Original Article

Cone Beam Computed Tomography-Guided Implant Surgery: Radiological Evaluation of Accuracy and Safety

Ali Hakiem Tawfieq

ABSTRACT

Objective: To assess the radiographic accuracy, angular deviation, longitudinal deviations and clinical safety in digital volumetric computed tomography-guided implant inserted cases.

Study Design: Prospective cohort study

Place and Duration of Study: This study was conducted at the Department of Oral and Maxillofacial Surgery, Baquba Teaching Hospital, Iraq from 1st April 2025 to 31st December 2025.

Methods: 50 patients with 60 implant sites. All patients had digital volumetric computed tomography-guided planning and surgery with computer-aided design/computer-aided manufacturing-based surgical guides. Differences in implant positions (coronal, apical, and angular) between planning and the actual postoperative situation were evaluated by digital volumetric computed tomography. Safety results and clinical complications were documented.

Results: Average differences in length were within clinically relevant levels. Angular deviations remained within the safety range. Surgical precision was in line with previous literature, with the normal deviations of implant position <1 mm, and angular deviation <5°. No significant neurovascular injury occurred.

Conclusion: The high radiological accuracy and safety of cone beam computed tomography-guided implantation surgery make it possible using a standard procedure.

Key Words: Surgical guide, Dental implant, Cone beam computed tomography

Citation of article: Tawfieq AH. Cone Beam Computed Tomography-Guided Implant Surgery: Radiological Evaluation of Accuracy and Safety. Med Forum 2026;37(7):114-118. doi:10.60110/medforum.370723.

INTRODUCTION

Appropriate placing of dental implants is one of the fundamental principles which could contribute to successful long-term implants and reduce biological and mechanical complications. Failure to position it appropriately may cause damage to important anatomical structures (as the inferior alveolar nerve, maxillary sinus perforation or poor prosthesis result). Standard radiographic technology in two dimensions captures only limited space and introduces the risk of positioning errors when implanting implants.[1,2]

The advent of cone-beam computed tomography (CBCT) has transformed implant treatment planning by providing three-dimensional images of bony structures at a fraction of the radiation dose than that delivered by conventional computed tomography.[3]

Cone-beam computed tomography provides the opportunity to accurately evaluate bone volume, bone shape and proximity to vital structures, which are important for implant planning. CBCT directed to measurement also the dimensions of temporomandibular joint components, counting (glenoid fossa, mandibular condyle and articular eminence) and all bony component in maxillofacial area.[4,5]

By merging CBCT data with digital implant planning software the prosthesis can be driven on implant placement.[6,7] The adoption of a digital workflow aids computer-aided placement and positioning of the implant according to anatomical and restorative factors resulting in greater predictability while minimizing surgical risks.[6] The better diagnostic value of CBCT compared to panoramic radiography in implant treatment planning.[8,9]

Cone-beam computed tomography-guided implant placement utilizes CAD/CAM milled guides to guide the virtual treatment plan to the clinical reality.[10] These guidance limit drilling direction and depth of implantation which decreases the operator´s influence thought to have an impact on bone mineral density. The reduction of linear deviations and angular errors has been significantly recoded in clinical studies if implantation is guided compared to the freehand procedure.[11,12]

Although guided implant surgery offers benefits, however small discrepancies between planned and realised implant locations will occur even when all possible errors are minimised (guide stability,

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Received: February, 2026
Reviewed: March-April, 2026
Accepted: May, 2026

fabrication tolerances of the surgical template, surgical access and patient's movement). Hence, the radiological assessment of implant precision through postoperative CBCT images is mandatory in order to evaluate both the feasibility and safety of guided surgical procedures.[13,14]

The purpose of this study is to assess the radiological accuracy and safety of CBCT-guided implant placement at Baqubah Dental Teaching Hospital, Diyala, Iraq by comparing linear and angular differences between planned implants positions with that of those placed in addition to documenting surgical complications.

METHODS

This was a prospective cohort study was carried out at Department of Oral and Maxillofacial Surgery, Baquba Teaching Hospital, Iraq from 1st April 2025 to 31st December 2025 vide letter No. 338353QM/Approval/SFHP dated March 19, 2025. Fifty patients (28 males and 22 females) requiring dental implant therapy were enrolled, with a total of 60 implant sites included. The partially edentulous patients aged 25-65 years requiring guided implant placement were included. Uncontrolled systemic diseases, pregnancy, and poor oral hygiene were excluded.

Postoperative CBCT scans were acquired within 1 week after surgery. Deviations between planned and placed implant positions were measured in coronal linear deviation (mm), apical linear deviation (mm) and angular deviation (degrees). Clinical follow-up assessed as neurovascular complications, maxillary sinus perforations, soft tissue injuries and adverse events were recorded during surgery and up to 6 months postoperatively.

All patients received preoperative CBCT scans (Planmeca ProMax 3D) with standardized settings (FOV 10 × 10 cm, voxel size 0.2 mm), and intraoral scans for prosthetic planning. CBCT DICOM data were imported into guided implant planning software. Surgical guides were CAD/CAM fabricated with fully guided drill sleeves. Implants were placed via flapless or minimal flap approach. Postoperative CBCT scans were acquired within after surgery. Radiological accuracy was evaluated by measuring coronal deviation, apical deviation, and angular deviation between planned and actual implant positions using CBCT superimposition techniques. Measurements followed protocols validated in previous accuracy studies (Figs. 1-2). Intraoperative and postoperative complications, including neurovascular injury, sinus perforation, and infection, were recorded during a 6-month follow-up period. The data was analyzed through SPSS-25. t-test and ANOVA were used to compare deviations by arch, guide type, and surgical approach. Significance was set at $p<0.05$.

RESULTS

There were 30 (50%) males and 30 (50%) females (Table 1). Table 2 showed the ages of the patients who underwent dental implant. There were 21 (47.6%) females and 52.38% males in age group 25-35, 20 in age group 35-45, 50% females and 50% males, 10 in age group 45-55, 50% females and 50% males, and 9 in age group 55-65, 55.5% females and 44.4% males. Table 3 shows the number of dental implants in each jaw and in which region. The Mandible had 40 implants, 20 in the posterior region and 20 in the anterior region (50%). The maxilla had 20 implants, 10 in the posterior region and 10 in the anterior region (50%).

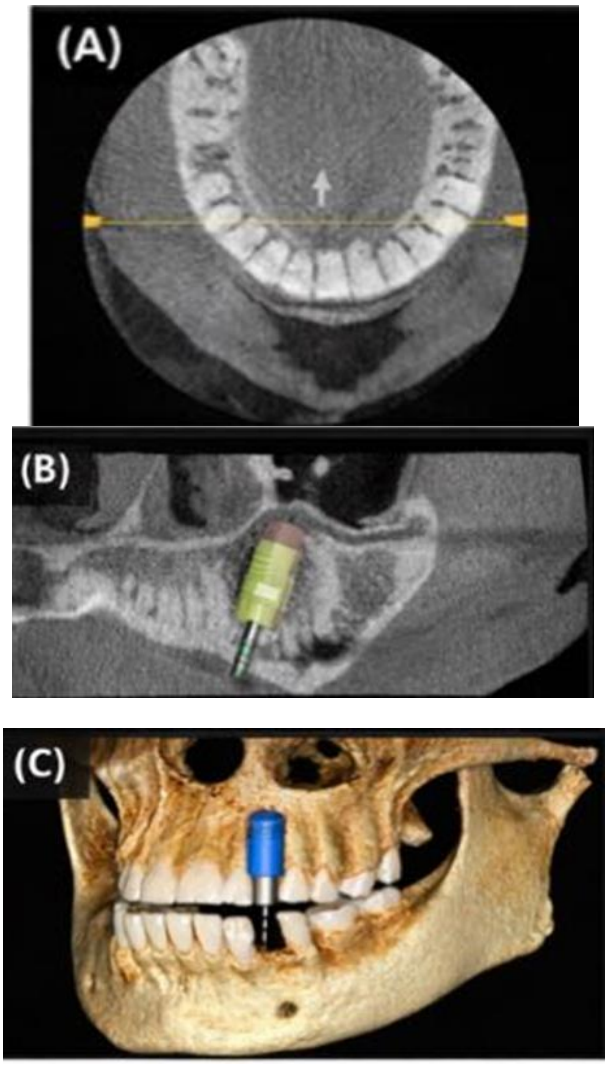

Figure No. 1: Preoperative CBCT images showing (A) axial view (B) Cross sectional view (C) 3D reconstructed with virtual implant plan

Figure No. 2: Surgical guide in place during implant insertion

Table 4 showed the postoperative complication, it was clarified that there is no problem after the implantation in 56 out of 60 cases, while there is a problem in 4 cases, representing a percentage of 93.3%. The post-transplant problems were manifested as sinus perforation Mild inflammation soft tissue injury.

Table No. 1: Gender of implant patients (n=60)

Gender	No.	%
Males	30	50.0
Females	30	50.0

Table No. 2: Age of implant patients (n=60)

Age (years)	Total	Females	Males
25 – 35	21	10 (47.6%)	11 (52.38%)
36-45	20	10 (50%)	10 (50%)
46-55	10	5 (50%)	5 (50%)
56-65	9	5 (55.5%)	4 (44.4%)

Table No. 3: Number of implant in each jaw and regions (n=60)

Jaw	Total	Posterior Region	Anterior Region
Mandible	40	20 (50%)	20 (50%)
Maxilla	20	10 (50%)	10 (50%)

Table No. 4: Postoperative Complications (n=60)

Complication	No.	%
No	56	93.3
Yes	4	6.7
Type of complication		
Sinus perforation	1	25.0
Mild inflammation	1	25.0
Soft tissue injury	2	50.0

DISCUSSION

The findings of this study could confirm that CBCT-guided implant surgery reached good radiological outcome with mean coronal and apical deviations equal or lower than 1.5 mm, as well as angular deviation lower than 5°. These results are within the clinically acceptable safety margin and compare favorably with results from previous prospective clinical studies.[15-17]

A few systemic reviews have demonstrated that guided implant surgery provides better position accuracy than freehand in terms of anatomically challenging areas such as the posterior maxilla and mandible. The slopes obtained in this study are similar to those reported by Tahmaseb et al[7] and Vercruyssen et al[15] corroborating the reproducibility of directed routines.

The tendencies in maxillary sites, with slightly higher variation than in mandibular regions, could be explained by the differing bone density and cortical width.[18] Low bone density in the posterior maxilla has been previously recorded as a parameter related with guide stability and accuracy of drilling possibly explaining these findings.[19,20]

From the safety point of view, no neurovascular injury and very few perforations into the sinus were seen in this study which underlines the protective effect of CBCT-based planning.[20] The precise display of the inferior alveolar canal and the maxillary sinus helps the operator maintain safe zones during virtual planning.[21]

However, guided implant surgery is not to be error-free also. Accuracy may be compromised due to factors such as incorrect guide seating, manufacturing tolerances and lack of mouth opening. Thus, caregivers should continue to have a high level of suspicion and clinical judgment when using guided systems. CBCT-guided implant surgery should be acknowledged as standard of care for advanced cases or in anatomically challenging anatomic sites. Although comparable accuracies can be achieved using the traditional method under specific conditions, the guided one allows reproducible planning and intervention with lesser human error.

The results of this study similar to those reported elsewhere suggested that CBCT guided implant surgery can be regarded as an accurate and safe procedure.[13,17,21] Yet long-term comparisons between radiological accuracy on one hand, and implant survival as well as prosthetic success, on the other are required. Future longitudinal studies should investigate long-term functional outcomes and cost-effectiveness in diverse populations.

CONCLUSION

Cone beam computed tomography-guided implant surgery demonstrates high radiological accuracy and a strong safety profile, supporting its role as an effective and predictable modality for implant placement.

Author's Contribution:

Concept & Design or acquisition of analysis or	Ali Hakiem Tawfieq

interpretation of data:	
Drafting or Revising Critically:	Ali Hakiem Tawfieq
Final Approval of version:	The above author
Agreement to accountable for all aspects of work:	The above author

Conflict of Interest: The study has no conflict of interest to declare by any author.

Source of Funding: None

Ethical Approval: No. 338353QM/Approval/SFHP Dated 19.03.2025

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