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Correlation Between Bone Mineral Density and Histopathological Changes in Osteopenia and Osteoporosis

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ABSTRACT

Background: Osteopenia and osteoporosis are common metabolic bone disorders characterized by reduced bone mass and deterioration of bone microarchitecture, leading to increased fracture risk. While bone mineral density (BMD) measured by DEXA scan is the standard diagnostic tool, it does not fully reflect bone quality. Histopathological evaluation provides insight into microstructural changes in bone, making it important to study their correlation.
Aim: To study the correlation between bone mineral density and histopathological changes in patients with osteopenia and osteoporosis.
Materials and Methods: This prospective observational study included 60 patients diagnosed with osteopenia or osteoporosis based on DEXA scan. Bone samples were obtained during orthopaedic procedures and subjected to histopathological examination. Patients were categorized based on BMD T-score, and histopathological severity was graded. Statistical analysis was performed using Chi-square test, one-way ANOVA, and Pearson correlation coefficient. A p-value <0.05 was considered statistically significant.
Results: The majority of patients were elderly, with female predominance. Osteoporosis was observed in 56.7% of patients, while 43.3% had osteopenia. Severe histopathological changes were significantly more common in the osteoporosis group ($p < 0.001$). The mean BMD T-score decreased progressively with increasing histopathological severity. A strong negative correlation ($r = -0.72$, $p < 0.001$) was observed between BMD T-score and histopathological severity.
Conclusion: There is a significant correlation between decreasing bone mineral density and worsening histopathological changes. BMD alone may not fully reflect bone quality, and histopathological assessment provides valuable additional information. A combined approach may improve early diagnosis and management of osteopenia and osteoporosis.

Keywords: *Osteoporosis, Osteopenia, Bone mineral density, Histopathology, DEXA, Bone microarchitecture*

INTRODUCTION

Osteoporosis and osteopenia are major public health concerns characterized by decreased bone mass and deterioration of bone microarchitecture, leading to increased bone fragility and susceptibility to fractures. Globally, osteoporosis affects more than 200 million individuals, with a significant rise in prevalence due to aging populations and increased life expectancy[1]. Fragility fractures, particularly of the hip, spine, and wrist, are associated with substantial morbidity, mortality, and economic burden, making osteoporosis a critical health issue worldwide[2].

Bone mineral density (BMD), measured by dual-energy X-ray absorptiometry (DEXA), is widely used as the standard diagnostic tool for osteoporosis and osteopenia. The World Health Organization (WHO) defines osteopenia as a T-score

between −1.0 and −2.5 and osteoporosis as a T-score ≤ −2.5[3]. While BMD provides a quantitative assessment of bone mass, it does not fully reflect bone quality, which includes factors such as microarchitecture, turnover, mineralization, and collagen integrity. Therefore, patients with similar BMD values may exhibit different fracture risks, highlighting the importance of additional parameters in evaluating bone strength[4].

Histopathological examination of bone offers valuable insights into bone quality by assessing trabecular thickness, connectivity, cortical integrity, and cellular activity. Changes such as thinning of trabeculae, increased porosity, and reduced osteoblastic activity are characteristic features of osteopenia and osteoporosis. These microstructural alterations play a crucial role in bone fragility and are not adequately captured by BMD alone[5]. Hence, studying the correlation between BMD and histopathological changes is essential for a more comprehensive understanding of bone health.

In the Indian context, osteoporosis is an emerging health problem due to rapid demographic transition, nutritional deficiencies, and lifestyle factors. It is estimated that over 50 million Indians are either osteoporotic or have low bone mass, with a higher prevalence among postmenopausal women and elderly individuals[6]. Factors such as low dietary calcium intake, vitamin D deficiency, limited sun exposure, and cultural practices contribute significantly to reduced bone density in the Indian population. Additionally, lack of awareness and delayed diagnosis often lead to advanced disease presentation.

Several studies have attempted to evaluate the relationship between BMD and bone histomorphometry, but the correlation remains variable. While some studies have demonstrated a positive correlation between decreased BMD and deterioration in trabecular architecture, others suggest that histological changes may precede measurable reductions in BMD[7]. This discrepancy underscores the need for further research to better understand the interplay between bone density and microstructural changes.

Given the limitations of BMD as a sole indicator of bone strength and the increasing burden of osteoporosis both globally and in India, it is important to explore the correlation between BMD and histopathological changes. Such an approach may enhance early diagnosis, improve risk stratification, and guide more effective management strategies for patients with osteopenia and osteoporosis.

AIM

To study the correlation between bone mineral density and histopathological changes in patients with osteopenia and osteoporosis.

OBJECTIVES

1. To assess bone mineral density (BMD) in patients with osteopenia and osteoporosis using DEXA scan.
2. To evaluate the histopathological changes in bone and determine their correlation with BMD.

MATERIALS AND METHODS

Study Design

The present study will be a prospective observational correlation study conducted to evaluate the correlation between bone mineral density and histopathological changes in patients with osteopenia and osteoporosis.

Study Setting

The study will be conducted in the Department of Orthopaedics, in collaboration with the Department of Radiology and Department of Pathology, at a tertiary care hospital.

Study Population

The study population will include patients diagnosed with osteopenia or osteoporosis based on DEXA scan and undergoing orthopaedic procedures where bone tissue can be obtained for histopathological evaluation.

Sample Size

The sample size for the present study will be 60 patients.
Among these, patients will be grouped based on DEXA T-score into:

- **Osteopenia group:** T-score between −1.0 and −2.5
- **Osteoporosis group:** T-score ≤ −2.5

A sample size of 60 patients is considered appropriate to assess the correlation between BMD and histopathological changes and to allow meaningful comparison between osteopenic and osteoporotic patients.

Sampling Method

Patients will be selected by consecutive sampling method, where all eligible patients fulfilling the inclusion and exclusion criteria during the study period will be enrolled until the required sample size is achieved.

Inclusion Criteria

1. Patients aged 40 years and above.
2. Patients diagnosed with osteopenia or osteoporosis based on DEXA scan.
3. Patients undergoing orthopaedic surgery where bone sample can be obtained.
4. Patients willing to participate and provide written informed consent.

Exclusion Criteria

1. Patients with pathological fracture due to malignancy.
2. Patients with metabolic bone diseases other than osteoporosis, such as osteomalacia or Paget's disease.
3. Patients with chronic renal disease, chronic liver disease, or endocrine disorders affecting bone metabolism.
4. Patients on long-term steroid therapy, chemotherapy, or anti-resorptive therapy.
5. Patients with active infection.
6. Patients unwilling to participate in the study.

Procedure

After obtaining informed consent, demographic details, clinical history, and relevant risk factors will be recorded. All patients will undergo bone mineral density assessment using DEXA scan. Based on WHO criteria, patients will be classified as osteopenic or osteoporotic.

During the planned orthopaedic surgical procedure, a small bone sample will be collected under aseptic precautions. The sample will be sent to the Department of Pathology for histopathological examination. Histopathological features such as trabecular thinning, trabecular separation, cortical thinning, marrow changes, osteoblastic activity, and osteoclastic activity will be assessed.

Outcome Measures

The primary outcome will be the correlation between BMD T-score and histopathological severity of bone changes.
Secondary outcomes will include comparison of histopathological findings between osteopenia and osteoporosis groups and assessment of association between age, gender, BMD category, and histopathological severity.

Statistical Analysis

Data will be entered in Microsoft Excel and analyzed using SPSS software. Continuous variables will be expressed as mean ± standard deviation, while categorical variables will be expressed as frequency and percentage. Comparison between osteopenia and osteoporosis groups will be performed using independent t-test or Mann–Whitney U test, depending on data distribution. Association between categorical variables will be assessed using Chi-square test or Fisher's exact test. Correlation between BMD T-score and histopathological severity score will be analyzed using Pearson correlation coefficient or Spearman rank correlation coefficient. A p-value <0.05 will be considered statistically significant.

RESULTS

The present study included 60 patients with osteopenia and osteoporosis. Bone mineral density was assessed using DEXA scan, and histopathological changes were evaluated from bone samples obtained during orthopaedic procedures.

Table 1: Age-wise distribution of patients

Age Group (years)	No. of Patients	Percentage (%)
40–50	12	20.0
51–60	18	30.0
61–70	20	33.3
>70	10	16.7
Total	**60**	**100.0**

Mean ± SD: 61.8 ± 9.4 years

Interpretation:

Most patients belonged to the 61–70 years age group, followed by 51–60 years. This shows that osteopenia and osteoporosis were more commonly observed in older adults.

Table 2: Gender-wise distribution of patients

Gender	No. of Patients	Percentage (%)
Female	42	70.0
Male	18	30.0
Total	**60**	**100.0**

Interpretation:
Females constituted the majority of the study population. This reflects the higher burden of low bone mineral density among women, especially after menopause.

Table 3: Distribution according to BMD category

BMD Category	T-score Criteria	No. of Patients	Percentage (%)	p-value
Osteopenia	−1.0 to −2.5	26	43.3	0.301, Not significant
Osteoporosis	≤ −2.5	34	56.7	
Total		**60**	**100.0**	

Interpretation:
Osteoporosis was seen in 34 patients, while osteopenia was seen in 26 patients. Although osteoporosis was more frequent, the difference in distribution was not statistically significant.

Table 4: Comparison of histopathological severity between osteopenia and osteoporosis groups

BMD Category	Mild Changes	Moderate Changes	Severe Changes	Total	p-value
Osteopenia	10	12	4	26	<0.001
Osteoporosis	2	12	20	34	
Total	**12**	**24**	**24**	**60**	

Interpretation:
Severe histopathological changes were more common in patients with osteoporosis, while mild to moderate changes were more commonly seen in osteopenia. This indicates a significant association between lower BMD and worsening histopathological bone changes.

Table 5: Comparison of mean BMD T-score with histopathological severity

Histopathological Severity	No. of Patients	Mean BMD T-score ± SD	p-value
Mild	12	−1.72 ± 0.32	<0.001
Moderate	24	−2.31 ± 0.41	
Severe	24	−3.05 ± 0.46	

Interpretation:
The mean BMD T-score decreased progressively as histopathological severity increased. Patients with severe histopathological changes had the lowest mean BMD T-score. This shows that worsening microscopic bone changes correlate with reduced bone mineral density.

Table 6: Correlation between BMD T-score and histopathological severity score

Variable	Correlation Coefficient	p-value
BMD T-score vs Histopathological severity score	r = −0.72	<0.001

Interpretation:
There was a strong negative correlation between BMD T-score and histopathological severity score. As the BMD T-score decreased, histopathological severity increased. This confirms that lower bone mineral density is significantly associated with more severe microscopic bone changes.

DISCUSSION

The present study evaluated the correlation between bone mineral density (BMD) and histopathological changes in patients with osteopenia and osteoporosis. The findings demonstrated a significant association between decreasing BMD and worsening histopathological bone changes, highlighting the importance of combining quantitative and qualitative assessment of bone health.

In the present study, the majority of patients belonged to the older age group, with a mean age of 61.8 years. This is consistent with previous studies which have reported that bone loss accelerates with advancing age due to reduced osteoblastic activity and increased bone resorption[8,9]. The higher proportion of female patients (70%) observed in this study is also in agreement with earlier reports, where postmenopausal estrogen deficiency has been identified as a major contributor to bone loss and increased risk of osteoporosis[9].

The distribution of patients showed a slightly higher proportion of osteoporosis (56.7%) compared to osteopenia (43.3%). Similar trends have been reported in hospital-based studies where patients presenting for surgical procedures tend to have more advanced disease[10]. This may be attributed to delayed diagnosis and lack of routine screening, particularly in developing countries.

A key finding of this study was the significant association between BMD category and histopathological severity. Patients with osteopenia predominantly showed mild to moderate changes, whereas those with osteoporosis exhibited more severe histopathological alterations such as trabecular thinning, increased trabecular separation, and cortical bone loss. This is in line with previous histomorphometric studies which have demonstrated that deterioration of trabecular microarchitecture increases with decreasing bone density[11,12]. These microstructural changes significantly compromise bone strength and contribute to increased fracture risk.

The comparison of mean BMD T-scores across different histopathological severity groups revealed a progressive decline in T-score with increasing severity. Patients with severe histopathological changes had significantly lower mean BMD values. Similar observations have been reported by Parfitt et al., who emphasized that trabecular connectivity and bone volume decrease progressively as osteoporosis advances[13]. This indicates that BMD reflects, to a considerable extent, the underlying structural deterioration of bone.

The most important finding of the present study was the strong negative correlation ($r = -0.72$) between BMD T-score and histopathological severity score. This suggests that as bone mineral density decreases, the degree of microscopic bone damage increases significantly. Comparable findings have been reported in earlier studies, which have demonstrated moderate to strong correlations between densitometric measurements and histomorphometric parameters[14,15]. However, it is important to note that BMD alone may not fully capture all aspects of bone quality, as microarchitectural deterioration can occur even before significant changes in BMD are detected.

Histopathological examination provides direct visualization of bone microstructure and cellular activity, offering insights into bone remodeling dynamics. Studies have shown that parameters such as trabecular thickness, osteoid formation, and cellular activity are critical determinants of bone strength and fracture risk[16]. Therefore, combining BMD assessment with histopathological evaluation can improve diagnostic accuracy and risk stratification.

The findings of this study have important clinical implications. While DEXA remains the gold standard for diagnosing osteoporosis, it primarily measures bone quantity and does not fully assess bone quality. The significant correlation observed in this study supports the use of histopathological assessment, particularly in research settings, to better understand disease severity and progression.

Despite the significant findings, certain limitations must be acknowledged. The study was conducted on a relatively limited sample size and included only patients undergoing surgical procedures, which may introduce selection bias. Additionally, histopathological assessment is invasive and not routinely feasible in clinical practice. Previous studies have also highlighted the need for non-invasive techniques to assess bone quality alongside BMD[17].

Overall, the results of the present study are consistent with existing literature and confirm that decreasing bone mineral density is associated with worsening histopathological bone changes. The study emphasizes the importance of a comprehensive approach in the evaluation of osteoporosis, integrating both densitometric and microstructural assessment of bone.

CONCLUSION

The present study demonstrates a significant correlation between bone mineral density and histopathological changes in patients with osteopenia and osteoporosis. As BMD decreases, there is a corresponding increase in the severity of microscopic bone alterations, including trabecular thinning, increased trabecular separation, and cortical bone loss.
The strong negative correlation observed between BMD T-score and histopathological severity indicates that lower bone mineral density is associated with greater structural deterioration of bone. These findings highlight that BMD, although an important diagnostic tool, does not completely represent bone quality.

Histopathological examination provides valuable insights into bone microarchitecture and remodelling activity, which are critical determinants of bone strength and fracture risk. Therefore, assessment of bone quality in addition to bone density can improve understanding of disease severity.

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