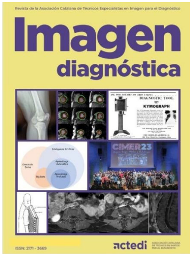

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Low-Dose Cone-Beam Computed Tomography for Posterior Mandibular Implant-Site Assessment: Image Quality and Diagnostic Reliability

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Abstract: Objective: To achieve diagnostic quality bone imaging with the lowest possible radiation dose in posterior mandibular implant planning while maintaining the ability to adequately visualize the dimensions of the residual ridge and the location of the mandibular canal and the lingual concavity. **Hypotheses:** The use of a low-dose Cone-Beam Computed Tomography (CBCT) protocol for evaluating implant sites in the posterior mandible will provide sufficient image quality and diagnostic reliability. **Objective:** To evaluate image quality and the level of diagnostic reliability for a low-dose Cone-Beam Computed Tomography (CBCT) protocol used for implant-site assessment in the posterior mandible. **Methods:** A total of 72 partially edentulous adults and 104 posterior sites of implants were included in this prospective study of diagnostic reliability. All patients underwent small-field low-dose CBCT using 90 kVp, 4 mA, 8.9-second exposure and 0.3 mm isotropic voxel size. Two oral radiologists and one implantologist independently assessed visibility of the mandibular canal, mental foramen, ridge crest, buccolingual width, lingual undercut and implant feasibility. The measurements by CBCT were compared with the intraoperative measurements of the ridge width in flap cases in a linear way. The subjective image quality was assessed on a 5-point scale. The Intraclass correlation coefficient, weighted Kappa, Bland-Altman bias and diagnostic agreement were computed. **Results:** The mean overall image quality score was 4.21 ± 0.54. In the mandible, the diagnostic criteria for visibility of the canal was 96.2% and for the mental foramen/ anterior loop was 93.3% for the PM. Vertical bone height (ICC = 0.94) and buccolingual ridge width (ICC = 0.91) had excellent interobserver reliability and the canal visibility had substantial interobserver reliability (weighted kappa = 0.79). The mean difference between CBCT and intraoperative ridge width was 0.18 ± 0.46 mm ($p = 0.08$). The percentages of agreement between implant feasibility decisions and expert consensus were 92.3%. In 31.7% of sites, a change of initial implant plan was made using low dose CBCT. **Conclusions:** The image quality and reliability of low-dose CBCT for the evaluation of posterior mandible implant site were acceptable. May be suitable when using a limited field of view and task specific exposure parameters as part of routine planning prior to surgery.

Key Words: Cone-Beam Computed Tomography, Low-Dose Protocol, Dental Implant Planning, Posterior Mandible, Mandibular Canal, Diagnostic Reliability, Image Quality

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INTRODUCTION

The Cone-Beam Computed Tomography (CBCT) imaging technique stands out as an important three dimensional diagnostic technique in oral implantology for cross-sectional assessment of alveolar bone volume, ridge morphology, anatomical constraints and restorative space [1]. Implant planning, especially in the posterior mandible, is highly sensitive due to the presence of the inferior alveolar nerve, which can affect the length of the implant, along with the mental foramen, anterior loop and submandibular fossa and lingual plate morphology that can influence implant length, angulation and safety margin [2]. While conventional panoramic radiography is useful as a preliminary examination, certain factors cannot be displayed reliably, including buccolingual width, lingual concavity and the true spatial relationship between the implant osteotomy and the mandibular canal [3].

The rationale of CBCT in implant dentistry is whether the extra information provided by CBCT will be a factor in the treatment plan or will diminish the risk of surgery. Cross-sectional information is needed for the evaluation of implant sites, especially in the posterior mandibular area and/or in a more complex anatomical region, which supports the use of CBCT as reported in consensus reports and systematic reviews [4]. CBCT is, however, not a regular screening examination and should only be ordered as a one-time examination. The imaging field, exposure parameters and voxel size should be determined based on a specific diagnostic task, not based on a device default value [5].

Optimizing radiation is a key issue in today's dental radiology. The principle of keeping exposure as low as diagnostically acceptable acknowledges that the lowest technical dose may not be useful when the image quality is not of the quality that is needed to perform the task [6]. The effective dose for dental CBCT can also vary significantly among scanners, fields of view and protocols and the excessive use of large fields of view and high resolution settings can lead to higher doses for the patient without providing meaningful clinical information [7]. The posterior mandibular implant planning is focused primarily on the high-contrast evaluation of the cortical boundaries, cortication of the mandibular canal, ridge width and ridge height. Such structures are possible to see even if the exposure is reduced, creating noise in the images.

Previous studies indicate that lower CBCT exposure parameters are sufficient to provide a satisfactory level of objective measurement for implant planning purposes and that this might be not satisfactory in challenging areas like the posterior mandible at the subjective level [8,9]. Dense cortical bone, trabecular pattern, metallic restorations, canal cortication or patient motion are other factors that influence the posterior mandible and may impact diagnostic accuracy. Thus, the usefulness of low-dose CBCT must be assessed not just based on the image appearance but also interobserver agreement and clinically relevant planning decisions.

The aim of the present study was to evaluate the use of low-dose CBCT for the evaluation of the implant site in the posterior mandible in a clinical setting. The purpose was to assess whether there was diagnostic competence when using a small-field low-dose protocol for identification of the mandibular canal and measurement of residual ridge dimensions. Other secondary aims were to assess interobserver agreement, expert consensus and to determine the correlation with the intraoperatively measured ridge width and how many cases the low-dose CBCT influenced the implant planning based on panoramic imaging.

METHODS

The study aimed at determining the reliability of the diagnosis of the referenced treatment plan was a prospective diagnostic reliability study carried out in the dental clinics of Batterjee Medical College, Jeddah, Saudi Arabia. The study was task-specific imaging and CBCT was only ordered when a posterior planning implant was indicated following clinical examination and panoramic radiography.

Eligible adult patients (21-75 years of age) were those with one or more missing pre-molars or molars who needed diagnosis of the implant-site area. Patients were selected for this study based on the following inclusion criteria: Partially edentulous posterior mandibular occlusion, availability of preliminary panoramic radiography and implant placement planned within three months of radiography. Those who were excluded included pregnant women, previous fracture or reconstructive surgery of the mandible, pathology deforming the implant site, patients who could not remain still during the scan and patients with extensive metal artifacts that obscured the region of interest and patients who refused to participate.

Seventy-two patients with 104 posterior mandibular implant sites were enrolled. Single and short-span edentulous sites were included in the sample. At each site, a preliminary panoramic-based planning was carried out by an implantologist prior to the examination of CBCT data. The planned implant length, diameter, augmentation and surgical risk category were documented. Next, low dose CBCT scans were obtained and the planning process was repeated with the help of multiplanar reconstruction.

All scans were taken within a small field of view with only the mandibular quadrant/posterior mandibular segment visible. The low-dose protocol employed was 90 kVp, 4 mA, 8.9-second exposure time, 0.3 mm isotropic voxel size and noise reduction reconstruction with the manufacturer's software. Patients were seated and the occlusal plane was parallel to the floor, the center of the mandible was centered in the field. The motion control instructions were provided prior to scanning. Images were reconstructed at 1 mm intervals perpendicular to the dental arch, in axial, panoramic and cross-sectional planes.

All scans were independently evaluated by two oral and maxillofacial radiologists and one implantologist on calibrated monitors in a dimly lit reporting room. Each observer was blind to the other's score and the final decision. The following structures were examined: alveolar crest cortication, superior border of the mandibular canal, mental foramen, anterior loop (where present), lingual cortical plate and cancellous trabecular pattern in the submandibular fossa. The image quality was assigned a score of 1, non-diagnostic; 2, it was poor but was partially usable; 3, it was acceptable; 4, it was good; or 5, it was excellent. A score of 3 or greater was deemed to be for diagnostic purposes.

Standardized cross-sectional slices were taken and measured at the proposed implant center to take linear measurements. The vertical height was determined from the alveolar crest to the superior border of the mandibular canal, without subtracting a planned safety zone for evaluating implant feasibility. The width of ridges in the buccolingual direction, measured at right angles to the vertical height line, was measured at the crest and 3 mm apically from the crest. Axial and reconstructed panoramic views were used to measure mesiodistal space. Lingual undercut was categorized as absent, shallow, moderate and severe based on the depth and contour of the submandibular fossa.

For open flap implant surgery, the width at the time of surgery was measured with a sterile bone caliper after the flaps were reflected and prior to preparing the osteotomy. This direct measurement was correlated to the CBCT ridge width at the respective implant centre. The location of the mandibular canal was not exposed during surgery and was only assessed by experts, not by direct measurement. This expert consensus panel comprised two senior radiologists and one senior implant surgeon who examined all available CBCT sections together and reached consensus through discussion.

The main outcome was the percentage of sites that had diagnostically acceptable low-dose CBCT image quality for implant planning of the posterior mandible. Secondary outcomes included mean image quality score, visibility of key anatomical structures, interobserver agreement for image quality categories and canal visibility, interobserver agreement of low dose CBCT-based implant feasibility with expert consensus, intraclass correlation coefficient for linear measurements, CBCT to intraoperative ridge width difference and changes in treatment plan when compared to panoramic-based planning.

The data was analysed in SPSS 26. All continuous variables were presented as the mean ± standard deviation. Categorized variables were presented as numbers and percentages. Interobserver agreement for linear measurements was determined by using the intraclass correlation coefficient (ICC, two-way random-effects model). Ordinal image-quality and visibility scores were determined using weighted kappa. The paired t-test was used to compare CBCT and intraoperative ridge width measurements. The measurement bias and limits of agreement were estimated using Bland-Altman analysis. A p-value <0.05 was considered statistically significant.

RESULTS

Seventy-two patients with 104 posterior mandibular implant sites completed imaging and analysis. The mean age was 48.6±11.8 years and 40 patients (55.6%) were female. The most common sites were mandibular first molars (38.5%), followed by second molars (24.0%), second premolars (21.2%) and first premolars (16.3%). Mean overall residual vertical bone height above the mandibular canal was 13.8±3.1 mm and mean buccolingual ridge width at the crest was 6.4±1.5 mm.

Table 1: Demographic and Implant-Site Distribution

Variable	Value
Patients analyzed	72
Posterior mandibular sites	104
Age (years)	48.6±11.8
Female/Male	40/32
First premolar sites	17 (16.3%)
Second premolar sites	22 (21.2%)
First molar sites	40 (38.5%)
Second molar sites	25 (24.0%)
Open-flap sites with direct ridge measurement	68 (65.4%)

Values are Mean±SD or number (%)

The low-dose protocol produced diagnostically acceptable overall image quality in 99 of 104 sites (95.2%). The mean overall image-quality score was 4.21±0.54. Mandibular canal visibility was acceptable in 100 sites (96.2%), while ridge crest and buccolingual cortical boundaries were acceptable in 102 sites (98.1%). Mental foramen and anterior loop visibility were acceptable in 56 of 60 premolar-region evaluations (93.3%). The five sites rated below diagnostic quality were associated with motion blur or metal streak artifacts from adjacent restorations.

Interobserver reliability was excellent for vertical bone height (ICC = 0.94, 95% CI 0.91-0.96) and buccolingual ridge width (ICC = 0.91, 95% CI 0.87-0.94). Agreement was substantial for canal visibility (weighted kappa = 0.79) and overall image quality category (weighted kappa = 0.76). Severe lingual undercut was identified in 11 sites (10.6%) and moderate undercut in 24 sites (23.1%). The observers agreed on undercut classification in 88.5% of sites.

Intraoperative caliper measurements were available for 68 open-flap implant sites. Mean CBCT ridge width was 6.52±1.42 mm, while mean intraoperative ridge width was 6.34±1.39 mm. The mean difference was 0.18±0.46 mm, indicating a small non-significant overestimation by CBCT ($p = 0.08$). Bland-Altman limits of agreement ranged from -0.72-1.08 mm. Absolute measurement error was ≤0.5 mm in 51 sites (75.0%) and ≤1.0 mm in 64 sites (94.1%).

Implant feasibility decisions based on low-dose CBCT agreed with expert consensus in 96 of 104 sites (92.3%). Sensitivity for identifying sites requiring plan modification was 89.2% and specificity was 94.0%. Compared with panoramic-based planning, low-dose CBCT changed the planned implant length, diameter, angulation or need for augmentation in 33 sites (31.7%). The most frequent reasons for modification were reduced vertical safety distance to the mandibular canal, narrower-than-expected buccolingual width and detection of lingual undercut (Table 1-3).

Table 2: Low-Dose CBCT Image Quality and Anatomical Visibility

Parameter	Acceptable sites n (%)	Mean score±SD	Reliability
Overall image quality	99 (95.2%)	4.21±0.54	Kappa = 0.76
Alveolar crest cortication	102 (98.1%)	4.35±0.49	Kappa = 0.81
Mandibular canal visibility	100 (96.2%)	4.18±0.61	Kappa = 0.79
Mental foramen/anterior loop	56/60 (93.3%)	4.07±0.66	Kappa = 0.74
Lingual cortical plate	101 (97.1%)	4.24±0.58	Kappa = 0.78
Submandibular fossa contour	98 (94.2%)	4.02±0.71	Kappa = 0.72

Acceptable score was defined as score ≥3 on a 5-point scale

Table 3: Diagnostic Reliability and Measurement Outcomes

Outcome	Result	p-value/95% CI
ICC for vertical bone height	0.94	95% CI: 0.91-0.96
ICC for buccolingual ridge width	0.91	95% CI: 0.87-0.94
CBCT ridge width (mm)	6.52±1.42	-
Intraoperative ridge width (mm)	6.34±1.39	-
Mean CBCT-intraoperative difference	0.18±0.46 mm	p = 0.08
Agreement with expert feasibility decision	96/104 (92.3%)	-
Plan modification after CBCT	33/104 (31.7%)	p<0.001

ICC: Intraclass correlation coefficient, CI: Confidence interval

DISCUSSION

The current study revealed that a small-field low-dose CBCT protocol yielded diagnostically acceptable image quality in the majority of the implant sites located in the posterior region of the mandible and exhibited high reliability for the measurements that were made. The results are clinically relevant, as when planning an implant in the posterior mandible, both anatomical safety and radiation responsibility are the key points to consider. A low-dose technique for maintaining the vision of the canal and the reliability of the width of the ridges may minimise the need for unnecessary radiation exposure without affecting planning confidence.

The diagnostic acceptability rate (95.2%) indicates that low-dose CBCT may be adequate for routine assessment of the posterior mandible for implant placement, provided the patient position and the imaging field are kept under control. The effective doses reported for dental CBCT use vary widely among different devices and fields of view and hence it is necessary to select the CBCT exposure protocol for each patient case individually rather than using a single exposure protocol [8]. Studies for implant planning have also demonstrated that it is possible to lower dose without compromising the diagnostic information for high-contrast bone evaluations [9].

The visibility of the mandibular canal was adequate at 96.2% of the sites and interobserver agreement was high. This is critical as the canal visibility and the mental foramen defines the vertical bone height available and the safe range for deciding the length of implants. CBCT is reported in earlier studies to be useful in planning mandibular implants if conventional radiographs are inadequate due to the improved visibility of the anatomical landmarks and agreement between observers [10].

The measurement of vertical bone height and buccolingual ridge width was found to be very reliable for linear measurement. This is consistent with the evidence that CBCT is a reliable and accurate means of obtaining linear measurements across the image in the area of presurgical treatment planning for implants; however, there may be instances in which the measurements are overestimated or underestimated by more than 1 mm in certain areas [11]. In this study, the difference in ridge width between the CBCT and the intraoperative measurement was 0.18 mm and may not be clinically significant when adequate surgical safety margins are used.

Recent systematic review evidence has also shown satisfactory accuracy of linear measurements from low-dose CBCT for implant planning but that there may be more difficulty with measurements in the posterior mandible than on other parts of the body [12]. That is what we have seen in our results. Patient movement and metal artifacts predominated as the cause of the few non-diagnostic or borderline scans and not low-dose noise. Hence, dose reduction should not be done without patient stabilisation, artefact reduction, selection and quality of the field and the reconstruction.

The plan modification rate observed after low-dose CBCT is also significant (31.7%). CBCT was used to modify panoramic-based plans, often due to a decrease in buccolingual width and/or proximity to the mandibular canal or lingual concavity. This is also clinically relevant with regard to the benefits of cross-sectional imaging in certain posterior mandibular locations. Some dose optimisation studies have shown that setting lower periods of exposure maintains objective implant planning parameter values but may not maintain subjective diagnostic confidence for different observers and regions [13,14]. In our study, the level of agreement did not decrease with less exposure, thus indicating that the protocol was still sufficient for the specified diagnostic task.

The image-quality scores were poorer in sites that had a metallic restoration near the edentulous span. This is as one would expect, as beam hardening and streak artifacts may affect the interpretation of the cortices, especially near the mandibular canal. In such instances, a modification of the field, artifact reduction algorithm, repeat scan only when needed and alternative planning strategies may be necessary. Importantly, artifacts may be more related to the reconstruction physics and metal distribution and thus may not be best addressed by increasing dose.

The study suggests that the adopted protocol for implant imaging should address the clinical question with diagnostic confidence and without any unnecessary radiation. The available low-dose implant-planning studies and reviews suggest that this can be achieved by reducing the milliamperage, exposure time and basis images for some tasks without sacrificing spatial definition and contrast [15-17]. However, low doses protocols need to be tested for each CBCT scanner, due to the differences in the design, detector efficiency and reconstruction algorithms of the various scanners.

The present study has certain limitations. It was performed with one CBCT unit and results cannot be automatically extrapolated to other units. A standard-dose scan was not included in the study for direct comparison as the same clinical exposure was not repeated. The location of the canal was determined by the experts, not by an invasive procedure such as surgery (which would be unethical in routine implant surgery). Only the width of the ridge in open-flap cases was available during surgery. Also, surgical outcomes at the end of the surgery and neurosensory status after the surgery were not endpoints. Future multi-center studies are needed to document the accuracy of guided surgery and patient outcomes when using the low dose protocol that is specific to the device, as well as objective noise and contrast measurements and the effect of low dose planning.

CONCLUSIONS

Low-dose small-field CBCT achieved a diagnostically acceptable image quality and high diagnostic reliability for the evaluation of posterior mandibular implants. The protocol had excellent interobserver reliability for linear bone measurements, substantial agreement for visibility of the mandibular canal and close agreement with the intraoperative ridge width measurements. A significant number of panoramic-based planning procedures were also changed by low-dose CBCT, as it was able to reveal anatomical constraints that were not discernible on 2D imaging. Based on the limitations of this study, low-dose CBCT could be used as an appropriate preoperative imaging modality in selected posterior implant sites in mandibles based on diagnostic needs, with strict field-of-view limitation.

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