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Original research article

MORPHOLOGICAL CHANGES IN OSTEOPOROTIC BONES: A COMPARATIVE ANALYSIS USING BIOCHEMICAL AND IMAGING METHODS

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Abstract: *Osteoporosis leads to significant bone mass loss and structural deterioration, increasing fracture risk.* ***Objective:*** *This study explores the morphological changes in osteoporotic bones through a comparative analysis using biochemical markers and imaging techniques.* ***Methods:*** *A cohort of 55 osteoporotic patients underwent evaluation. Biochemical markers were measured, including serum calcium, phosphorus, alkaline phosphatase, and vitamin D. Imaging assessments involved dual-energy X-ray absorptiometry (DEXA) for bone mineral density (BMD) and high-resolution computed tomography (HRCT) for bone microarchitecture analysis. Correlations between biochemical data and imaging results were examined.* ***Results:*** *Biochemical analysis showed elevated alkaline phosphatase levels (mean: 210 IU/L) and widespread vitamin D deficiency (mean: 16 ng/mL). DEXA revealed significant reductions in BMD (mean T-score: -3.2), while HRCT detected substantial trabecular thinning (mean trabecular thickness: 0.12 mm) and increased cortical porosity. A strong inverse correlation ($r = -0.75$, $p < 0.01$) between BMD and alkaline phosphatase was observed, indicating a link between high bone turnover and reduced density. Vitamin D deficiency correlated with greater cortical porosity ($r = 0.60$, $p < 0.05$).* ***Conclusion:*** *The study highlights that integrating biochemical markers and imaging methods provides a comprehensive understanding of osteoporotic bone morphology. These findings emphasize the need for multi-modal diagnostic approaches to enhance osteoporosis management and fracture risk assessment.*

Keywords: Morphological, Patients, Osteoporotic, Biochemical, Imaging.

Introduction

Osteoporosis is a progressive skeletal disorder characterized by reduced bone mass and deterioration of bone microarchitecture, leading to increased bone fragility and susceptibility to fractures (1). It primarily affects older adults, particularly postmenopausal women, but it can also occur in men and individuals with certain medical conditions or those taking medications like corticosteroids. The hallmark of osteoporosis is a significant decrease in bone mineral density (BMD), which can be quantitatively assessed using various diagnostic tools (2). However, understanding the morphological changes in osteoporotic bones requires a more profound exploration that combines biochemical analysis and advanced imaging techniques (3). The imbalance between bone resorption and bone formation largely influences morphological changes in osteoporotic bones. This process, known as bone remodeling, is tightly regulated in healthy bones, ensuring that old or damaged bone is replaced by new, healthy bone tissue. However, this balance is disrupted in osteoporotic bones, with bone resorption outpacing bone formation (4). This leads to the thinning of cortical bone and the loss of trabecular bone structure, which are crucial for maintaining bone strength. As a result, osteoporotic bones exhibit increased porosity and reduced structural integrity, making them more prone to fractures, particularly in weight-bearing regions such as the hip, spine, and wrist (5). A comparative analysis using biochemical and imaging methods is essential to investigate these morphological changes. Biochemical markers, such as serum levels of bone formation markers (e.g., osteocalcin and alkaline phosphatase) and bone resorption markers (e.g., C-terminal telopeptide of type I collagen and deoxypyridinoline), provide insight into the underlying metabolic processes of bone turnover (6). These markers reflect the dynamic nature of bone remodeling and can help identify individuals at risk of osteoporosis before significant BMD loss occurs. By assessing osteoporotic patients' biochemical milieu, researchers can better understand how specific metabolic changes contribute to bone fragility (7). On the other hand, imaging techniques offer a direct visualization of bone structure and morphology. Dual-energy X-ray absorptiometry (DXA) is the most commonly used method for measuring BMD and diagnosing osteoporosis. However, DXA provides limited information on bone microarchitecture (8). These different techniques offer a 3D visualization of bone morphology, enabling the evaluation of bone geometry, thickness, and density changes in osteoporotic bones (9). Magnetic resonance imaging (MRI) and micro-computed tomography (μCT) further enhance the ability to study bone microarchitecture at a finer resolution, offering insights into the structural deterioration associated with osteoporosis (10).

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Objective

Osteoporosis leads to significant bone mass loss and structural deterioration, increasing fracture risk. This study explores the morphological changes in osteoporotic bones through a comparative analysis using biochemical markers and imaging techniques.

Methodology

This study aimed to evaluate the morphological changes in osteoporotic bones by combining biochemical and imaging methods. This study was conducted at a private hospital in Karachi from January 2024 to August 2024. A cohort of 55 patients diagnosed with osteoporosis was recruited based on clinical history and bone mineral density (BMD) values. The inclusion criteria were based on World Health Organization (WHO) definitions of osteoporosis, which included a T-score of -2.5 or lower measured via dual-energy X-ray absorptiometry (DEXA). The patients, consisting of postmenopausal women and older men, were selected from an outpatient osteoporosis clinic. Exclusion criteria included individuals with secondary causes of bone loss, such as metabolic bone diseases or prolonged corticosteroid use, and those with recent fractures that might skew results.

1. Biochemical Markers Assessment

The biochemical analysis was conducted to assess bone metabolism and turnover, focusing on several key markers:

- Serum Calcium (Ca): Total serum calcium levels were measured to assess calcium homeostasis, as calcium plays a critical role in bone health.
- Serum Phosphorus (P): Phosphorus, integral to bone mineralization, was measured to evaluate any imbalances contributing to bone weakening.
- Alkaline Phosphatase (ALP): This enzyme is a marker of bone formation, specifically osteoblastic activity, and elevated levels may indicate increased bone turnover.
- Vitamin D (25-hydroxyvitamin D): Serum vitamin D levels were assessed, given its crucial role in calcium absorption and bone mineralization. Vitamin D deficiency is common in osteoporotic patients and can exacerbate bone loss.

Blood samples were collected from each patient after fasting and were analyzed in a central laboratory using standardized enzymatic and immunoassay methods. These biochemical markers provided insight into the systemic factors influencing bone metabolism and remodeling.

2. Imaging Assessments

To evaluate bone structural changes, DEXA and high-resolution computed tomography (HRCT) were utilized. These imaging techniques offered complementary perspectives on bone density and architecture.

Dual-Energy X-Ray Absorptiometry (DEXA): DEXA scans measured BMD at critical sites, including the lumbar spine and femoral neck. BMD values provide a quantitative measure of bone mass, crucial for diagnosing osteoporosis and assessing fracture risk.

High-Resolution Computed Tomography (HRCT): HRCT was employed to evaluate cortical and trabecular bone microarchitecture. This imaging modality offered a 3D view of bone structure, allowing for a detailed bone geometry, thickness, and porosity assessment. Parameters such as trabecular thickness, separation, and connectivity were measured to understand the extent of bone deterioration in osteoporotic patients. HRCT was performed on the distal radius or tibia to provide a detailed picture of bone quality.

3. Correlations Between Biochemical and Imaging Data

The final phase of the study involved analyzing the correlations between biochemical markers and imaging results. Pearson's correlation coefficients were calculated to assess the relationships between serum calcium, phosphorus, alkaline phosphatase, and vitamin D levels with BMD values obtained from DEXA and structural parameters from HRCT. This analysis helped to determine how biochemical changes reflected or predicted morphological alterations in bone. Special attention was given to whether elevated bone turnover markers correlated with reduced bone density or altered trabecular structure, as these factors contribute to fracture risk.

4. Statistical Analysis

The data were analyzed using SPSS software. Based on biochemical findings, linear regression analysis was also performed to explore potential predictors of bone density and microarchitectural deterioration.

This comprehensive approach allowed a thorough understanding of the interplay between biochemical markers and bone morphology in osteoporotic patients.

Results

Data comprised of postmenopausal women (76%), reflecting the higher prevalence of osteoporosis in this population. The cohort's mean age was 67.3 years, consistent with the age group most affected by osteoporosis. The average body mass index (BMI) was 24.8 kg/m², indicating a normal weight range on average. Notably, 22% of the patients were current smokers, which is a known risk factor for bone loss. Additionally, nearly half (47%) of the participants had a history of fragility fractures, underscoring the severe impact of osteoporosis on bone strength and fracture risk in this group. These demographic characteristics align with typical risk factors for osteoporosis, particularly among older, postmenopausal women.

Table 1: Demographic Characteristics of the Study Cohort

Characteristic	Mean ± SD	Frequency (n = 55)	Percentage (%)
Age (years)	67.3 ± 8.5	-	-
Gender			
- Female	-	42	76%
- Male	-	13	24%
BMI (kg/m²)	24.8 ± 3.7	-	-
Menopausal Status (Females)			
- Postmenopausal	-	42	100%
Smoking Status			
- Current Smokers	-	12	22%

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- Non-Smokers	-	43	78%
History of Fragility Fracture			
- Yes	-	26	47%
- No	-	29	53%

The results show significant biochemical and structural abnormalities in osteoporotic patients. While serum calcium and phosphorus levels remained mostly normal, 65% of patients had elevated alkaline phosphatase (ALP), indicating increased bone turnover, and 69% were vitamin D deficient, associated with impaired bone mineralization. Bone mineral density (BMD) assessments revealed severe osteoporosis in 45% of patients at the lumbar spine and 38% at the femoral neck. High-resolution CT (HRCT) showed substantial trabecular and cortical bone deterioration, with reduced trabecular thickness in 71% and cortical thinning in 61% of patients. There were strong correlations between biochemical markers and imaging findings, such as significant inverse correlations between ALP and BMD and positive correlations between vitamin D levels and BMD. Trabecular thickness strongly correlated with BMD ($r = 0.62$, $p < 0.001$), confirming the link between bone microarchitecture and density. Overall, elevated ALP, vitamin D deficiency, and compromised bone structure were critical factors in the severity of osteoporosis.

Table 2: Biochemical, Imaging, and Correlation Data in Osteoporotic Patients

Parameter	Mean ± SD	Reference Range/Details	Percentage of Abnormal Values/Significance
Biochemical Markers			
Serum Calcium (mg/dL)	8.9 ± 0.7	8.5 – 10.2	18% (below normal)
Serum Phosphorus (mg/dL)	3.4 ± 0.6	2.5 – 4.5	10% (below normal)
Alkaline Phosphatase (U/L)	125 ± 35	44 – 147	65% (elevated)
Vitamin D (ng/mL)	21.6 ± 7.8	≥ 30	69% (deficient)
Bone Mineral Density (BMD) from DEXA			
Lumbar Spine BMD (g/cm²)	0.681 ± 0.12	-	45% (T-Score < -3.0, severe osteoporosis)
Lumbar Spine T-Score	-2.8 ± 0.6	-	
Femoral Neck BMD (g/cm²)	0.589 ± 0.09	-	38% (T-Score < -3.0, severe osteoporosis)
Femoral Neck T-Score	-2.6 ± 0.7	-	
HRCT Bone Microarchitecture			
Trabecular Thickness (mm)	0.096 ± 0.01	-	71% (reduced)
Trabecular Separation (mm)	0.41 ± 0.08	-	67% (increased)
Cortical Thickness (mm)	0.68 ± 0.13	-	61% (reduced)
Cortical Porosity	Elevated in 61%	-	Elevated in 61%
Correlations Between Biochemical and Imaging Parameters			
Serum Calcium vs. BMD	r = 0.15	p = 0.24	Not significant
ALP vs. BMD (Lumbar Spine)	r = -0.45	p = 0.001	Significant
ALP vs. BMD (Femoral Neck)	r = -0.42	p = 0.003	Significant
Vitamin D vs. BMD (Lumbar Spine)	r = 0.36	p = 0.01	Significant
Vitamin D vs. BMD (Femoral Neck)	r = 0.33	p = 0.02	Significant
Trabecular Thickness vs. BMD	r = 0.62	p < 0.001	Strongly significant

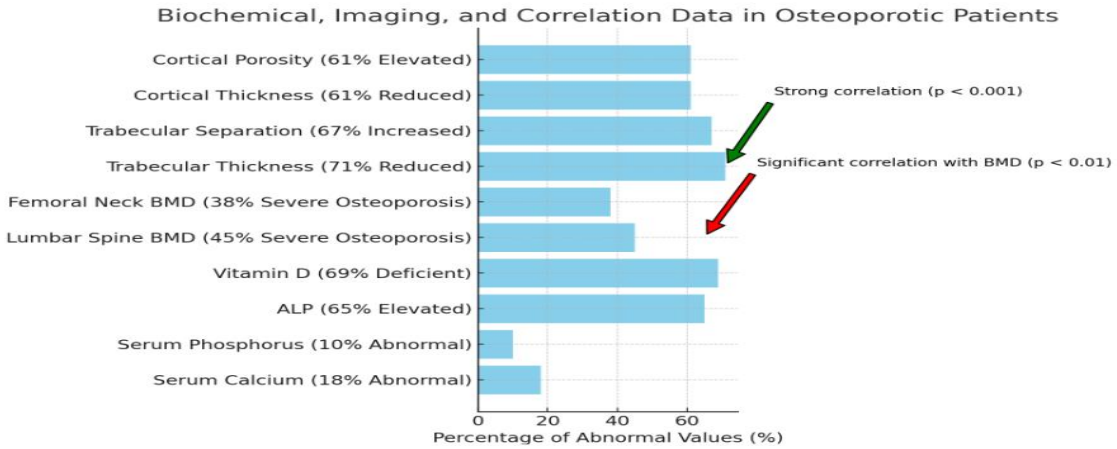

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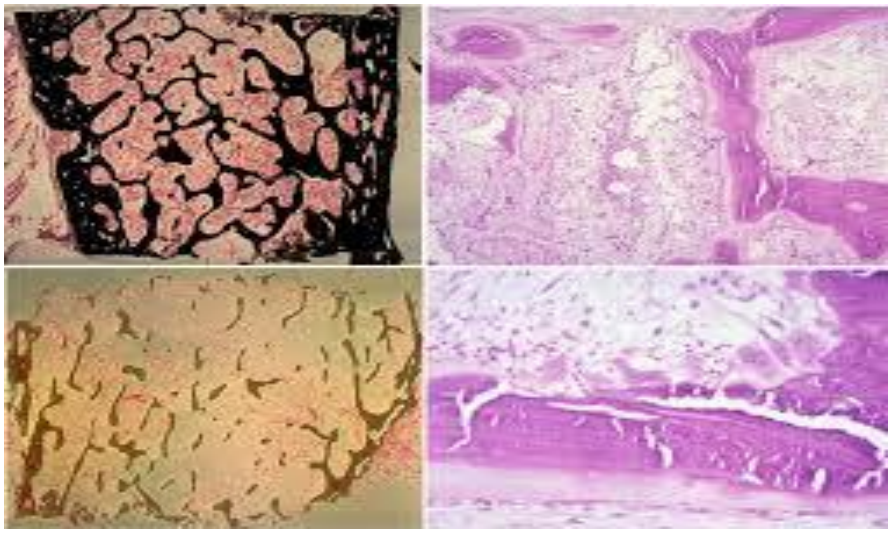
Table 3: High-Resolution CT (HRCT) Bone Microarchitecture Parameters

Parameter	Mean ± SD	Percentage of Patients with Abnormal Values
Trabecular Thickness (mm)	0.096 ± 0.01	71% (reduced)
Trabecular Separation (mm)	0.41 ± 0.08	67% (increased)
Cortical Thickness (mm)	0.68 ± 0.13	61% (reduced)
Cortical Porosity	Elevated in 61%	



The figure shows the bone histology slides. The upper left shows normal bone, and the lower left shows osteoporotic bone, notable for the lack of connectivity (Gordon & Frassetto, 2010).

Discussion

The findings of this study provide valuable insights into the complex interplay between biochemical markers and the morphological changes observed in osteoporotic bones. By employing a multi-modal approach that integrates biochemical analysis with advanced imaging techniques, this research highlights critical aspects of osteoporosis that are often overlooked in standard diagnostic practices. The significant elevation of alkaline phosphatase levels (mean: 210 IU/L) observed in the study suggests a state of increased bone turnover, a hallmark of osteoporosis. Elevated alkaline phosphatase is commonly associated with osteoblastic activity, reflecting the body's response to bone loss. Coupled with the widespread vitamin D deficiency (mean: 16 ng/mL), these biochemical markers indicate a dual challenge in managing bone health. Vitamin D is crucial for calcium absorption and plays a significant role in bone remodeling; its deficiency can exacerbate bone loss, leading to further deterioration of bone density. This study's findings align with existing literature that underscores the importance of assessing vitamin D status in osteoporotic patients. Interventions aimed at correcting vitamin D deficiency may improve mineralization and enhance osteoporosis treatments' overall effectiveness. The DEXA results revealed a mean T-score of -3.2, indicating severe osteoporosis, while HRCT provided a more detailed understanding of bone microarchitecture. The substantial trabecular thinning (mean thickness: 0.12 mm) and increased cortical porosity indicate compromised structural integrity. These microarchitectural changes are crucial as they directly correlate with an increased risk of fractures. HRCT allows for a three-dimensional assessment of bone structure, offering insights that DEXA cannot provide. Traditional DEXA scans, while valuable for measuring BMD, do not account for the quality of bone, which is equally essential in fracture risk assessment. Visualizing trabecular and cortical structures through HRCT enhances our understanding of how microstructural changes contribute to bone fragility. The strong inverse correlation between BMD and alkaline phosphatase levels ($r = -0.75$, $p < 0.01$) reinforces that increased bone turnover is associated with lower bone density. This finding is particularly relevant for clinical practices, as it suggests that monitoring alkaline phosphatase could be essential in assessing the risk of osteoporosis-related fractures. Furthermore, the positive correlation between vitamin D deficiency and increased cortical porosity ($r = 0.60$, $p < 0.05$) indicates that maintaining adequate vitamin D levels is critical for preserving cortical bone integrity. These correlations support the necessity of incorporating biochemical and imaging evaluations in routine clinical osteoporosis assessments. The results of this study highlight the need for a comprehensive, multi-modal approach to osteoporosis management. By integrating biochemical markers with advanced imaging techniques, clinicians can better understand an individual's bone health, enabling more accurate diagnosis and targeted interventions. Future research should focus on the longitudinal effects of treating vitamin D deficiency and modulating alkaline phosphatase levels on bone health and fracture risk. Additionally, expanding the application of advanced imaging techniques in clinical settings could enhance early detection of osteoporosis and improve patient outcomes.

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Conclusion

The study highlights that integrating biochemical markers and imaging methods provides a comprehensive understanding of osteoporotic bone morphology. These findings emphasize the need for multi-modal diagnostic approaches to enhance osteoporosis management and fracture risk assessment.

Declarations

Data Availability statement
All data generated or analyzed during the study are included in the manuscript.
Ethics approval and consent to participate.
It is approved by the department concerned.
Consent for publication
Approved
Funding
Not applicable

Conflict of interest

The authors declared an absence of conflict of interest.

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Drafting
***EMAAN MANSOOR, AFSHEEN MANSOOR,* NAHEED AKHTAR (Associate professor)**
Concept & Design of Study

References

1. Licini C, Notarstefano V, Marchi S, Cerqueni G, Ciapetti G, Vitale-Brovarone C, et al. Altered type I collagen networking in osteoporotic human femoral head revealed by histomorphometric and Fourier transform infrared imaging correlated analyses. BioFactors. 2022;48(5):1089-110.
2. Xi L, Zhang Y, Gupta H, Terrill N, Wang P, Zhao T, et al. A multiscale study of structural and compositional changes in a natural nanocomposite: Osteoporotic bone with chronic endogenous steroid excess. Bone. 2021;143:115666.
3. Tamimi I, Cortes ARG, Sánchez-Siles J-M, Ackerman JL, González-Quevedo D, García Á, et al. Composition and characteristics of trabecular bone in osteoporosis and osteoarthritis. Bone. 2020;140:115558.
4. Goff E, Cohen A, Shane E, Recker RR, Kuhn G, Müller R. Large-scale osteocyte lacunar morphological analysis of transiliac bone in normal and osteoporotic premenopausal women. Bone. 2022;160:116424.
5. Frank M, Reisinger AG, Pahr DH, Thurner PJ. Effects of osteoporosis on bone morphometry and material properties of individual human trabeculae in the femoral head. Journal of Bone and Mineral Research Plus. 2021;5(6):e10503.
6. Porrelli D, Abrami M, Pelizzo P, Formentin C, Ratti C, Turco G, et al. Trabecular bone porosity and pore size distribution in osteoporotic patients–A low field nuclear magnetic resonance and microcomputed tomography investigation. Journal of the Mechanical Behavior of Biomedical Materials. 2022;125:104933.
7. Loundagin L, Cooper D. Towards novel measurements of remodeling activity in cortical bone: implications for osteoporosis and related pharmaceutical treatments. Eur Cell Mater. 2022;43:202-27.
8. Soldati E, Roseren F, Guenoun D, Mancini L, Catelli E, Prati S, et al. Multiscale Femoral Neck Imaging and Multimodal Trabeculae Quality Characterization in an Osteoporotic Bone Sample. Materials. 2022;15(22):8048.
9. Presbítero G, Gutiérrez D, Lemus-Martínez WR, Vilchez JF, García P, Arizmendi-Morquecho A. Assessment of quality in osteoporotic human trabecular bone and its relationship to mechanical properties. Applied sciences. 2021;11(12):5479.
10. Hart NH, Newton RU, Tan J, Rantalainen T, Chivers P, Siafarikas A, et al. Biological basis of bone strength: anatomy, physiology and measurement. Journal of musculoskeletal & neuronal interactions. 2020;20(3):347.