

CBCT Versus MDCT and Panoramic Radiography for Preoperative Dental Implant Planning: A Prospective Comparative Study

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ABSTRACT:

Introduction: Accurate preoperative imaging is fundamental to successful dental implant therapy. This study compared the diagnostic performance of CBCT, MDCT, and digital panoramic radiography for preoperative implant planning.

Methods: A prospective cross-sectional study enrolled 80 adults (mean age: 47.5 ± 12.3 years) with partial edentulism. Each patient underwent all three modalities within one week. Two oral radiologists independently assessed alveolar bone height and width, anatomical landmark visibility, bone density, image quality (5-point Likert scale), radiation dose, and interobserver agreement (Cohen's κ ; intraclass correlation coefficient [ICC]).

Results: MDCT and CBCT showed significantly higher measurement accuracy (95% and 93%, respectively) and anatomical landmark detection (97% and 95%, respectively) than panoramic radiography (72% and 74%; $p < 0.001$). Image quality scores were higher for MDCT (4.8 ± 0.3) and CBCT (4.6 ± 0.4) versus panoramic radiography (3.7 ± 0.6 ; $p < 0.001$). Radiation dose was highest for MDCT ($36 \pm 3.8 \mu\text{Sv}$), followed by CBCT ($24 \pm 2.1 \mu\text{Sv}$) and panoramic radiography ($14 \pm 2.5 \mu\text{Sv}$; $p < 0.001$). Interobserver agreement was excellent for MDCT ($\kappa = 0.92$; ICC = 0.96) and CBCT ($\kappa = 0.89$; ICC = 0.94), and moderate for panoramic radiography ($\kappa = 0.64$; ICC = 0.71).

Conclusions: CBCT provides an optimal balance between diagnostic accuracy, image quality, and radiation safety, supporting its role as the preferred modality for routine implant planning. MDCT remains valuable for complex cases requiring precise bone density quantification.

Keywords: CBCT; MDCT; Dental implant planning; Panoramic radiography; Radiation dose; Image quality; Interobserver reliability

INTRODUCTION

Dental implant therapy has emerged as a widely accepted and predictable treatment modality for the rehabilitation of partially or completely edentulous patients. Successful implant placement relies heavily on accurate preoperative assessment of alveolar bone dimensions, bone quality, and the precise localization of critical anatomical structures, including the mandibular canal, mental foramen, and maxillary sinus.¹⁻⁴

Conventional imaging techniques, particularly digital panoramic radiography, have long served as an initial diagnostic tool in implant planning owing to their wide availability, low cost, and relatively low radiation exposure. However, panoramic radiography is inherently limited by its two-dimensional nature, magnification errors, geometric distortion, and inability to provide buccolingual bone width measurements—a parameter essential for accurate implant positioning.^{5,6}

The introduction of three-dimensional (3D) imaging modalities has substantially enhanced diagnostic capabilities in dental implantology. Multi-detector computed tomography (MDCT) has traditionally been regarded as the reference standard for cross-sectional imaging, offering excellent image quality, reliable Hounsfield Unit (HU) measurements for bone density assessment, and superior soft tissue contrast.⁷ However, MDCT is associated with higher radiation exposure, greater cost, and limited accessibility in routine dental practice.⁸

Cone-beam computed tomography (CBCT) has emerged as a dedicated maxillofacial imaging modality that provides high-resolution 3D images at a substantially lower radiation dose compared to MDCT. CBCT enables accurate assessment of alveolar bone height and width, detailed visualization of anatomical landmarks, and improved preoperative treatment planning.⁹ Nevertheless, CBCT has recognized limitations, particularly regarding the standardization and reproducibility of grayscale values for bone

density estimation, which remain less consistent than HU measurements derived from MDCT.¹⁰

Given the increasing reliance on advanced imaging in implant dentistry, there is a need for comprehensive comparative studies that evaluate not only diagnostic accuracy but also clinically relevant parameters such as radiation dose, image quality, and interobserver reliability.¹¹ Although several studies have compared these modalities individually, few have provided an integrated, multi-parametric assessment within a single prospective patient cohort.

The aim of this study was therefore to compare the diagnostic performance of CBCT, MDCT, and digital panoramic radiography in preoperative dental implant planning, with particular emphasis on alveolar bone measurement accuracy, anatomical landmark detection, bone density assessment, image quality, radiation exposure, and interobserver agreement.

MATERIALS AND METHODS

Study Design and Patient Population

This prospective cross-sectional study enrolled 80 adult patients (mean age: 47.5 ± 12.3 years) referred for preoperative dental implant assessment between April 2020 and March 2022 from the outpatient dental clinics of Al-Azhar university.

Inclusion criteria comprised adult patients (≥ 18 years) with partial edentulism requiring implant placement. Patients were excluded if they had a history of maxillofacial trauma, previous implant placement in the region of interest, pathological lesions affecting bone quality, current pregnancy, or contraindications to computed tomography (CT) imaging.

The study protocol was approved by the Institutional Ethics Committee (Reference No.: 387; Approval Date: 15/3/2020). All procedures were conducted in accordance with the Declaration of Helsinki. Written informed consent was obtained from all participants prior to enrollment.

Imaging Protocols

All patients underwent digital panoramic radiography, CBCT, and MDCT within a one-week interval to minimize the effects of anatomical variation between examinations.

Digital Panoramic Radiography

Panoramic images were acquired using a standardized digital panoramic unit (SIRONA STRATO 2000 digital version) under manufacturer-recommended exposure parameters. All images were obtained with the patient in an upright position, with standardized head alignment.

Cone-Beam Computed Tomography

CBCT scans were performed using a dedicated maxillofacial unit (J Morita Veraviewepocs 3D R100, Japan) with standardized field of view (FOV), voxel size, and exposure parameters. Patients were positioned according to manufacturer guidelines, and images were reconstructed in axial, coronal, and sagittal planes.

Multi-Detector Computed Tomography

MDCT examinations were performed using a multi-slice CT scanner (Siemens 32 slice, German) with standardized acquisition parameters, including tube voltage, tube current, slice thickness, and reconstruction interval. Images were reconstructed using a bone algorithm in multiple planes.

Image Analysis

All images were independently evaluated by two experienced oral and maxillofacial radiologists who were blinded to each other's assessments.

Alveolar Bone Measurements

Alveolar bone height and width were measured at proposed implant sites using standardized reference points. MDCT measurements served as the reference standard for accuracy comparisons.

Anatomical Landmark Assessment

The visibility and delineation of key anatomical structures—including the mandibular canal,

mental foramen, and maxillary sinus—were assessed and recorded as either clearly visible or not visible.

Bone Density Assessment

Bone density was quantitatively assessed in MDCT using Hounsfield Units (HU). In CBCT, bone density was evaluated using grayscale values as a semi-quantitative indicator. Panoramic radiography was not used for bone density assessment.

Image Quality Evaluation

Image quality was subjectively assessed using a 5-point Likert scale (1 = poor; 5 = excellent), based on sharpness, contrast, and overall diagnostic acceptability.

Radiation Dose Assessment

Radiation dose for each imaging modality was recorded in microsieverts (μSv) based on machine-reported dose indices.

Interobserver Reliability

Interobserver agreement between the two radiologists was assessed using Cohen's kappa (κ) for categorical variables and the intraclass correlation coefficient (ICC) for continuous measurements.

Statistical Analysis

Data were analyzed using IBM SPSS Statistics, version 26.0 (IBM Corp., Armonk, NY). Continuous variables are expressed as mean $\pm$ standard deviation (SD); categorical variables are presented as frequencies and percentages. Comparisons among the three imaging modalities were performed using repeated-measures analysis of variance (ANOVA) followed by Bonferroni post hoc correction for multiple comparisons. A two-tailed p-value of <0.05 was considered statistically significant.

RESULTS

A total of 80 patients were included in the analysis (mean age: 47.5 ± 12.3 years). All patients completed the three imaging examinations within the designated one-week

interval. Patient demographic characteristics are summarized in Table 1.

Table 1. Patient Demographic Characteristics

Variable	Value
Total patients, n	80
Mean age (years), mean $\pm$ SD	47.5 $\pm$ 12.3
Age range (years)	23-75 years
Male, n (%)	30 (37%)
Female, n (%)	50 (63%)
Study design	Prospective cross-sectional
Study period	April 2020 – March 2022
SD, standard deviation	

Alveolar Bone Measurement Accuracy

Both MDCT and CBCT demonstrated significantly higher accuracy in alveolar bone

height and width measurements compared to panoramic radiography (Table 2). MDCT achieved the highest accuracy (95%), followed by CBCT (93%), whereas panoramic radiography showed markedly lower accuracy (72%). Differences among the three modalities were statistically significant ($p < 0.001$).

Anatomical Landmark Detection

Detection rates for critical anatomical landmarks—including the mandibular canal, mental foramen, and maxillary sinus—were highest for MDCT (97%), followed by CBCT (95%), and were significantly lower for panoramic radiography (74%; $p < 0.001$; Table 2).

Table 2. Comparison of Diagnostic Performance Across Imaging Modalities

Parameter	MDCT	CBCT	Panoramic Radiography	<i>p</i> -Value
Measurement accuracy, %	95	93	72	<0.001
Anatomical landmark detection, %	97	95	74	<0.001
Image quality score, mean $\pm$ SD	4.8 $\pm$ 0.3	4.6 $\pm$ 0.4	3.7 $\pm$ 0.6	<0.001
Radiation dose (μ Sv), mean $\pm$ SD	36 $\pm$ 3.8	24 $\pm$ 2.1	14 $\pm$ 2.5	<0.001
Bone density assessment	Quantitative (HU)	Semi-quantitative (grayscale)	Not applicable	—
CBCT, cone-beam computed tomography; HU, Hounsfield Units; MDCT, multi-detector computed tomography; SD, standard deviation; μ Sv, microsieverts.				

Bone Density Assessment

Quantitative bone density assessment was successfully performed using HU in MDCT. In CBCT, grayscale values were used as a semi-

quantitative indicator of bone density (Figure 1). Panoramic radiography did not allow reliable bone density evaluation and was therefore excluded from this analysis.

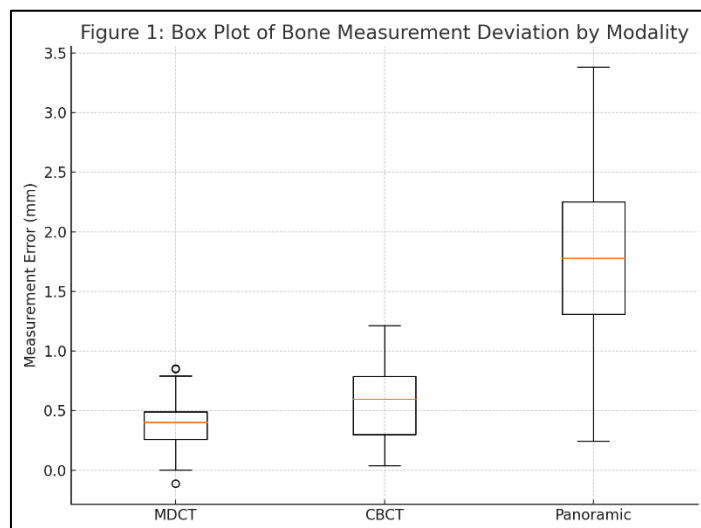


Figure 1. Box plots displaying measurement deviation in alveolar bone height and width for each imaging modality, benchmarked against MDCT as the reference standard. Panoramic radiography demonstrates greater variability and lower accuracy compared to both three-dimensional modalities. CBCT, cone-beam computed tomography; MDCT, multi-detector computed tomography.

Image Quality Evaluation

Image quality scores were highest for MDCT (mean: 4.8 ± 0.3), followed by CBCT (4.6 ± 0.4), with panoramic radiography demonstrating significantly lower scores (3.7 ± 0.6 ; $p < 0.001$; Table 2; Figures 2 and 3). Representative cross-

sectional images are illustrated in Figures 2 and 3.

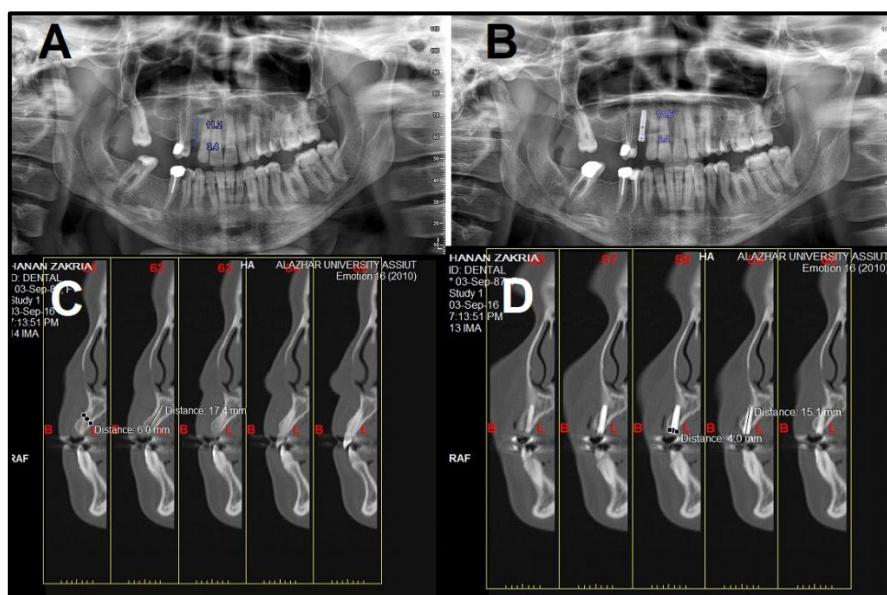


Figure 2. Representative clinical images illustrating preoperative and postoperative dental implant evaluation. (A) Digital panoramic radiograph showing measurements of alveolar bone height and width at the right maxillary canine edentulous site prior to implant placement. (B) Postoperative digital panoramic radiograph demonstrating implant placement at the right maxillary canine region with measurements of

implant length and diameter. (C) MDCT cross-sectional images with measurements of alveolar bone height and width at the selected implant site during preoperative evaluation. (D) MDCT cross-sectional images with measurements of implant length and width following placement. MDCT, multi-detector computed tomography.

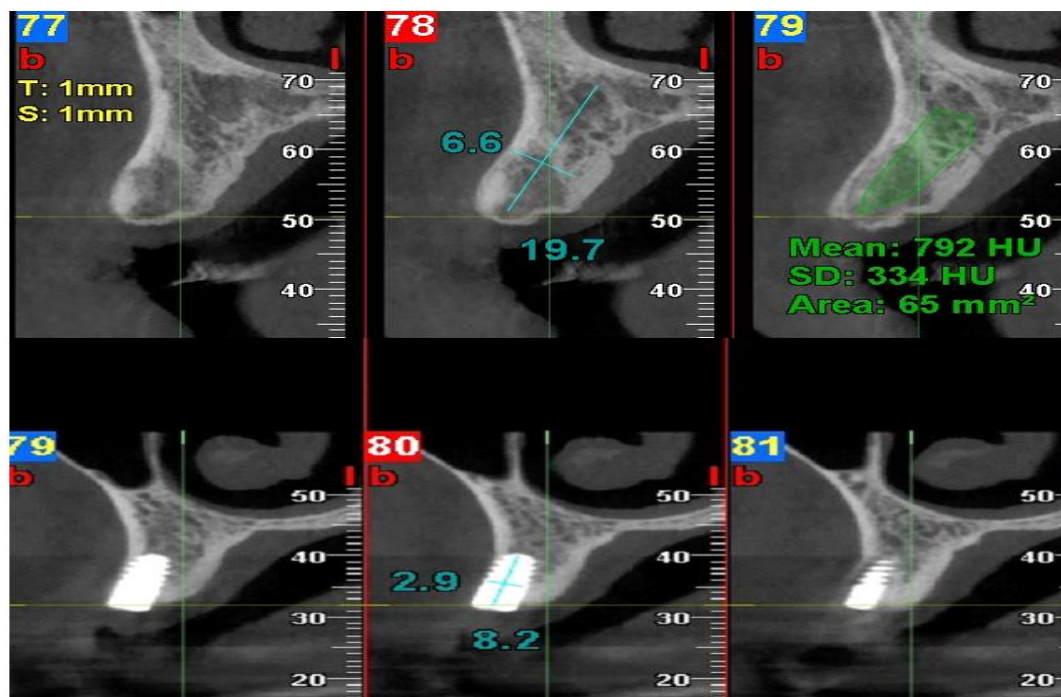


Figure 3. Representative CBCT cross-sectional images demonstrating measurements of alveolar bone height and width at selected implant sites during preoperative evaluation, and corresponding measurements of implant length and width following placement. CBCT, cone-beam computed tomography.

Radiation Dose

Radiation dose analysis revealed that MDCT had the highest exposure ($36 \pm 3.8 \mu\text{Sv}$), followed by CBCT ($24 \pm 2.1 \mu\text{Sv}$), and panoramic radiography exhibited the lowest dose ($14 \pm 2.5 \mu\text{Sv}$). Differences among modalities were statistically significant ($p < 0.001$; Table 2).

Interobserver Reliability

Interobserver agreement was excellent for both MDCT ($\kappa = 0.92$; ICC = 0.96) and CBCT ($\kappa = 0.89$; ICC = 0.94). Panoramic radiography demonstrated only moderate agreement ($\kappa = 0.64$; ICC = 0.71; Table 3), reflecting its inherent operator-dependent variability (Table 3).

Table 3. Interobserver Reliability of Imaging Modalities

Parameter	MDCT	CBCT	Panoramic Radiography
Cohen's κ	0.92	0.89	0.64
Intraclass correlation coefficient (ICC)	0.96	0.94	0.71
Agreement level	Excellent	Excellent	Moderate

DISCUSSION

This prospective study provides a comprehensive multi-parametric comparison of CBCT, MDCT, and digital panoramic radiography in the context of preoperative dental implant planning. The findings collectively demonstrate the superior diagnostic performance of 3D imaging modalities over conventional two-dimensional panoramic radiography across all evaluated parameters.

Both CBCT and MDCT exhibited significantly higher accuracy in alveolar bone measurements compared to panoramic radiography, with accuracy rates of 93% and 95%, respectively. These findings are consistent with prior literature emphasizing the limitations of two-dimensional imaging, particularly the magnification errors and geometric distortion inherent to panoramic radiography, as well as its fundamental inability to assess buccolingual bone dimensions.¹²⁻¹⁴

Regarding anatomical landmark visualization, both CBCT and MDCT demonstrated superior performance compared to panoramic radiography. Precise identification of critical structures—particularly the mandibular canal and maxillary sinus—is essential to prevent intraoperative neurovascular complications. The high detection rates observed in this study (97% for MDCT and 95% for CBCT) reinforce the clinical value of 3D imaging in enhancing surgical safety and planning accuracy.¹⁵⁻¹⁷

Bone density assessment remains a key distinguishing feature between MDCT and CBCT. In this study, MDCT provided reliable quantitative measurements using HU, supporting its established role as the reference standard for bone quality evaluation. In contrast, CBCT-derived grayscale values served only as a semi-quantitative indicator, reflecting the known limitations in standardization and reproducibility of CBCT-based density measurements. This finding is consistent with existing literature suggesting that CBCT is less reliable than MDCT for absolute bone density quantification.¹⁸⁻²⁰

Image quality analysis revealed marginally higher scores for MDCT compared to CBCT, although both modalities were rated significantly higher than panoramic radiography. The superior soft tissue contrast and standardized acquisition parameters of MDCT contribute to its higher image quality ratings. Nevertheless, CBCT provides sufficient spatial resolution and diagnostic quality for the majority of implant planning scenarios.^{20,21}

Radiation dose is a critical determinant in imaging modality selection. In the present study, MDCT demonstrated the highest radiation exposure, followed by CBCT, while panoramic radiography exhibited the lowest dose. Despite this, the significant diagnostic limitations of panoramic imaging must be carefully weighed against its lower radiation burden. CBCT, offering a substantially lower radiation dose than MDCT while maintaining high diagnostic accuracy, represents a more balanced and clinically appropriate choice for routine implant assessment.^{20,22,23}

Interobserver agreement was excellent for both CBCT and MDCT, as reflected by high κ and ICC values, indicating strong reproducibility and measurement reliability. In contrast, panoramic radiography showed only moderate agreement, likely attributable to its inherent two-dimensional limitations and greater operator-dependent variability. These findings highlight the importance of advanced imaging modalities in reducing diagnostic uncertainty and improving reproducibility in implant planning.^{19,24,25}

From a clinical perspective, the results of this study support the use of CBCT as the primary imaging modality for routine dental implant planning, offering an optimal balance between diagnostic performance, radiation safety, and clinical accessibility. MDCT should be reserved for complex cases requiring precise bone density assessment or evaluation of associated pathological conditions. Panoramic radiography may retain a role as an initial screening tool but should not be used as the sole modality for implant planning decisions.

LIMITATIONS

Several limitations of this study warrant acknowledgment. First, the single-center design and modest sample size ($n = 80$) may limit the generalizability of findings to broader patient populations. Second, although CBCT grayscale values were analyzed, no calibration phantom was employed to correlate them with HU—an important methodological limitation for bone

density comparisons. Third, this study did not evaluate long-term clinical outcomes (e.g., implant survival rates) in relation to the preoperative imaging modality used. Future multi-center studies with larger cohorts, standardized CBCT calibration protocols, and long-term clinical follow-up are warranted to further validate these findings and to perform cost-benefit analyses across modalities.

CONCLUSION

Within the limitations of this prospective study, CBCT demonstrated an optimal balance between diagnostic accuracy, image quality, and radiation dose, supporting its role as the preferred imaging modality for routine preoperative dental implant planning. MDCT remains valuable for complex cases requiring precise bone density quantification and detailed anatomical evaluation. Panoramic radiography,

while limited in diagnostic scope, may serve as an initial screening tool.

These findings are consistent with current clinical guidelines advocating the use of CBCT in dental implant planning and underscore the need for continued standardization of CBCT-based bone quality assessment protocols. Prospective studies correlating preoperative radiographic findings with postoperative implant outcomes are warranted to further validate these recommendations.

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