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Radiographic Study of Osteoporosis Detection in the Jaw

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Abstract

Objective: To investigate the reliability of panoramic radiographs in detecting osteoporosis disease. **Material and Methods**: Three hundred patients, regardless of gender, were included, aged between 40 and 50 years. One hundred fifty patients had confirmed systemic osteoporosis by DXA scan (experimental group), while the other 150 patients had no history of osteoporosis (Healthy control group). The study used the Ramus Index to calculate the grey mean values on panoramic images, which correlates with bone mineral density (BMD) compared with the data of dual-energy X-ray absorptiometry (DXA) as the gold standard reference. **Results**: The findings demonstrated that panoramic images and the Ramus Index were a reliable indicator of osteoporosis ($p<0.001$) (80% sensitivity, 90% specificity, and 85% accuracy). **Conclusion**: Quantitative grey-level evaluation of panoramic images demonstrated diagnostic validity.

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Introduction

"Osteoporosis is a metabolic-related disease marked by decreased bone mineral density (BMD)", leading to elevated bone fragility and an elevated risk of fractures [1]. This disorder is caused by disequilibrium between bone formation and resorption, reducing bone mineral composition in the whole body, considerably affecting bone microstructure and increasing vulnerability to fractures in the hip, femur, wrist, spine and other situations [2,3] states that osteoporosis is a condition where the value of bone mineral density is equal to 2.5 standard deviations (or more) below the mean level for young adults. The diagnosis is based on several risk factors, with evaluation of the lumbar spine and femur considered the most significant regions [3,4].

Over 200 million individuals are influenced by "osteoporosis" worldwide, with one-fifth of males and one-third of females over the age of fifty vulnerable to fractures [5]. With the continued aging of populations worldwide, the rate of osteoporosis will increase, creating a serious economic challenge [5]. Osteoporosis reflects a classic multicausal disorder where genetic tendency, exogenous effects, endogenous biological variables, and lifestyle preferences contribute to differentiate individual vulnerability. [6] The normal path of bone mass follows a predictable manner, peaking about age 30, with men typically achieving greater peak bone mass than women, due to this peak, both genders facing an age-related regression in bone density at a rate of 0.5 to 1% per year [7]. On the other hand, the clinical presentation of osteoporosis shows high gender predilection, with epidemiological studies suggesting the prevalence rates of 2 to 8% in men over 50 years compared to rates of 33 to 47% in women for the same age group [8].

The physiopathology of osteoporosis, especially in post-menopausal women, has often been related to endocrine disturbances. The main role of estrogen insufficiency and subsequent secondary hyperparathyroidism has been strongly supported, with these hormonal alterations commonly aggravated by insufficient dietary intake and the frequent prevalence of vitamin D inadequacy in aging people [6].

Estrogen exerts its protective effects on bone mainly through estrogen receptor-alpha, which keeps the critical equilibrium between bone formation and resorption. Decreased signaling of estrogen receptor-alpha leads to interruption of this balance, causing inordinate bone resorption [9]. The fundamental pathway for this process includes complicated interactions between ERα and the primary osteogenesis pathway, including "insulin-like growth factor (IGF) and Wnt/β-

catenin signaling systems". Estrogen insufficiency-induced negative regulation of ERα diminishes numerous activities of stem cells in bone marrow, decreasing their proliferative efficiency, F-actin stress fiber formation and alkaline phosphatase activity. Moreover, ERα acts as a crucial controller of primary osteogenic genes such as osteocalcin, osteopontin and osterix [10-12].

Experimental evidence from ovariectomized rat samples has supported these findings, showing an apparent association between osteoporosis due to sex hormones insufficiency and decreased mineral density of the jawbone, with major consequences for quality and regenerative capability of alveolar bone [13-17]. In addition to these hormonal mechanisms, several additional risk factors promote the development of osteoporosis, long term glucocorticoid use causes bone loss through osteoblast inhibition [18,19], furthermore, smoking negatively influences bone metabolism through several pathways [20]. Insufficient calcium use disrupts bone mineralization [4], and diabetes mellitus changes bone quality due to high blood sugar, creating harmful glycated proteins. [20].

Osteoporosis of the jaw has several adverse effects on oral health, delaying healing following tooth extraction, orthodontic treatment, periodontal disease progression and dental implant success [5,21,22]. Osteoporosis treatments such as bisphosphonates can enhance jawbone mineral density, which in turn has risks involving osteonecrosis of the jaw related to bisphosphonates [23].

The mandible, as a component of the axial skeleton, revealed exclusive properties that allow the identification of osteoporosis-related alterations through radiographic analysis. Studies confirm that osteoporosis causes a decline in bone mineral density, influencing densitometric, morphometric and architectural qualities of the jaw. Frequent radiographic signs include extensive radiolucency of the mandible and maxilla, reduced thickness of the mandibular inferior cortex, cortical weakening, and amplified prominence of anatomical landmarks like the nasal cavity and maxillary sinus [24].

Radiography is used as a diagnostic procedure for the assessment of dentition and jawbone anomalies in practical dentistry [25,26]. Dental radiographs, especially intraoral and panoramic images, have displayed the capability of identifying early signs of bone diseases. Panoramic radiography is one of the most prevalent radiographic method due to its ability to get extensive visualization of the maxillofacial structure [27,28]. Radiographic bone measurement indices, such as the panoramic mandibular index, mandibular cortical width, and cortical index have been suggested as reliable indices for evaluating low bone mineral density using dental panoramic radiographs [28].

The current study was designed to assess the reliability of panoramic radiographs in detecting "osteoporosis".

Material and Methods

The study was carried out at several specialized dental centers, in Baghdad, Iraq, between April 2024 and May 2025. The study included 300 patients of both genders aged between 40 and 50 years who were referred for panoramic images. One hundred fifty patients had confirmed systemic osteoporosis by DXA scan (experimental group), while the other 150 patients had no history of osteoporosis (healthy control group). All panoramic images were analyzed to assess bone density using ImageJ software [version 2.3.0, 2023; NIH, USA]. [29] The Ramus Index was used for bone density analysis of the jaws by measuring the grey values on panoramic images through histogram analysis of pixel intensities. This was achieved by calculating the mean grey values (MGV) in the selected region of the mandible on panoramic images. A square (box) of 30 x 30 mm was drawn on the panoramic image in the mandibular region, and then the mean grey values within this box were analyzed. The superior side of this square was drawn to be tangent to the mandibular sigmoid notch, the anterior side extended toward the anterior edge of the ramus, the posterior side extended toward the posterior margin of the ramus, and the inferior side of the square reached close to the mid-ramus region. Radiographic data from panoramic images were analyzed to compare localized bone density with systemic DXA results (Figure 1).

The parameters of the DXA scan used in the study as the gold standard reference are DXA sensitivity: 90%, specificity: 95%, and accuracy: 93%. [30, 31] All parameters of the panoramic X-ray system were adjusted to be similar to all panoramic images (kVp: 80 kV, mA: 10 mA and exposure time: 15 seconds).

Bone Density Evaluation

A- Parameters of localized bone density on panoramic images:

Normal bone density (High Density - Radiopaque): Mean grey values range between 160-255.

Osteopenia (Moderate Density - Less radiopaque): Mean grey values range between 100-159.

Osteoporosis: Low Density (More Radiolucent): Mean grey values range between 0–99.

B- "Dual-Energy X-ray Absorptiometry (DXA)" [32]:

The diagnosis of osteoporosis via "DXA (Dual-Energy X-ray Absorptiometry)" was based on T-scores, according to criteria of The World Health Organization (WHO) as follows:

Normal: T-score ≥ -1.0.

Bone density is within 1 standard deviation (SD) of the young adult mean.

Osteopenia or early osteoporosis (Low Bone Mass): T-score between -1.0 and -2.5.

Bone density is 1 to 2.5 SD below the young adult mean. Indicates increased fracture risk.

Osteoporosis: T-score ≤ -2.5

Bone density is 2.5 SDs or more below the young adult mean. High fracture risk.

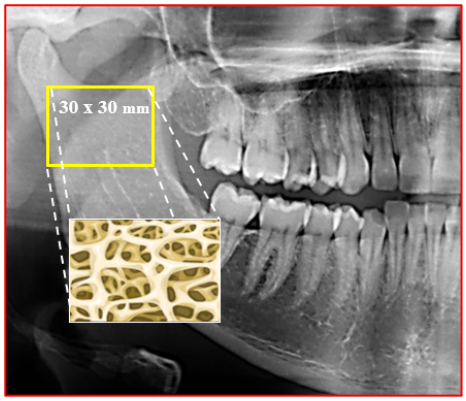

Figure 1. Ramus index (RI) applied in the study.

Inclusion Criteria

Patients of both genders aged between 40 and 50 years.

Patients had confirmed systemic osteoporosis by DXA test, included in the experimental group.

Patients had no history of osteoporosis in the healthy control group.

Exclusion Criteria

Patients with metabolic bone disorders other than osteoporosis (e.g., Paget's disease, osteomalacia).

Patients with systemic diseases that may affect bone metabolism or turnover (e.g., diabetes mellitus and chronic kidney disease).
Menopausal women.
Pregnant or lactating women.
Patients on corticosteroids or other medications known to alter bone metabolism within the past 6 months.
Patients treated with osteoporosis medications within the past 6 months.
Patients with periodontitis, trauma, malignancy or pathology affecting the maxilla or mandible.
Patients with dental implants, prostheses, or restorations interfering with bone evaluation.
Alcoholic patients and heavy smokers.
Patients on chemotherapy or radiotherapy.

Statistical Analysis

Chi-square test: used to assess the reliability of panoramic images in detecting osteoporosis compared to DXA (gold standard).

Cramér's V Test: to measure the strength of association.

ROC Curve Analysis – Determine the sensitivity and specificity of using grey values to classify osteoporosis by plotting a Receiver Operating Characteristic (ROC) curve.

Confidence Intervals (95%): To quantify the precision of diagnostic performance metrics (sensitivity, specificity, and accuracy).

Results

The findings demonstrated a strong correlation between the mean grey values (MGV) on panoramic radiographs and the actual bone density status measured by DXA (The gold standard). [Chi-square statistic (χ^2) =169.28, p-value < 0.001]. The Cramér's V test = 0.75, confirming the high reliability for bone density measurements on panoramic images for the detection of osteoporosis. In the osteoporotic group, 80% of patients had low grey mean values (more radiolucent), consistent with the expected low bone density in osteoporosis. This means that panoramic images correctly identified a large number of osteoporotic patients. In addition, 16.7% of osteoporotic patients had moderate grey mean values (less radiolucent), suggesting osteopenia or expected future osteoporosis, and only 3.3% of osteoporotic patients had high grey mean values, suggesting a normal density despite having osteoporosis according to DXA. In the control group, 66.7% % of individuals had high grey mean values, confirming their normal bone density. Only 23.3% showed moderate grey mean values, and 10% demonstrated low grey mean values, suggesting a small rate of false positives where the panoramic images suggested bone loss, even though the DXA did not.

The statistics test revealed that the diagnostic efficiency of the procedure has moderate sensitivity, high specificity, and good accuracy, but it is statistically less effective than DXA in all parameters ($p < 0.05$). Sensitivity for panoramic imaging (80%) is significantly lower than DXA (90%) [$Z = -3.16$, $p < 0.00$], Specificity for panoramic imaging (90%) is lower compared to DXA (95%) [$Z = -2.24$, $p = 0.025$], confirming reduced specificity. In the same way, accuracy for panoramic images (85%) is statistically lower than DXA's (93%) [$Z = -2.89$, $p = 0.004$]. Confidence intervals 95% enhanced confirmation of these findings. Sensitivity for panoramic images (73.6–86.4%) does not reach DXA's standard sensitivity (~ 90%), proving its inferiority. Specificity (85.2–94.8%) minimally overlaps with DXA's specificity (~ 95%), indicating possible similarity in an ideal situation, although still mostly lower. Accuracy (81.0–89.0%) is still less than DXA's accuracy (~ 93%), supporting that panoramic imaging is less accurate. In addition, AUC = 0.95% indicated excellent diagnostic performance.

Discussion

"Osteoporosis" is a systemic disorder identified by reduced bone mineral density and disturbance of bone architecture. Systemic osteoporosis affects the radial, spinal, femoral, craniofacial bones and oral structures, directly influencing various oral conditions and dental procedures [33,34].

Osteoporosis is primarily associated with increased risk of complications in dental practice due to advanced alveolar bone resorption, causing delayed healing after tooth extractions and a greater risk of pathological fractures during dental procedures, in addition to the progression of the periodontal disease much faster. Orthodontic treatments encounter difficulties in tooth movement, and denture wearers often exhibit an improper fit resulting from jawbone reduction. Antiresorptive medications such as bisphosphonates also have a marked risk of bisphosphonate-related jaw osteonecrosis after aggressive dental surgery. In dental implants, the osteoporotic bones of the jaw mostly lead to impaired osseointegration, raising the danger of implant failure too early. Osteoporosis also alters the mechanobiology through the bone-implant integration, causing more challenges, as the bone may struggle to withstand normal mastication forces, possibly leading to peri-implant bone loss and implant overload with time. Therefore, comprehensive pre-surgical evaluation is critical, involving bone density assessments to investigate the quality of the jawbone, and dentists should consider less invasive techniques.

The association between oral health status and osteoporosis is still controversial. The dentist can monitor patients for osteoporosis, aims to examine people at osteoporosis risk and support their urgent referral [35]. Some studies reported the association between the mandibular bone mineral content and many skeletal locations frequently utilized for bone densitometry indicators in the identification of osteoporosis [36]. The assessment of dental radiographs might contribute to the identification of osteoporosis [37]. Many studies have reported that panoramic radiography may act as a dependable screening method for osteoporosis detection [38,39]. Various radio-morphometric indices have been suggested to evaluate the association of bone loss in the mandible, such as Panoramic Mandibular Index (PMI), Mandibular Cortical Index (MCI), Mental Index (MI), Mandibular Cortical Width (MCW) and Antegonial Index (AI) [35,40-42]. Many researchers suggested using the Mandibular Cortical Index (MCI), the Mental Index (MI), and a visual estimation index on panoramic images for bone mineral density evaluation, and they concluded that these three indices presented as helpful tools for the detection of osteoporosis [43].

Many studies used panoramic images to detect osteoporosis and have proven their efficiency in that regard. Therefore, the current study relied on panoramic imaging to evaluate the reliability of panoramic images using grey values for detecting osteoporosis compared to the measurements of dual-energy X-ray absorptiometry (DXA), which was used as the gold standard reference. The study evolved the Ramus Index (RI) to calculate the grey mean values on panoramic images, which correlate with bone mineral density (BMD) using ImageJ software.

The study showed an evident relationship between osteoporosis identified through panoramic images (using grey mean values) and the diagnosis, which relied on DXA. The study found that the vast majority of individuals in the control health group (93.3%) showed high grey mean values consistent with normal bone density. A minor proportion of them (4%) revealed moderate mean grey values; in addition, a diminished percentage (2.7%) showed low mean grey values, which could propose

signs of early or existing osteoporosis. In contrast, most patients (80%) in osteoporotic patients showed low mean grey values, a suggestive result of decreased bone mineral density or osteoporosis. A small percentage of them (16.7%) revealed moderate mean grey values, proposing osteopenia, while only a few cases (3.3%) had high mean grey values, which could be due to human variation.

These results reported that panoramic images (based on grey mean value analysis) have a good sensitivity (80%), high specificity (90%), and good accuracy (85%). Therefore, on panoramic images, most osteoporotic patients were correctly identified by low mean grey values, and most healthy control individuals were correctly identified by high mean grey values. On the opposite side, the current study showed some misclassifications (false negatives and false positives), suggesting that although panoramic imaging showed great potential as a screening tool, it should not replace DXA for definitive diagnosis.

However, the sensitivity of radiographic images in identifying early bone loss is still restricted, and bone density reduction may not be observable until marked bone loss. In addition, the radiographic findings of osteoporosis can interfere with other conditions, like periodontitis or other metabolic bone disorders, causing it difficult to differentiate from osteoporosis, On the other hand, populations at higher risk for osteoporosis (like post-menopausal women), dental radiographs can serve as a helpful adjunct in the early detection for patients. Dentists must be trained to identify minimal alterations in bone density and refer patients for additional assessment if necessary. So, integration of radiographic features with clinical predisposing factors such as a history of fractures, gender, and age can enhance diagnostic accuracy.

Conclusions

Panoramic image analysis using grey values can be considered a reliable adjunctive tool for distinguishing osteoporotic patients from healthy controls, particularly in situations where DXA scans are not readily available. Although useful as a screening method, its performance in sensitivity, specificity, and accuracy is statistically less effective than DXA. Therefore, it should not replace the DXA method for definitive diagnosis, and it should be used as part of a multimodal approach rather than a standalone diagnostic criterion.

In addition, dentists must remain careful and analyze panoramic findings within the wider clinical setting. Factors such as anatomical variations, patient positioning and image quality can affect grey values evaluation and may cause misclassification. However, because of its common availability in dental and maxillofacial practices, panoramic radiography presents a cost-efficient and accessible initial screening tool. This is particularly valuable in areas with limited services or access to advanced imaging technologies. Moreover, integrating AI-based or machine learning models with the method used in this study may further enhance the diagnostic possibility of panoramic images and reduce examiner variability.

Ethical Approval

The study was conducted following the ethical standards of the Ethics Committee for Scientific Research at the College of Dentistry, University of Wasit, Ref. No. 122024 on 25/4/2024. Informed consent was obtained from all individual participants included in the study.

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None.

Conflicts of Interest

None to declare.

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