased bone mineral density in affected patients, while others have reported increased bone mineral density or no significant association.[5-6]

Degenerative spine disease is a spectrum of age-related changes affecting the vertebrae, intervertebral discs, and surrounding spinal tissue structures. The development and progression of degenerative spine diseases are influenced by a variety of risk factors, such as an aging population, female gender, obesity, a heavy physical workload, smoking, genetic predisposition, and a decrease in bone mineral density. The burden of these disorders is anticipated to increase significantly as life expectancy continues to rise globally. This will result in significant socioeconomic challenges due to increased healthcare utilization, work absenteeism, and disability. Nevertheless, degeneration becomes clinically significant when it results in symptoms such as neurological deficits, spinal instability, or back pain. Medical imaging is important for detecting degenerative changes, assessing disease severity, and directing treatment.[3,7]

The prevalence of lumbar degenerative spine disease varies by geographical region and population, reflecting changes in demographics, socioeconomic status, occupational exposure, and access to healthcare. Low back pain, the most common symptom of various degenerative spinal disorders, continues to be the primary cause of disability across the world, resulting in a significant health and financial cost.[8]

The aim of this study is to investigate the correlation between lumber spinal degenerative diseases with bone mineral density and trabecular bone score, specifically degenerative spondylolisthesis, retrolisthesis, and lumbar spinal stenosis.

2-PATIENTS AND METHODS

A hospital-based observational case-control study was conducted at the Orthopedic and Spine Clinics of Al-Basrah Teaching Hospital, Basrah, Iraq, over a 12-month period from June 2025 to June 2026. The study included

781 participants, comprising 521 patients presenting with symptoms and radiological evidence of degenerative lumbar spine disease and 260 healthy controls matched according to age.

Eligible participants were aged ≥40 years, had one or more degenerative lumbar spine disorders, had undergone dual-energy X-ray absorptiometry (DXA) for bone mineral density (BMD) assessment, and had complete clinical, radiological, BMD, and trabecular bone score (TBS) data.

Patients with acute vertebral fractures or spinal trauma, congenital spinal deformities, spinal infection, primary or secondary spinal tumors, inflammatory spinal diseases such as ankylosing spondylitis, metabolic diseases other than osteoporosis, or incomplete clinical or radiological records were excluded.

Ethical approval was obtained from the Ethical Committee of the University of Basrah, College of Medicine (No. 030409-020-2026), and approval was also obtained from the Basrah Directorate of Health and the administration of Basrah Teaching Hospital. The nature and scope of the study were explained to the participants, informed consent was obtained before data collection, and confidentiality of the collected information was maintained.

Demographic and clinical data, including age, sex, occupation, body weight, height, body mass index, smoking status, and relevant medical comorbidities, were collected prospectively using a structured data collection form. Relevant comorbidities included hypertension, diabetes mellitus, ischemic heart disease, abdominal aortic calcification, and asthma.

Radiological assessment included standing lumbar spine radiographs, including standing, flexion, and extension views, together with computed tomography and magnetic resonance imaging. Lumbar radiographs were obtained according to a standardized protocol centered on the lumbosacral spine and were evaluated by a single observer for degenerative radiographic features. The presence of degenerative spondylolisthesis, retrolisthesis, lumbar spinal stenosis, disc prolapse, and the affected vertebral level was documented.

Bone mineral density of the lumbosacral spine was measured using a GE Lunar Prodigy Advance densitometer with its dedicated Encore version 17 software by an experienced operator. Both anteroposterior and lateral projections were obtained to evaluate the vertebral bodies and posterior elements, using array mode and single-beam mode, respectively. Bone density values were calculated using the scanner software's default analysis mode.

According to the World Health Organization classification criteria for adult bone mineral density, osteoporosis was defined as a T-score ≤−2.5 standard deviations below the mean lumbar spine BMD. Osteopenia was defined as a T-score between −1.0 and −2.5 standard deviations, whereas a T-score >−1.0 was considered normal bone mineral density.

Trabecular bone score was assessed by reanalyzing the anteroposterior lumbar spine DXA scans from L1–L4 using TBS Insight software version 3.0.3.0. The same regions of interest used for BMD assessment were applied to the TBS evaluation. The final TBS value was calculated as the mean of the individual vertebral measurements from L1 to L4 and their relevant combinations. Participants were categorized into three groups according to TBS values: normal microarchitecture (TBS ≥1.35), partially degraded microarchitecture (TBS 1.20–1.35), and fully degraded microarchitecture (TBS <1.20).

The collected clinical and radiological variables were entered into the study database and analyzed to assess their associations with bone mineral density and trabecular bone score. The primary radiological variables included degenerative spondylolisthesis, retrolisthesis, lumbar spinal stenosis, disc prolapse, and the affected lumbar vertebral level.

Statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS), version 31.0. Continuous variables were expressed as mean ± standard deviation (SD), whereas categorical variables were presented as frequencies and percentages. Comparisons between continuous variables were performed using the independent-samples Student's t-test, while categorical variables were compared using the Chi-square test or Fisher's exact test, as appropriate. For comparisons involving more than two groups, one-way analysis of variance (ANOVA) was applied. Correlations between BMD, TBS, and the studied variables were assessed using Pearson's or Spearman's correlation coefficient according to the distribution of the data. A P-value of <0.05 was considered statistically significant.

3-RESULTS

Table 3.1 shows the demographic, anthropometric, medical, and spinal characteristics of the study participants. The mean age of the participants was 61.29 ± 9.01 years. Females constituted the majority of the study population, accounting for 649 (83.1%), compared with 132 (16.9%) males, giving a female-to-male ratio of approximately 4.9: 1. The mean BMI was 24.41 ± 2.01 kg/m². Regarding occupation, housewives were the predominant group (83.1%), followed by retired participants (9.3%) and employees (7.2%), while heavy workers represented only 0.4% of the study population. Regarding medical history, hypertension was the most frequent comorbidity, reported in 42.1%, followed by diabetes mellitus (27.0%). Ischemic heart disease, abdominal aortic calcification, and asthma were less frequently reported, occurring in 3.2%, 3.1%, and 0.6%,

respectively. Active smoking was reported in 2.7% of participants. Furthermore, among the degenerative spinal disorders, lumbar spinal stenosis was the most common diagnosis, affecting 289 (37.0%) participants, followed by degenerative spondylolisthesis in 223 (28.6%) and retrolisthesis in 9 (1.15%). Regarding the affected spinal levels, L4–L5 was the most frequently involved level (33.0%), followed by combined involvement of L3–L4 and L4–L5 (15.4%) and L5–S1 (9.9%). Other single or combined spinal levels were less frequently affected.

Table 3.1: Demographic and anthropometric characteristics, past medical history, and distribution of degenerative spine diseases and affected spinal levels (n = 781).

Variable	Number (%) / Mean ± SD
Age (years)	61.29 ± 9.01
Male	132 (16.9%)
Female	649 (83.1%)
Body Mass Index (kg/m²)	24.41 ± 2.01
Housewife	649 (83.1%)
Heavy worker	3 (0.4%)
Retired	73 (9.3%)
Employee	56 (7.2%)
Active smoking	21 (2.7%)
Hypertension	329 (42.1%)
Diabetes mellitus	211 (27.0%)
Ischemic heart disease	25 (3.2%)
Abdominal aortic calcification	24 (3.1%)
Asthma	5 (0.6%)
Degenerative spondylolisthesis	223 (28.6%)
Retrolisthesis	9 (1.15%)
Lumbar spinal stenosis	289 (37.0%)
L1–L2	1 (0.1%)
L2–L3	2 (0.3%)
L3–L4	45 (5.8%)
L4–L5	258 (33.0%)
L5–S1	77 (9.9%)
L2–L3 and L4–L5	1 (0.1%)
L2–L3 and L3–L4	6 (0.8%)
L3–L4 and L4–L5	120 (15.4%)
L3–L4 and L5–S1	1 (0.1%)
L4–L5 and L5–S1	7 (0.9%)
L2–L3, L3–L4 and L4–L5	3 (0.4%)

Table 3.2 demonstrates the distribution of participants according to BMD and TBS categories. Regarding BMD, the majority of participants had normal BMD, accounting for 527 (67.5%), while 172 (22.0%) had osteopenia and 82 (10.5%) had osteoporosis. Thus, approximately one-third of the study population (32.5%) had reduced BMD, including osteopenia or osteoporosis. In contrast, the distribution according to TBS demonstrated a greater proportion of impaired bone microarchitecture. Only 91 (11.7%) of participants had a normal TBS, whereas 421 (53.9%) had partially degraded trabecular microarchitecture and 269 (34.4%) had degraded microarchitecture. Therefore, abnormalities in trabecular bone microarchitecture were considerably more frequent than low BMD in this study population.

Table 3.2: Distribution of the study participants according to their bone mineral density and trabecular bone score categories (n = 781).

Variable	Category	Number	Percent
Bone mineral density	Normal	527	67.5%
	Osteopenia	172	22.0%
	Osteoporosis	82	10.5%
Trabecular bone score	Normal	91	11.7%
	Partially degraded	421	53.9%
	Degraded	269	34.4%

Table 3.3 compares cases and controls regarding demographic, anthropometric, and medical characteristics. The mean age was 61.71 ± 8.78 years among cases and 59.22 ± 9.09 years among controls,

with no statistically significant difference (P = 0.139). Similarly, there was no statistically significant difference in sex distribution (P = 0.093) or BMI (P = 0.342) between the two groups. Occupation differed significantly between cases and controls (P = 0.028), with housewives representing the largest occupational group in both groups. Active smoking did not differ significantly between cases and controls (P = 0.430). Additionally, several medical characteristics showed statistically significant differences. Hypertension was significantly more frequent among cases than controls (47.6% vs. 31.15%, P < 0.001), as was diabetes mellitus (30.71% vs. 19.61%, P < 0.001). Ischemic heart disease was also significantly more frequent among cases (4.6% vs. 0.4%, P = 0.021). Similarly, abdominal aortic calcification was significantly more frequent among cases (4.6% vs. 0%, P = 0.009). Asthma did not show a statistically significant difference between the two groups (P = 0.131).

Table 3.3: Comparison between cases and controls regarding their demographic, anthropometric, and past medical history characteristics (n = 781).

Variable	Cases = 521, number (%)	Controls = 260, number (%)	P value
Age, mean ± standard deviation	61.71 ± 8.78	59.22 ± 9.09	0.139
Male	81 (15.5%)	51 (19.6%)	0.093
Female	440 (84.5%)	209 (80.4%)	
Body mass index, mean ± standard deviation	24.89 ± 2.41	24.21 ± 1.97	0.342
Housewife	439 (84.3%)	210 (80.8%)	0.028
Heavy worker	3 (0.4%)	0 (0%)	
Retired	51 (9.8%)	22 (8.5%)	
Employee	28 (5.5%)	28 (10.7%)	
Active smoking	15 (2.9%)	6 (2.3%)	0.430
Hypertension	248 (47.6%)	81 (31.15%)	<0.001
Diabetes mellitus	160 (30.71%)	51 (19.61%)	<0.001
Ischemic heart disease	24 (4.6%)	1 (0.4%)	0.021
Abdominal aortic calcification	24 (4.6%)	0 (0%)	0.009
Asthma	5 (1.0%)	0 (0%)	0.131

Table 3.4 demonstrates the association between the major degenerative spinal diseases and BMD and TBS categories. Degenerative spondylolisthesis showed a statistically significant association with BMD category (P < 0.001). The proportion of participants with degenerative spondylolisthesis was higher in the osteopenia and osteoporosis categories than in the normal BMD category. A similarly significant association was observed between degenerative spondylolisthesis and TBS category (P < 0.001), with a markedly greater proportion occurring among participants with degraded trabecular microarchitecture. Moreover, lumbar spinal stenosis also demonstrated a statistically significant association with BMD category (P < 0.001) and TBS category (P < 0.001). The occurrence of lumbar spinal stenosis was greater among participants with osteopenia and those with degraded or partially degraded trabecular microarchitecture compared with those having normal measurements. In contrast, retrolisthesis was not significantly associated with either BMD (P = 0.148) or TBS (P = 0.107). These findings indicate that, within the present study population, degenerative spondylolisthesis and lumbar spinal stenosis demonstrated significant relationships with measures of bone quantity and microarchitecture, whereas retrolisthesis did not.

Table 3.4: Association between degenerative spine diseases and bone mineral density and trabecular bone score categories.

Variable	BMD Normal = 527	BMD Osteopenia = 172	BMD Osteoporosis = 82	BMD P value	TBS Normal = 91	TBS Partially degraded = 421	TBS Degraded = 269	TBS P value
Degenerative spondylolisthesis	90 (17.1%)	78 (45.3%)	55 (67.1%)	<0.001	4 (4.4%)	90 (21.4%)	129 (48.0%)	<0.001
Retrolisthesis	5 (0.9%)	4 (2.3%)	0 (0%)	0.148	2 (0.5%)	2 (0.5%)	5 (1.9%)	0.107
Lumbar spinal stenosis	170 (32.3%)	90 (52.3%)	29 (35.4%)	<0.001	25 (27.5%)	129 (30.6%)	135 (50.2%)	<0.001

Table 3.5 presents the relationship between the affected spinal level and BMD and TBS categories among cases. The L4–L5 level was the most frequently affected level across the different BMD and TBS categories, particularly among participants with osteoporosis and degraded TBS. However, the overall association between affected spinal level and BMD category was not statistically significant (P = 0.220). Similarly, there was no statistically significant association between affected spinal level and TBS category (P = 0.378). Although

differences in the distribution of affected levels were observed across BMD and TBS categories, these differences did not reach statistical significance. Therefore, the present findings do not demonstrate a significant relationship between the specific spinal level affected by degenerative disease and either BMD or trabecular bone microarchitecture.

Table 3.5: Association between affected spinal level and bone mineral density and trabecular bone score categories among cases (n = 521).

Variable	BMD Normal	BMD Osteopenia	BMD Osteoporosis	TBS Normal	TBS Partially degraded	TBS Degraded
L1–L2	1 (0.2%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (0.4%)
L2–L3	1 (0.2%)	1 (0.6%)	0 (0%)	0 (0%)	0 (0%)	2 (0.7%)
L3–L4	22 (4.2%)	17 (9.9%)	6 (7.3%)	2 (2.2%)	15 (3.6%)	28 (10.4%)
L4–L5	133 (25.23%)	78 (45.3%)	47 (57.3%)	21 (23.1%)	105 (24.9%)	132 (49.1%)
L5–S1	33 (6.3%)	30 (17.4%)	14 (17.1%)	3 (3.3%)	33 (7.8%)	41 (15.2%)
L2–L3 and L4–L5	1 (0.2%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	1 (0.4%)
L2–L3 and L3–L4	4 (0.8%)	1 (0.6%)	1 (1.2%)	0 (0%)	3 (0.7%)	3 (1.1%)
L3–L4 and L4–L5	66 (12.5%)	40 (23.3%)	14 (17.1%)	4 (4.4%)	55 (13.1%)	61 (22.7%)
L3–L4 and L5–S1	0 (0%)	0 (0%)	1 (1.2%)	0 (0%)	0 (0%)	1 (0.4%)
L4–L5 and L5–S1	3 (0.6%)	4 (2.3%)	0 (0%)	0 (0%)	6 (1.4%)	1 (0.4%)
L2–L3, L3–L4 and L4–L5	0 (0%)	3 (1.7%)	0 (0%)	0 (0%)	3 (0.7%)	0 (0%)

P value: BMD = 0.220; TBS = 0.378.

Table 3.6 demonstrates the correlations between degenerative spinal diseases and BMD and TBS. Degenerative spondylolisthesis showed a moderate negative correlation with BMD ($r = -0.336$, $P < 0.001$) and a slightly stronger negative correlation with TBS ($r = -0.385$, $P < 0.001$). These findings indicate that the presence of degenerative spondylolisthesis was associated with lower BMD and poorer trabecular bone microarchitecture. Retrolisthesis showed very weak negative correlations with both BMD ($r = -0.037$, $P = 0.304$) and TBS ($r = -0.051$, $P = 0.152$), neither of which was statistically significant. Lumbar spinal stenosis showed a very weak, non-significant negative correlation with BMD ($r = -0.028$, $P = 0.431$). However, its correlation with TBS was negative and statistically significant ($r = -0.230$, $P = 0.009$), indicating an association between lumbar spinal stenosis and poorer trabecular bone microarchitecture despite the absence of a significant correlation with BMD.

Table 3.6: Correlation between degenerative spine diseases with bone mineral density and trabecular bone score.

Variable	BMD Correlation coefficient	BMD P value	TBS Correlation coefficient	TBS P value
Degenerative spondylolisthesis	−0.336	<0.001	−0.385	<0.001
Retrolisthesis	−0.037	0.304	−0.051	0.152
Lumbar spinal stenosis	−0.028	0.431	−0.230	0.009

4- DISCUSSION

In the present study, the mean age of the 781 participants was 61.29 ± 9.01 years, and females constituted the majority of the study population (83.1%). The predominance of older participants is consistent with the established age-related increase in degenerative spinal disorders. Population-based data have shown that the prevalence of spine degeneration increases progressively with age, particularly among older adults.[9] The marked female predominance in the current study may partly reflect the high proportion of older women in the study population and the greater burden of age-related skeletal deterioration among postmenopausal women. Previous research has also demonstrated comparable gender differences in degenerative lumbar disease and spine surgery populations.[10]

The mean BMI in the current study was 24.41 ± 2.01 kg/m², indicating that most participants were not markedly obese. Occupational distribution was dominated by housewives, while heavy workers represented only 0.4% of the study population. Although occupation differed significantly between cases and controls, the very small number of heavy workers limits interpretation of the effect of heavy occupational loading. A systematic review and meta-analysis has reported an association between occupational loading and imaging-defined spinal degeneration, particularly with repeated or substantial mechanical exposure.[11]

Hypertension and diabetes mellitus were the most frequent medical comorbidities in the study population and were significantly more common among cases than controls. Ischemic heart disease and abdominal aortic calcification were also significantly more frequent

among cases. These findings support the concept that degenerative spinal disease may be influenced by systemic metabolic and vascular factors rather than being exclusively a local mechanical process. Previous studies have linked diabetes, hypertension, cardiovascular disease, and vascular calcification with degenerative changes of the lumbar and thoracolumbar spine, potentially through chronic inflammation, endothelial dysfunction, impaired microcirculation, and altered nutrient supply to the intervertebral disc and vertebral endplates.[12,13] Smoking did not differ significantly between the two groups in the present study, while asthma was uncommon and showed no significant association. The small number of smokers and participants with asthma may have limited the ability to detect meaningful associations.

Lumbar spinal stenosis was the most common degenerative disorder in the present study, affecting (37.0%) of participants, followed by degenerative spondylolisthesis (28.6%) and retrolisthesis (1.15%). The L4–L5 level was the most frequently affected single level (33.0%), followed by L5–S1 (9.9%) and L3–L4 (5.8%), while combined L3–L4 and L4–L5 involvement accounted for 15.4%. This distribution is compatible with the recognized mechanical vulnerability of the lower lumbar motion segments. Previous population and clinical studies have reported a high burden of degenerative lumbar disorders and a predominance of degenerative vertebral translation at the L4–L5 level.[9,14]

In the present study, (67.5%) of participants had normal BMD, whereas (22.0%) had osteopenia and (10.5%) had osteoporosis, meaning that (32.5%) had reduced BMD. In contrast, only (11.7%) had normal TBS, while (53.9%) had partially degraded and 34.4% had degraded trabecular microarchitecture. Thus, abnormal TBS was considerably more frequent than reduced BMD. This finding supports the complementary role of TBS in evaluating skeletal quality because BMD quantifies bone mineral quantity, whereas TBS provides information related to trabecular microarchitecture.[15] The discrepancy between BMD and TBS in the current population suggests that relying on BMD alone may fail to identify some patients with impaired skeletal microarchitecture.

Degenerative spondylolisthesis demonstrated the strongest relationship with bone health in the present study. It was significantly associated with both BMD and TBS categories ($P < 0.001$ for each) and showed significant negative correlations with BMD ($r = -0.336$, $P < 0.001$) and TBS ($r = -0.385$, $P < 0.001$). The slightly stronger correlation with TBS suggests that trabecular microarchitectural deterioration may be particularly relevant in patients with degenerative spondylolisthesis. A systematic review has described a complex interaction between vertebral osteoporosis and lumbar degenerative changes, supporting the possibility that reduced vertebral bone quality may influence spinal mechanics and degeneration.[16]

Lumbar spinal stenosis also demonstrated significant associations with both BMD and TBS categories ($P < 0.001$ for each). However, its correlation with BMD was not statistically significant ($r = -0.028$, $P = 0.431$), whereas its correlation with TBS was weak but statistically significant ($r = -0.230$, $P = 0.009$). This pattern further emphasizes that TBS may provide additional information about skeletal status that is not fully reflected by areal BMD. TBS is recognized as a complementary DXA-derived parameter that can contribute to fracture-risk assessment and characterization of bone quality.[15,17]

In contrast, retrolisthesis showed no significant association with either BMD or TBS and no significant correlation with either parameter. This finding should be interpreted cautiously because only nine participants had retrolisthesis, substantially reducing the statistical power for detecting an association. Differences in the biomechanical and pathological mechanisms underlying retrolisthesis and degenerative spondylolisthesis may also contribute to the different findings.[14,16]

The affected spinal level was not significantly associated with either BMD category ($P = 0.220$) or TBS category ($P = 0.378$). Although L4–L5 was the predominant level across several bone-quality categories, the absence of statistical significance suggests that reduced bone quality may represent a generalized skeletal characteristic rather than a localized phenomenon restricted to a particular degenerative level. This interpretation is compatible with evidence that TBS reflects overall skeletal trabecular microarchitecture and complements BMD rather than representing a purely site-specific marker of degenerative change.[15,17] The findings have practical implications for patients being considered for spinal intervention. Osteoporosis and impaired bone quality are relevant concerns in patients undergoing spinal surgery because poor bone stock may compromise implant purchase and increase the risk of fixation-related complications. A systematic review and meta-analysis demonstrated a substantial burden of osteoporosis among older patients undergoing spinal surgery, while a narrative review emphasized the importance of recognizing poor bone quality when planning spinal instrumentation.[18,19] Therefore, assessment of BMD together with TBS may be useful, particularly in patients with degenerative spondylolisthesis or lumbar spinal stenosis. When poor bone quality is identified, appropriate surgical planning, including optimization of fixation strategy and consideration of augmentation techniques when indicated, may help improve construct stability.[19]

The study has several limitations. First, because patients were assessed at a single time point, the study was able to identify correlations between degenerative lumbar

spine diseases, bone mineral density, and trabecular bone score, but it was unable to determine whether impaired bone quality preceded or resulted from the degenerative changes. Second, bone quality was determined using DXA-derived bone mineral density and trabecular bone score, while advanced techniques for assessing bone microarchitecture, such as high-resolution peripheral quantitative computed tomography (HR-pQCT), were not available. Third, bone mineral density and trabecular bone score were only assessed at the lumbar spine. However, degenerative changes may affect lumbar DXA findings despite the use of TBS, so assessing other skeletal sites like proximal femur could provide more comprehensive assessment of skeletal health. Finally, biochemical markers of bone metabolism, such as serum vitamin D, parathyroid hormone, and bone turnover markers, were not investigated. Consequently, it was impossible to determine whether the observed correlations between degenerative lumbar spine diseases, bone mineral density, and trabecular bone score were influenced by underlying metabolic bone abnormalities.

5- CONCLUSION AND RECOMMENDATION

Degenerative lumbar spine diseases were predominantly observed in older females, with L4–L5 being the most frequently affected level. Reduced BMD was present in 32.5% of participants, whereas abnormal TBS was considerably more frequent (88.3%). Degenerative spondylolisthesis showed the strongest relationship with both BMD and TBS, while lumbar spinal stenosis was significantly associated with both measures and showed a significant negative correlation with TBS. Retrolisthesis showed no significant relationship with BMD or TBS, although its small sample size limits interpretation. The affected spinal level was not significantly associated with BMD or TBS. Hypertension, diabetes mellitus, ischemic heart disease, and abdominal aortic calcification were more frequent among cases. Overall, TBS provided complementary information to BMD in assessing bone quality. Therefore, patients with degenerative lumbar spine disease, particularly those with degenerative spondylolisthesis or lumbar spinal stenosis, should be considered for BMD and TBS assessment for early detection of impaired bone quality, especially before spinal fixation. In patients with poor bone quality, fixation strategies should be individualized and appropriate augmentation techniques considered when indicated. Larger multicenter and longitudinal studies are recommended to further clarify the relationship between bone quality and degenerative spinal disease.

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