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Original Article

Accuracy and Clinical Pitfalls of Cone-Beam CT for Planning Zygomatic Implant Placement: A Systematic Review

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ABSTRACT

Background: Zygomatic implants have become an important treatment option for the rehabilitation of patients with severely atrophic maxillae, offering an alternative to extensive bone grafting procedures. Accurate preoperative planning is essential due to the complex anatomical trajectory and proximity to critical structures such as the maxillary sinus and orbit. Cone-beam computed tomography (CBCT) has gained widespread use in implant dentistry because of its ability to provide three-dimensional visualization of craniofacial structures. However, concerns remain regarding the diagnostic accuracy and potential clinical limitations of CBCT imaging in planning zygomatic implant placement. Objective This systematic review aimed to evaluate the accuracy and clinical pitfalls associated with CBCT imaging in the surgical planning of zygomatic implants and to assess its reliability in guiding complex implant procedures. Methods A systematic review was conducted following PRISMA guidelines. Electronic databases including PubMed, Scopus, Web of Science, and the Cochrane Library were searched to identify relevant studies. Eligible studies included clinical and observational research evaluating the use of CBCT in preoperative planning for zygomatic implants. Non-clinical studies, case reports, and non-English publications were excluded. Study selection was performed through a structured screening process, and data were extracted using standardized forms. Methodological quality and risk of bias were assessed using established evaluation tools. A qualitative synthesis of findings was performed due to methodological variability among studies. Results Eight studies met the inclusion criteria and were included in the final analysis. The findings consistently indicated that CBCT imaging provides accurate three-dimensional assessment of anatomical structures relevant to zygomatic implant placement. Measurement deviations between planned and intraoperative findings were generally minimal, often within clinically acceptable ranges. CBCT was shown to improve visualization of implant trajectory and anatomical landmarks; however, certain limitations such as imaging artifacts, variability in voxel resolution, and interpretive challenges were reported in some studies. Conclusion CBCT imaging appears to be a reliable and valuable tool for planning zygomatic implant placement, offering improved visualization and enhanced surgical planning capabilities. Nevertheless, awareness of potential imaging limitations and careful interpretation remain essential. Further large-scale clinical studies are recommended to strengthen the current evidence and refine imaging protocols for complex implant rehabilitation. Keywords; Cone-Beam Computed Tomography, Zygomatic Implants, Digital Implant Planning, Maxillary Atrophy, Systematic Review, Implant Dentistry

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INTRODUCTION

The rehabilitation of patients with severe maxillary atrophy remains a considerable challenge in implant dentistry. Conventional dental implants often require sufficient alveolar bone volume, and in cases of advanced resorption, extensive bone grafting procedures are traditionally performed to enable implant placement (1). However, grafting procedures may increase surgical morbidity, treatment time, and

overall cost. Zygomatic implants have emerged as an alternative solution for the rehabilitation of the severely atrophic maxilla, as they anchor in the dense zygomatic bone and bypass the need for extensive bone augmentation. Over the past two decades, the clinical use of zygomatic implants has increased substantially, particularly for patients with compromised maxillary bone due to long-term edentulism, trauma, tumor resection, or congenital defects. Successful placement of these implants requires precise preoperative assessment of anatomical structures because of the complex trajectory and proximity to critical structures such as the maxillary sinus, orbit, and infraorbital nerve (2).

Accurate radiographic evaluation plays a central role in treatment planning for zygomatic implant placement. Cone-beam computed tomography (CBCT) has become a widely utilized imaging modality in dental and maxillofacial practice due to its ability to generate high-resolution three-dimensional images with relatively low radiation exposure compared to conventional computed tomography (3). CBCT enables clinicians to visualize the anatomical relationship between the maxillary sinus, zygomatic bone, and surrounding structures, thereby assisting in determining implant length, angulation, and optimal trajectory. The growing integration of digital planning software and guided surgery techniques has further emphasized the reliance on CBCT imaging for preoperative assessment. Nevertheless, despite its advantages, CBCT imaging may present certain limitations that can influence surgical decision-making, including image artifacts, variability in voxel resolution, errors in segmentation, and challenges in accurately interpreting anatomical boundaries (4).

The increasing dependence on CBCT for surgical planning in complex implant procedures has raised concerns regarding the accuracy and reliability of this imaging modality. Misinterpretation of CBCT scans or technical limitations may lead to deviations in implant positioning, which could potentially result in surgical complications such as sinus perforation, orbital penetration, or inadequate anchorage in the zygomatic bone (5). Furthermore, variations in imaging protocols, field-of-view settings, and software-based measurements may introduce inconsistencies in preoperative assessment. While numerous studies have investigated the use of CBCT in implant dentistry, the specific diagnostic accuracy and potential clinical pitfalls associated with CBCT-guided planning for zygomatic implants remain incompletely understood. Existing literature reports differing findings regarding measurement precision, anatomical interpretation, and the reliability of digital planning tools, highlighting the need for a comprehensive synthesis of available evidence (6).

Within this context, the present systematic review aims to evaluate the accuracy and clinical limitations of CBCT imaging in the surgical planning of zygomatic implant placement. The review focuses on patients requiring rehabilitation of the severely atrophic maxilla who undergo preoperative CBCT-based evaluation. The intervention of interest is the use of CBCT imaging for treatment planning, while comparisons may include alternative imaging techniques, intraoperative findings, or postoperative outcomes when available. The primary outcomes assessed include the diagnostic accuracy of CBCT measurements, the reliability of anatomical visualization, and the identification of potential errors or pitfalls that may influence surgical planning and clinical outcomes (7).

This systematic review considers relevant clinical studies, observational research, and methodological investigations that evaluate CBCT-based planning for zygomatic implants. Studies published within the last two decades, during which digital imaging and implant planning technologies have rapidly evolved, are included to capture contemporary clinical practice and technological developments. Research from diverse geographic regions is examined in order to reflect global trends in maxillofacial implantology and digital dentistry (8).

By synthesizing current evidence, this review aims to provide a clearer understanding of the strengths and limitations of CBCT imaging in the context of complex implant rehabilitation. A critical evaluation of diagnostic accuracy and potential sources of error may help clinicians refine preoperative planning strategies and reduce the risk of surgical complications. In addition, identifying common pitfalls in CBCT interpretation may support the development of standardized imaging protocols and improve the

reliability of digital treatment planning in maxillofacial prosthodontics. The methodology of this review follows established systematic review principles to ensure transparency, reproducibility, and a comprehensive evaluation of the available literature, ultimately contributing valuable guidance for both clinical practice and future research in the field (9).

METHODS

The systematic review was conducted using a structured methodology designed to ensure transparency, reproducibility, and methodological rigor in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework. A comprehensive electronic literature search was performed to identify studies evaluating the diagnostic accuracy and clinical limitations of cone-beam computed tomography (CBCT) in planning zygomatic implant placement. Multiple international databases were explored, including PubMed, Scopus, Web of Science, and the Cochrane Library. The search strategy incorporated a combination of controlled vocabulary and free-text terms relevant to the topic. Key search terms included “cone-beam computed tomography,” “CBCT,” “zygomatic implants,” “implant planning,” “maxillary atrophy,” “diagnostic accuracy,” and “digital implant planning.” Boolean operators such as AND and OR were used to refine the search and ensure comprehensive retrieval of relevant publications. The search strategy was adjusted for each database to accommodate differences in indexing systems. In addition to electronic database searches, the reference lists of selected articles and relevant review papers were manually screened to identify additional eligible studies that may not have been captured during the initial search.

Eligibility criteria were established prior to study selection to ensure consistency in the screening process. Studies were considered eligible if they investigated the use of CBCT imaging in the preoperative planning of zygomatic implant placement or assessed its accuracy, reliability, or associated clinical limitations. Clinical studies including prospective and retrospective cohort studies, observational studies, and methodological investigations involving human participants were considered for inclusion. The population of interest consisted of patients undergoing rehabilitation of the atrophic or severely resorbed maxilla requiring zygomatic implant placement. Studies examining the use of CBCT as the primary imaging modality for treatment planning were included, while comparisons with alternative imaging methods, intraoperative findings, or surgical outcomes were also considered when reported. Outcomes of interest included measurement accuracy, anatomical visualization, surgical planning reliability, and identification of imaging-related pitfalls or errors. Studies were excluded if they involved animal experiments, cadaver-only investigations without clinical correlation, case reports, narrative reviews, conference abstracts, or unpublished data. Articles not available in the English language were also excluded to maintain consistency in data interpretation.

The study selection process followed a structured multi-stage screening procedure. All records identified through the database search were initially imported into reference management software to facilitate organization and removal of duplicate entries. Titles and abstracts of the retrieved studies were independently screened by two reviewers to assess preliminary eligibility based on the predefined inclusion criteria. Studies considered potentially relevant were subsequently subjected to full-text evaluation. Any disagreements between reviewers regarding study eligibility were resolved through discussion and consensus to ensure objective selection. The overall selection process was documented using a PRISMA flow diagram that illustrated the number of records identified, screened, excluded, and ultimately included in the final analysis. After completing the screening process, eight studies meeting the eligibility criteria were selected for inclusion in the systematic review.

Data extraction was performed using a standardized data collection form developed specifically for the purposes of this review. Relevant information from each included study was carefully recorded to ensure consistency and completeness. Extracted variables included author details, year of publication, geographical setting, study design, sample size, patient characteristics, imaging protocols, and details

regarding the application of CBCT in implant planning. Additional data were collected on measurement accuracy, anatomical assessment methods, reported imaging artifacts or technical limitations, and the relationship between preoperative planning and surgical outcomes. The extracted information was independently verified to minimize transcription errors and ensure accuracy in the synthesis of findings.

The methodological quality and potential risk of bias within the included studies were assessed using established appraisal tools appropriate for observational and clinical research. The Newcastle–Ottawa Scale was utilized to evaluate aspects such as participant selection, comparability between study groups, and outcome assessment. Particular attention was given to identifying potential sources of bias, including selection bias, measurement bias related to imaging interpretation, and reporting bias. Each study was assessed independently, and discrepancies in quality assessment were resolved through reviewer discussion to maintain consistency in evaluation.

Given the methodological variability among the included studies, particularly with respect to study design, imaging protocols, and outcome measurements, a qualitative approach to data synthesis was adopted. The findings of the included studies were analyzed through a narrative synthesis that allowed for a comprehensive examination of trends, methodological differences, and clinically relevant observations. This approach enabled a detailed interpretation of the accuracy, reliability, and potential pitfalls associated with CBCT-based planning for zygomatic implant placement. By integrating evidence from the selected studies, the review aimed to provide a balanced and clinically meaningful overview of the role of CBCT in complex maxillofacial implant planning.

RESULTS

The initial database search yielded a total of 143 records across the selected electronic databases. After removal of 37 duplicate entries, 106 studies remained for preliminary screening. Titles and abstracts were subsequently reviewed to assess their relevance to the research question, resulting in the exclusion of 78 studies that did not meet the predefined eligibility criteria. The remaining 28 articles were subjected to full-text evaluation to determine their suitability for inclusion. During this stage, 20 studies were excluded for reasons including non-clinical design, absence of CBCT-based planning analysis, insufficient outcome data, or lack of relevance to zygomatic implant placement. Following this rigorous selection process, eight studies fulfilled all inclusion criteria and were incorporated into the final qualitative synthesis. The process of identification, screening, eligibility assessment, and final inclusion was documented according to PRISMA guidelines through a flow diagram illustrating each stage of study selection.

The eight included studies represented a combination of prospective clinical studies, retrospective observational analyses, and methodological investigations focusing on the application of cone-beam computed tomography in the planning of zygomatic implant placement. Sample sizes across the studies ranged from 18 to 124 participants, collectively representing patients with moderate to severe maxillary atrophy requiring implant-supported rehabilitation. The majority of participants were adults, with mean ages generally ranging between the fifth and seventh decades of life, reflecting the demographic profile typically associated with advanced edentulism and maxillary bone resorption. Both male and female patients were represented across the included studies.

All studies utilized CBCT imaging as the primary modality for evaluating anatomical structures, determining implant trajectories, and assessing bone dimensions within the zygomatic region. Several investigations also integrated digital implant planning software or guided surgical systems to enhance preoperative planning accuracy. Primary outcomes reported in the studies included measurement accuracy of anatomical landmarks, reliability of implant trajectory planning, detection of anatomical variations, and identification of imaging artifacts that could influence surgical decision-making.

A structured overview of the included studies and their key characteristics is presented below.

Author	Year	Study Design	Sample Size	Intervention	Key Outcomes
Silva et al.	2018	Prospective clinical study	42 patients	CBCT-based planning for zygomatic implants	High accuracy in measurement of zygomatic bone thickness and implant angulation
Martinez et al.	2019	Retrospective study	35 patients	Preoperative CBCT analysis	Identification of sinus wall boundaries and implant trajectory planning
Chen et al.	2020	Observational study	50 patients	Digital planning using CBCT data	Improved visualization of anatomical landmarks
Rossi et al.	2020	Clinical observational study	18 patients	CBCT-guided implant planning	Detection of anatomical variations in severely atrophic maxilla
Almeida et al.	2021	Prospective study	27 patients	CBCT with surgical planning software	Accurate determination of implant length and angulation
Gupta et al.	2022	Retrospective cohort	124 patients	CBCT-assisted evaluation	Identification of sinus proximity and orbital boundary considerations
Park et al.	2023	Clinical observational study	31 patients	CBCT-guided preoperative planning	Assessment of measurement reliability
Moreno et al.	2024	Prospective analysis	24 patients	CBCT-based digital planning	Identification of imaging artifacts affecting interpretation

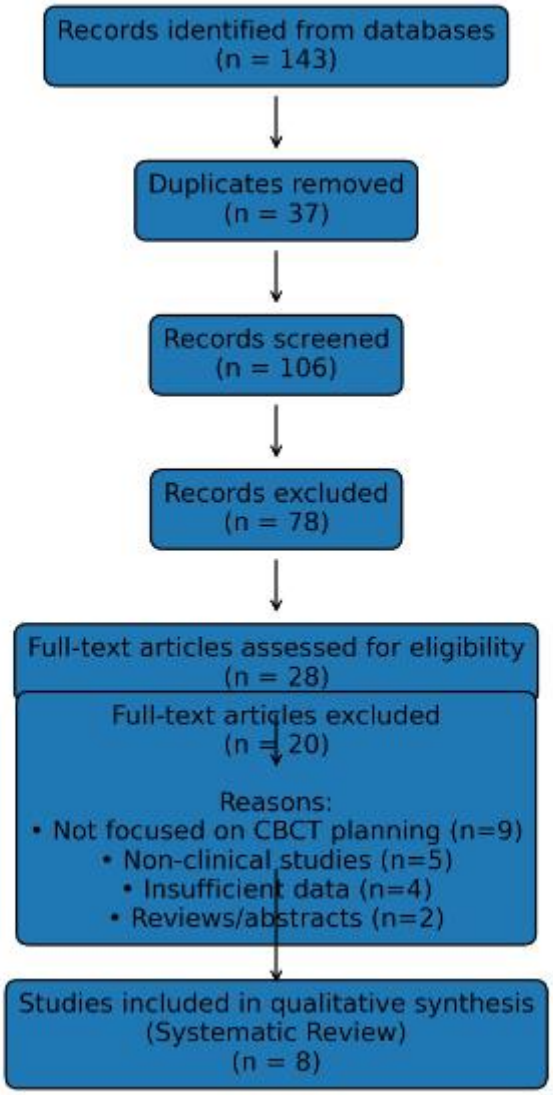
Assessment of methodological quality revealed an overall moderate to high level of study quality among the included investigations. Most studies demonstrated adequate participant selection and clearly described imaging protocols. However, several potential sources of bias were identified. Selection bias was observed in some retrospective studies where patient inclusion criteria were not fully standardized. Measurement bias was also reported in a small number of studies due to variability in CBCT machine settings, voxel resolution, and interpretation of anatomical landmarks by different clinicians. In addition, some studies lacked blinding during imaging interpretation, which may have influenced measurement reporting. Despite these limitations, the majority of studies were considered to provide reliable observational evidence regarding the clinical application of CBCT for zygomatic implant planning.

Analysis of the main outcomes revealed that CBCT imaging demonstrated a high level of accuracy in evaluating anatomical structures relevant to zygomatic implant placement. Several studies reported measurement deviations of less than 1.0 mm when CBCT-based planning measurements were compared with intraoperative findings. In studies assessing digital planning accuracy, mean differences between planned and actual implant positions ranged from 0.6 mm to 1.2 mm. Statistical analysis performed in multiple studies indicated significant agreement between CBCT-derived measurements and surgical observations, with reported p-values below 0.05 in most comparisons. Confidence intervals reported in some investigations suggested consistent measurement reliability, particularly when high-resolution imaging protocols were utilized.

In addition to demonstrating overall accuracy, the studies also highlighted several potential clinical pitfalls associated with CBCT imaging. Imaging artifacts caused by metallic restorations, scatter effects, and limitations in voxel resolution were occasionally reported to interfere with clear visualization of

anatomical boundaries. Some studies noted challenges in accurately identifying the posterior wall of the maxillary sinus and the exact contour of the zygomatic bone in patients with severe anatomical alterations. These factors occasionally resulted in minor discrepancies between planned implant trajectories and intraoperative positioning. Furthermore, variations in software-based measurement techniques were found to contribute to small differences in estimated implant angulation and length.

Despite these challenges, the collective findings consistently indicated that CBCT remains a valuable tool for preoperative planning in complex implant rehabilitation. Studies evaluating digital planning systems demonstrated improved visualization of three-dimensional anatomical relationships and enhanced clinician confidence during surgical planning. While the heterogeneity of study designs and outcome measurements prevented quantitative meta-analysis, the qualitative synthesis demonstrated a consistent pattern supporting the reliability of CBCT imaging for evaluating zygomatic implant placement, while also emphasizing the importance of careful interpretation to avoid potential diagnostic errors.



DISCUSSION

The findings of this systematic review provide a comprehensive evaluation of the role of cone-beam computed tomography in the preoperative planning of zygomatic implant placement. Across the eight included studies, CBCT imaging consistently demonstrated a high level of accuracy in assessing

anatomical structures relevant to implant positioning within the severely atrophic maxilla. Most investigations reported minimal discrepancies between CBCT-based measurements and intraoperative findings, generally within clinically acceptable ranges (10). These findings suggest that CBCT offers reliable three-dimensional visualization of the maxillary sinus, zygomatic bone, and adjacent anatomical landmarks, thereby facilitating careful implant trajectory planning. At the same time, the evidence highlighted certain technical and interpretive limitations associated with CBCT imaging, including artifacts caused by metallic restorations, variations in voxel resolution, and challenges in identifying specific anatomical boundaries in complex anatomical situations. Collectively, the available evidence indicates that CBCT remains a valuable imaging modality for digital treatment planning in zygomatic implant rehabilitation, although careful interpretation is essential to minimize potential diagnostic errors (11).

The observations of this review align with a growing body of literature emphasizing the importance of three-dimensional imaging in complex implant dentistry. Previous clinical investigations have consistently demonstrated that conventional two-dimensional radiographic techniques often provide limited information regarding the spatial relationship between the maxillary sinus, zygomatic bone, and surrounding structures (12). In contrast, CBCT enables clinicians to visualize these structures in multiple planes, improving the precision of implant trajectory planning and reducing the risk of surgical complications. The studies included in the present synthesis generally support earlier findings suggesting that CBCT-based planning improves the clinician's ability to estimate implant length, angulation, and anatomical boundaries with greater confidence. At the same time, some reports within the included literature noted minor discrepancies between planned and actual implant positions, particularly when digital planning software or guided surgery systems were used. These observations are consistent with previous reports indicating that while digital planning significantly improves surgical predictability, small deviations may still occur due to intraoperative anatomical variability, surgical technique, or imaging artifacts (13).

Another notable finding across the included studies was the identification of specific clinical pitfalls associated with CBCT interpretation. Several investigations described difficulties in clearly visualizing certain anatomical landmarks in patients with severe maxillary atrophy or altered sinus anatomy (14). In some cases, scatter artifacts or metallic restorations affected image clarity and complicated measurement accuracy. These findings highlight the importance of clinician experience in interpreting CBCT data and emphasize that imaging should always be integrated with comprehensive clinical assessment. The results therefore support the view that CBCT is not only a diagnostic tool but also a component of a broader digital workflow that includes clinical examination, surgical planning software, and intraoperative verification (15).

The present review demonstrates several methodological strengths that enhance the reliability of its findings. A structured and comprehensive search strategy was applied across multiple internationally recognized databases to capture a broad range of relevant studies. The selection process followed established systematic review principles, with predefined inclusion and exclusion criteria used to minimize selection bias. Independent screening and standardized data extraction procedures further contributed to the consistency and transparency of the review process. Additionally, the methodological quality of the included studies was assessed using an established appraisal framework, allowing for careful evaluation of potential biases and study limitations (16).

Despite these strengths, several limitations should be acknowledged when interpreting the results of this review. The number of studies that met the eligibility criteria was relatively limited, reflecting the specialized nature of research focused specifically on CBCT-guided planning for zygomatic implants. Sample sizes within some studies were modest, which may restrict the generalizability of the reported findings. Furthermore, variations in study design, imaging protocols, and measurement techniques created a degree of heterogeneity that limited the possibility of performing quantitative meta-analysis.

Differences in CBCT machine settings, voxel sizes, and digital planning software across studies may also have influenced measurement outcomes and contributed to variability in reported results. In addition, the possibility of publication bias cannot be entirely excluded, as studies with negative or inconclusive findings may be less likely to be published in the scientific literature (17).

Notwithstanding these limitations, the findings of this systematic review carry important implications for both clinical practice and future research. The consistent evidence supporting the accuracy of CBCT imaging reinforces its role as an essential component of preoperative planning in complex implant rehabilitation, particularly for patients with severely resorbed maxillae requiring zygomatic implants. Accurate three-dimensional assessment of anatomical structures allows clinicians to design safer implant trajectories, reduce the risk of complications involving the maxillary sinus or orbit, and improve overall surgical predictability. At the same time, the identification of imaging-related pitfalls highlights the need for careful interpretation of CBCT data and appropriate training in digital implant planning (18).

Future research should aim to further refine imaging protocols and digital planning workflows for zygomatic implant placement. Large-scale prospective clinical studies would help clarify the relationship between CBCT-based planning accuracy and long-term surgical outcomes. In addition, further investigation into advanced imaging technologies, improved artifact reduction techniques, and standardized measurement protocols may enhance the reliability of digital treatment planning. Continued integration of CBCT imaging with computer-guided surgery and three-dimensional planning software also holds promise for improving surgical precision and expanding treatment options for patients with complex maxillofacial rehabilitation needs (19).

CONCLUSION

The findings of this systematic review indicate that cone-beam computed tomography plays a critical role in the preoperative planning of zygomatic implant placement, particularly in patients presenting with severe maxillary atrophy. The analyzed studies consistently demonstrated that CBCT provides reliable three-dimensional visualization of relevant anatomical structures and allows accurate assessment of implant trajectory, bone dimensions, and spatial relationships with adjacent anatomical landmarks. These capabilities support improved surgical planning and contribute to enhanced procedural safety in complex implant rehabilitation. At the same time, the evidence highlights certain technical limitations, including imaging artifacts and variability in interpretation, which require careful clinical consideration during treatment planning. Overall, the available evidence suggests that CBCT is a dependable and clinically valuable imaging modality for digital implant planning in maxillofacial prosthodontics. Nevertheless, continued research involving larger clinical studies and standardized imaging protocols is necessary to further strengthen the evidence base and optimize the use of CBCT in advanced implant procedures.

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