Article

A CBCT-Based Comparative Study of Alveolar Bone Parameters and Implant Outcomes Among Patients Suffering the Mandibular First and Second Molar Defects

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AIM: This study aimed to evaluate the anatomical differences in the alveolar bone at edentulous sites of the mandibular first and second molars using cone-beam computed tomography (CBCT) and to assess their impact on implant outcomes, thereby providing clinical insights to improve implant success in the mandibular second molar region.
METHODS: A total of 504 patients with missing mandibular first or second molars were recruited in the Department of Stomatology at Foshan Fosun Chancheng Hospital between June 2020 and June 2023. These patients were divided into two groups: mandibular first molar loss (n = 226; as 'first-molar group') and mandibular second molar loss (n = 278; as 'second-molar group'). All patients underwent CBCT imaging, and measurements for parameters such as alveolar bone inclination, alveolar ridge width, and the distance from the alveolar crest to the mandibular canal were taken. Postoperative evaluations were conducted to assess deviations in the implant neck, apex, and insertion angle and to analyze the effect of anatomical parameters on implant outcomes in the mandibular second molar region.
RESULTS: There were no significant differences between the two groups in terms of sex, age, duration of tooth loss, presence of third molars, or smoking history ($p > 0.05$). The first-molar group exhibited significantly higher values for alveolar bone inclination, alveolar ridge width, and canal-crest distance compared to the second-molar group ($p < 0.05$). Immediately post-implantation, the neck deviation, apical deviation, and insertion angle deviation were all significantly lower in the first-molar group than in the second-molar group ($p < 0.05$). Six months postoperatively, the implant failure rate for the second-molar group (9.45%, $p < 0.001$) was significantly higher than that for the first-molar group (0.00%), along with greater marginal bone resorption ($p < 0.001$). Additionally, patients with failed implants in the mandibular second molar region showed significantly lower preoperative alveolar bone inclination than those with successful implants ($p < 0.05$).
CONCLUSIONS: The second-molar group presents less favorable anatomical conditions, such as reduced canal-crest distance and increased alveolar bone inclination, which may contribute to greater implant deviation when placed freehand. These findings suggest a need for enhanced preoperative planning and surgical precision in this region. However, as these observations are based on CBCT measurements and not direct intraoperative evidence, further studies are needed to validate these findings. Lower alveolar bone inclination may be a key factor in implant failure, highlighting the critical importance of preoperative planning and surgical precision in mandibular second molar implant procedures.

Keywords: cone-beam computed tomography; mandibular second molar defects; alveolar bone; implant outcomes

Introduction

The mandibular molars play a crucial role in chewing, maintaining dental arch morphology, and supporting tongue structures. Their loss is typically managed through implant restoration [1]. Due to anatomical characteristics in the mandibular second molar region, such as insufficient alveolar ridge height and a concavity in the lingual cortical plate of the mandibular body, the space available for implant placement is limited. Notably, the mandibular second molar tends to incline lingually, increasing the axial deviation of the implant. Additionally, being located deep in the oral cavity and having limited surgical visibility in this region further complicate the implant procedure for the mandibular second molar [2–5]. Therefore, a comprehensive assessment of the anatomical structure in the mandibular second molar area and the formulation of a precise implant plan are essential for improving clinical success rates.

Traditional two-dimensional imaging techniques are limited by overlap and distortion, which make visualization of complex mandibular anatomy challenging, especially in the mandibular second molar implant region. Cone-beam computed tomography (CBCT), with its advantages of clear three-dimensional imaging, low radiation dose, and high

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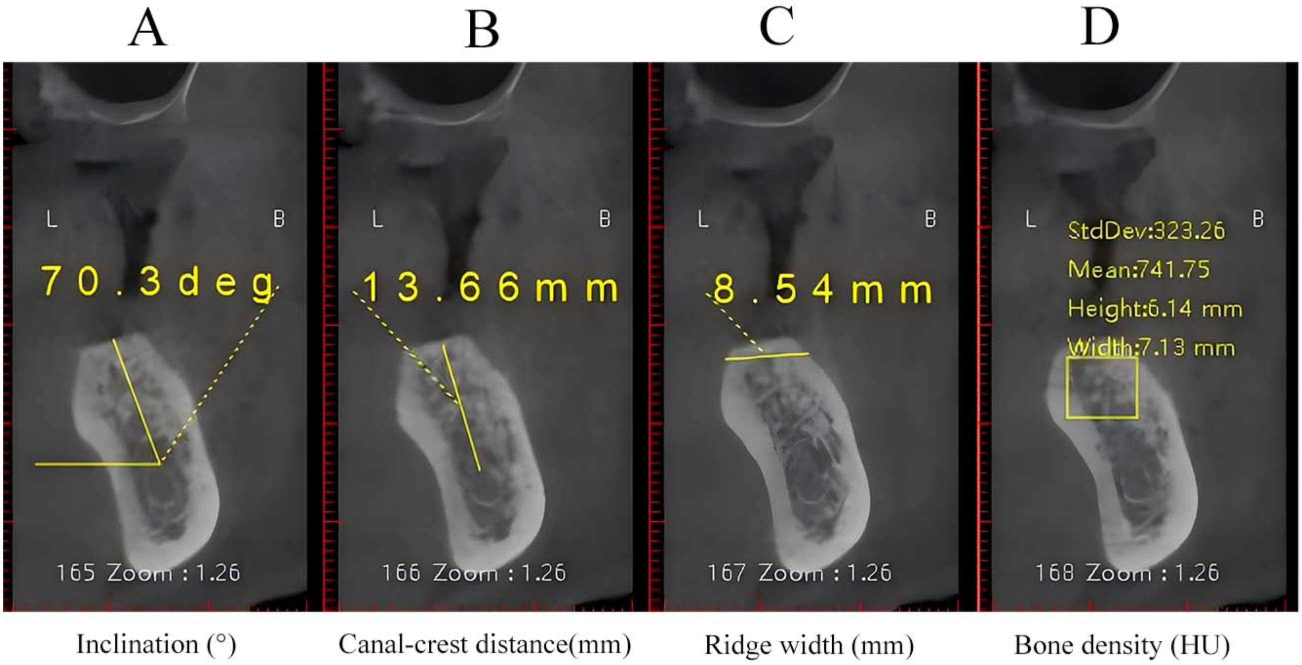

Fig. 1. Cone-beam computed tomography (CBCT) measurement parameters. (A) Alveolar bone inclination measurement. (B) Canal-crest distance measurement. (C) Alveolar ridge width measurement. (D) Bone density measurement, with the yellow-bordered box indicating the region of interest (ROI). HU, Hounsfield units.

spatial resolution, has become widely used in dental implantology, alveolar surgery, and periodontology [6–9].

In this study, CBCT was used to analyze the anatomical parameters of the alveolar bone in the mandibular second molar area, with the mandibular first molar serving as a control. The study aims to explore how these parameters impact implant outcomes, providing a theoretical basis for mandibular second molar implant restoration.

Materials and Methods

Study Subjects

This study included 504 patients with either mandibular first or second molar loss, who were treated at the Department of Stomatology, Foshan Fosun Chancheng Hospital, from June 2020 to June 2023. Among them, 226 patients had a missing mandibular first molar (included in the 'first-molar' group), and 278 had a missing mandibular second molar (included in the 'second-molar' group). All patients underwent CBCT imaging before surgery and were scheduled for implant restoration.

This study underwent an ethical review and was approved by the Medical Ethics Committee of Foshan Fosun Chancheng Hospital. The approval number is CYEC-LCYJ-2024014-PJ-20240628, and the approval date is 28 June 2024.

Inclusion criteria for this study are as follows: ① age ≥18 years; ② normal occlusion; ③ unilateral loss of the mandibular first or second molar, with a duration of more than 3 months; ④ presence of a normally erupted third molar without positional abnormalities or periodontal disease if the third molar is present; ⑤ sufficient keratinized gingiva width in the implant site; ⑥ good general health status, which is suitable for implant surgery; and ⑦ complete imaging records available.

Exclusion criteria for this study are as follows: ① pregnant or lactating women; ② patients with metabolic, endocrine, or circulatory disorders affecting bone health; ③ patients with a history of maxillofacial surgery or radiotherapy; ④ patients with craniofacial anomalies or moderate to severe dental crowding; ⑤ patients with acute systemic or oral inflammation; ⑥ patients with a history of heavy alcohol use; and ⑦ patients with imaging artifacts that severely hinder assessment.

CBCT Examination and Parameter Measurement

All patients underwent preoperative CBCT scanning using the Kavo 3D eXam CBCT device in adherence to these parameters: slice thickness 0.5 mm, resolution 0.3 mm, and field of view 16 × 12 cm, to ensure high-resolution imaging for accurate anatomical analysis.

All patients included in the study met the following criteria: soft tissue conditions: minimum 2 mm of keratinized gingiva, no inflammation, and no scarring.

Hard tissue conditions: alveolar ridge width ≥5 mm, canal-crest distance ≥10 mm, and bone density between 300 and 850 HU (Hounsfield units). These parameters were assessed through CBCT and clinical examination.

Patients were instructed to maintain a standing position with the head aligned. Three-dimensional image reconstruction

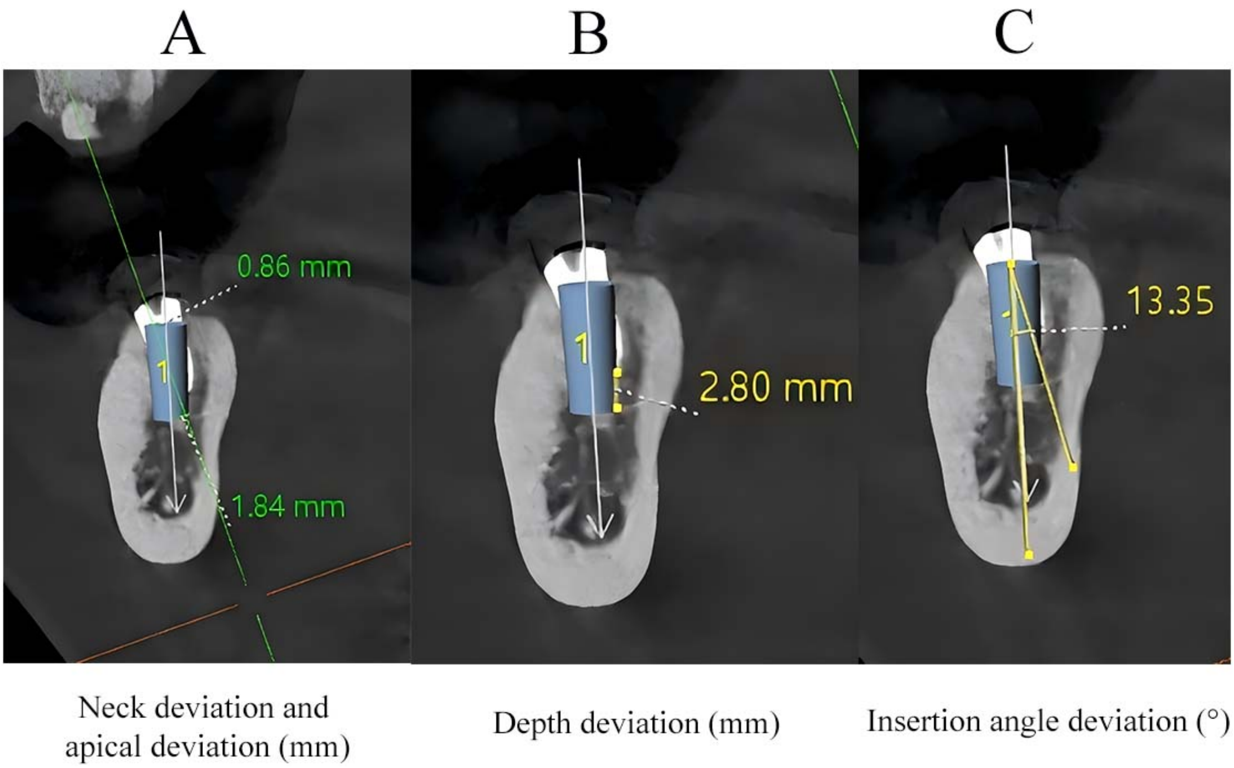

Fig. 2. Comparison of buccolingual parameter deviations in implantation. (A) Neck deviation in the buccolingual direction, showing the linear discrepancy at the implant shoulder. (B) Apical deviation in the buccolingual direction, illustrating the linear discrepancy at the implant apex. (C) Insertion angle deviation in the buccolingual direction, depicting the angular misalignment between planned and actual implant positions.

was performed with specialized software, and each anatomical parameter in the implant site was measured three times, with the average value recorded. Parameters stated below were measured: ① alveolar bone inclination (Fig. 1A); ② distance from the alveolar crest to the mandibular canal (canal-crest distance) (Fig. 1B); ③ alveolar ridge width (Fig. 1C); ④ alveolar bone density (measured in Hounsfield units) (Fig. 1D).

Alveolar Bone Inclination

Alveolar bone inclination refers to the angle between the line connecting the midpoint of the alveolar bone at the horizontal axis crossing the upper wall of the mandibular nerve canal and the crest of the alveolar ridge, and the horizontal axis. Alveolar bone inclination was measured using CBCT images. A horizontal plane was defined by a line passing through the superior border of the mandibular canal. The inclination angle was calculated between this horizontal plane and a line connecting the crest of the alveolar ridge to the midpoint of the alveolar bone. Measurements were repeated three times, and the average value was recorded.

Alveolar Bone Ridge Width

To measure the alveolar bone ridge width—which is the distance between the intersections of this line with the buccal and lingual edges of the alveolar bone—a vertical line was drawn 1 mm below the crest of the alveolar ridge, along the direction of the alveolar bone inclination.

Canal-Crest Distance

To measure the canal-crest distance, along the direction of the alveolar bone inclination, the distance from the crest of the alveolar ridge to the midpoint of the alveolar bone at the horizontal line crossing the upper wall of the mandibular nerve canal was measured.

Alveolar Bone Density

A rectangular region of interest (ROI) approximately 6 mm $\times$ 7 mm (42 mm^2) was selected 2 mm below the crest of the alveolar ridge. Bone density was measured in Hounsfield units (HU). The ROI was selected to minimize variability and ensure consistency in measurements.

Implant Surgery

Local infiltration anesthesia was administered with articaine, followed by a full-thickness mucoperiosteal flap. Pure titanium implants were placed directly by experienced surgeons using a freehand technique. Patients were followed up immediately post-surgery and again 6–12 months post-restoration, with CBCT images taken to evaluate implant outcomes.

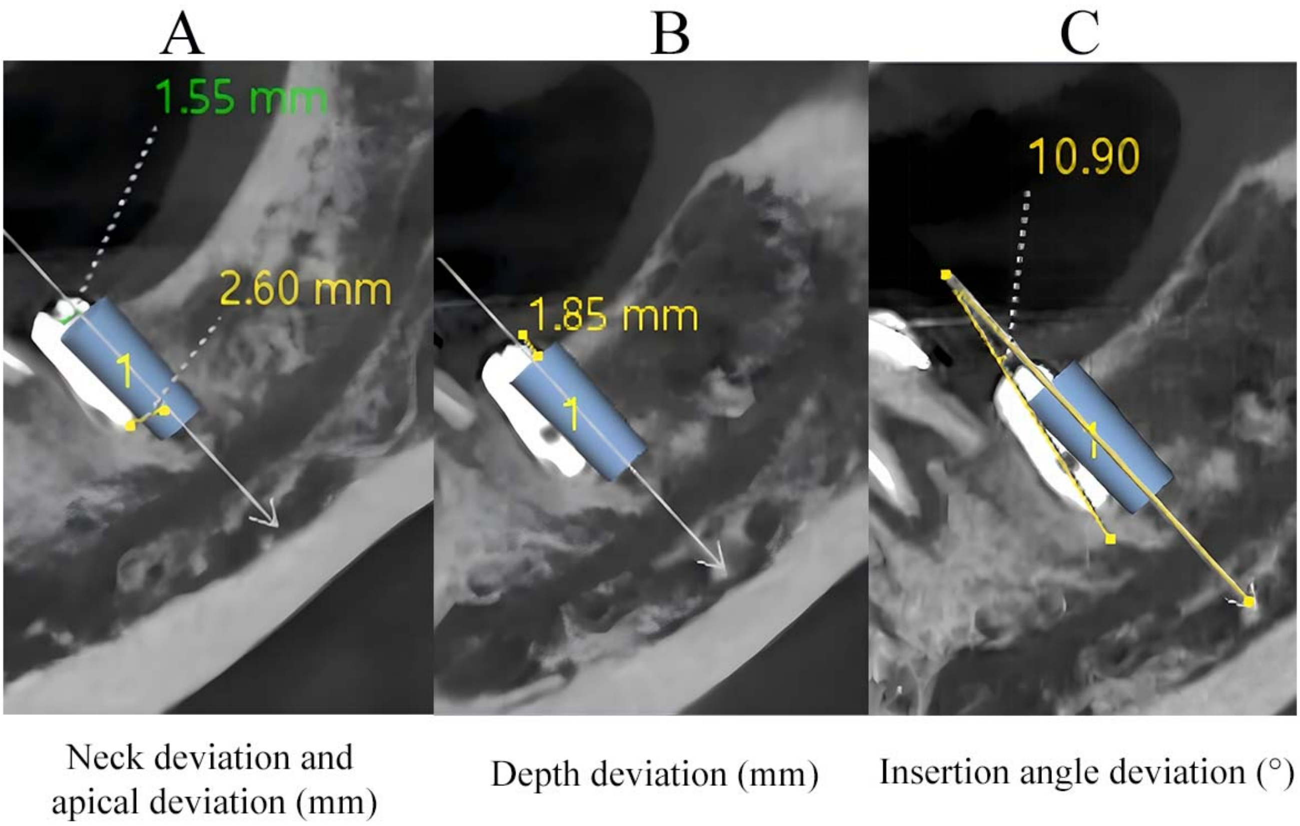

Fig. 3. Comparison of mesiodistal parameter deviations in implantation. (A) Neck deviation in the mesiodistal direction, showing the linear discrepancy at the implant shoulder. (B) Apical deviation in the mesiodistal direction, illustrating the linear discrepancy at the implant apex. (C) Insertion angle deviation in the mesiodistal direction, depicting the angular misalignment between planned and actual implant positions.

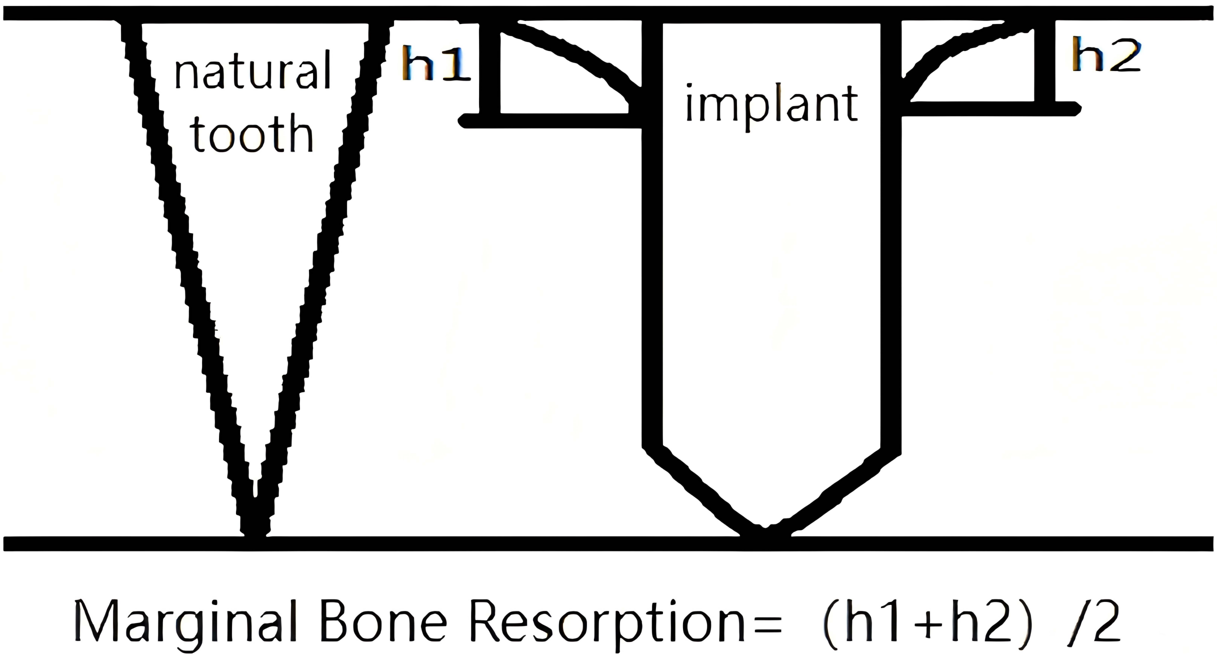

Fig. 4. Measurement of marginal bone resorption. The figure shows the measurement of marginal bone resorption using CBCT imaging, where a vertical line from the implant and bone position to a reference line determines the reduction in mesial and distal bone levels, averaged to calculate the resorption amount.

Table 1. Comparison of baseline characteristics in patients with mandibular first and second molar loss.

Group	n	Male/female	Age (years)	Duration of tooth loss (months)	Presence of third molar	Smoking history
First-molar	226	109/117	46.58 ± 7.69	9.45 ± 2.36	163 (72.12)	46 (20.35)
Second-molar	278	131/147	45.87 ± 8.43	8.96 ± 3.17	179 (64.39)	58 (20.86)
χ^2/t		0.061	0.978	1.929	3.420	0.020
p		0.804	0.329	0.054	0.064	0.888

Analysis of Implant Deviation

At follow-up, postoperative CBCT images were superimposed onto the preoperative planning images. The deviation between the actual and planned implant positions was compared in the buccolingual (Fig. 2) and mesiodistal directions (Fig. 3). The implants used in this study included various brands and models, such as Dentium Superline II (Dentium Co., Seoul, Republic of Korea), Straumann BLT (Straumann, Basel, Switzerland), and B&B Dental Implant EV lines (B&B Dental, Bologna, Italy), with diameters and lengths selected based on individual patient anatomy and clinical requirements. Implant sockets were prepared using sequential drilling under continuous irrigation to minimize the risk of bone burns. Torque settings for implant placement varied according to the implant system's specifications and the surgeon's clinical judgment to achieve optimal primary stability.

Measurement of Implant Deviations

CBCT scanning was performed using the same device and settings as the preoperative scan. The preoperative and postoperative scans were overlapped to compare the buccolingual and mesiodistal deviations between the preoperative design and the actual implant position, for measuring implant deviations. The measurements include:

(1) the angular deviation between the implant and the preoperative design direction;
(2) the distance from the implant apex to the upper wall of the mandibular nerve canal;
(3) the buccolingual thickness of the bone wall at the implant shoulder;
(4) the minimum distance between the implant shoulder and the adjacent implant or natural tooth;
(5) observation of any buccolingual perforation of the implant.

Evaluation of Marginal Bone Resorption

Panoramic radiographs were used to measure the marginal bone levels in the mesial and distal areas adjacent to the implant. The average of these values was taken as the representative measure of marginal bone resorption (Fig. 4).

Observational Indicators

The anatomical parameters of the alveolar bone in the implant sites of the mandibular first and second molars were compared. The implant outcomes for the mandibular first and second molars were evaluated, with failure defined as an implant angle deviation $>15°$, an insufficient distance from adjacent natural teeth or implants, or implant perforation of the cortical bone [10]. Additionally, the differences in alveolar bone parameters between patients with successful and failed mandibular second molar implants were analyzed.

Statistical Methods

All data were statistically analyzed using SPSS software (version 23.0, IBM Corp., Armonk, NY, USA). The normality of continuous variables was assessed using the Kolmogorov–Smirnov test, and variables are presented as mean ± standard deviation (SD) (for normally distributed data) or median ± interquartile range (for non-normally distributed data). Comparisons between groups for continuous variables were performed using independent-sample t-tests (or Mann–Whitney U tests when appropriate), while categorical variables were compared using chi-square tests or Fisher's exact tests as needed. Statistical significance was defined as $p < 0.05$.

Results

Comparison of Baseline Characteristics in Patients With Mandibular First and Second Molar Loss

According to Table 1, a total of 226 patients with mandibular first molar loss and 278 patients with mandibular second molar loss were included in this study. Number of molar loss at left and right sites for first-molar group was 130 (57.5%) and 96 (42.5%) cases, respectively, adding up to the total of 226 subjects in the group; whereas 140 (50.4%) and 138 (49.6%) individuals suffered molar loss at left and right sites, respectively, in the second-molar group of 278 cases upon re-verification, totaling in the group, presenting no statistically significant difference (p = 0.11). There were no statistically significant differences between the two groups in terms of gender, age, duration of tooth loss, presence of the third molar, or smoking history ($p > 0.05$), indicating that the baseline characteristics of both groups were comparable.

Comparison of CBCT-Measured Parameters in Mandibular First and Second Molar Implant Sites

CBCT measurements revealed that alveolar bone inclination, alveolar ridge width, and canal-crest distance in the

Table 2. Comparison of CBCT-measured parameters in mandibular first and second molar implant sites.

Group	n	Inclination (°)	Alveolar ridge width (mm)	Canal-crest distance (mm)	Bone density (HU)
First-molar	226	83.15 ± 13.46	6.63 ± 2.16	16.13 ± 2.66	463.88 ± 49.58
Second-molar	278	76.93 ± 12.09	5.46 ± 2.37	13.71 ± 2.79	459.43 ± 50.33
t		5.459	5.734	9.888	0.994
p		<0.001	<0.001	<0.001	0.321

Data presented above are normally distributed, as determined by the Kolmogorov–Smirnov test ($p > 0.05$), and thus presented as mean ± standard deviation (SD).

Table 3. Comparison of implant deviation between mandibular first and second molars.

Measurement location	Group	Neck deviation (mm)	Apical deviation (mm)	Depth deviation (mm)	Insertion angle deviation (°)
Buccolingual	First-molar	1.13 ± 0.32	2.65 ± 0.52	0.81 ± 0.19	5.43 ± 1.33
	Second-molar	1.81 ± 0.43	3.77 ± 0.46	0.84 ± 0.22	7.65 ± 1.72
	t	19.740	25.635	1.617	15.916
	p	<0.001	<0.001	0.106	<0.001
Mesiodistal	First-molar	1.63 ± 0.29	3.43 ± 0.74	0.84 ± 0.22	4.66 ± 1.39
	Second-molar	2.57 ± 0.46	6.38 ± 1.36	0.83 ± 0.24	6.43 ± 2.14
	t	26.705	29.273	0.483	10.729
	p	<0.001	<0.001	0.629	<0.001

first-molar group were significantly higher than those in the second-molar group ($p < 0.05$). However, no significant difference in bone density was observed between the two groups ($p > 0.05$), indicating similar bone density in both groups. These differences reflect the anatomical characteristics of the mandibular second molar region, such as reduced inclination and narrower alveolar ridge width, which may increase the difficulty of implant placement and the risk of implant deviation (Table 2).

Comparison of Implant Deviation Between Mandibular First and Second Molars

Immediately post-surgery, implant deviations in neck, apical, and insertion angle were assessed in both groups. The results indicated significantly greater deviations in the second-molar group, particularly in the buccolingual and mesiodistal directions ($p < 0.05$) (Table 3). This suggests that the anatomical conditions of the second molar region, with its narrower alveolar ridge and lower inclination, may increase the risk of positional deviation during implant placement.

Analysis of Implant Outcomes in Mandibular First and Second Molars

Six months later, 24 implant failures were identified in the second-molar group. Among the failed cases, 8 patients experienced cortical bone perforation during surgery, 10 patients exhibited marginal bone resorption >2 mm, and 6 patients had implant deviations >15° from the preoperative plan. Out of the initial 226 patients in the first-molar group, 206 completed the six-month follow-up, with no implant failures (0.00%). In the second-molar group, 254 out of 278 patients completed the follow-up, with 24 implant failures (9.45%, $p < 0.001$). Marginal bone resorption, measured for successful implants, was significantly greater in the second-molar group (0.59 ± 0.11 mm, n = 230) compared to the first-molar group (0.36 ± 0.09 mm, n = 206, $p < 0.001$) (Table 4). This indicates that the anatomical conditions of the mandibular second molar region may affect long-term implant stability, leading to a higher failure rate and increased marginal bone resorption. The discrepancy in patient numbers across Tables 1,2,4 arises from missing follow-up data for a small subset of patients in both groups.

Influence of Anatomical Parameters on Implant Outcomes in Mandibular Second Molars

In this analysis, the second-molar group initially comprised 278 patients with 24 implant failures. Thus, one would expect 254 successful implants; however, due to incomplete CBCT imaging data for 24 cases with otherwise successful implants, only 230 cases were included in the final analysis of anatomical parameters, with Table 5 reflecting data for this subset. Patients with lower preoperative alveolar bone inclination had a significantly higher implant failure rate (p = 0.027), suggesting that reduced inclination may be a key factor affecting implant stability and success rates.

Discussion

Tooth loss can significantly impair masticatory function, especially in anatomically complex areas like the mandibular molar region. Compared to the mandibular first molar, the mandibular second molar is often more inclined lingually and located deeper in the oral cavity, rendering implant placement more difficult [11]. Therefore, accurate assessment of the anatomical structure in the mandibular second molar region is crucial for enhancing implant success rates. Several studies have evaluated CBCT imaging in mandibu-

Table 4. Analysis of implant outcomes in mandibular first and second molars.

Group	Completed follow-up, n	Implant failure, n (%)	Marginal bone resorption (mm), mean ± SD (n)
First-molar	206	0 (0.00)	0.36 ± 0.09 (206)
Second-molar	254	24 (9.45)	0.59 ± 0.11 (230)
χ^2/t		20.536	24.159
p		<0.001	<0.001

Note: Out of the total 226 patients in the first-molar group, 206 had completed the six-month follow-up; out of 278 in the second-molar group, 254 had completed the follow-up. Marginal bone resorption was measured in cases of successful implants only.

Table 5. Influence of anatomical parameters on implant outcomes in mandibular second molars.

Group	n	Inclination (°)	Alveolar ridge width (mm)	Canal-crest distance (mm)	Bone density (HU)
Successful implant	230	77.65 ± 13.67	5.63 ± 1.69	13.68 ± 2.29	429.41 ± 46.58
Failed implant	24	71.15 ± 12.73	5.21 ± 1.53	12.83 ± 2.31	429.69 ± 47.86
t		2.230	1.168	1.729	0.028
p		0.027	0.244	0.085	0.978

lar molar implant outcomes, providing both consistent and contrasting findings to our study. For instance, Puri *et al*. [12] observed similar challenges in the mandibular second molar region, attributing higher implant deviation to concave ridge anatomy and limited bone volume, consistent with our results. Conversely, Shelley *et al*. [13] reported that CBCT imaging did not significantly alter implant perforation rates in anterior mandibular implants, suggesting that imaging alone may not mitigate surgical challenges without proper technique.

This study found that the alveolar bone inclination and alveolar ridge width were significantly lower in the mandibular second molar area compared to the first molar area. The observed implant failure rate of 9.45% in the second-molar group is higher than the typically reported rates for implant surgery. This elevated failure rate may be attributed to anatomical challenges in the second molar region, such as reduced canal-crest distance and lower alveolar bone inclination, both of which complicate implant placement. Furthermore, variations in surgical techniques, insufficient irrigation during drilling, and potential bone burns may have contributed to the increased failure rate. Possible contributing factors include anatomical challenges, lower preoperative bone inclination, and insufficient bone density in this group. Additionally, patient-specific factors, such as bone density, bone quality, and systemic health conditions, may have influenced implant outcomes. For example, patients with lower preoperative alveolar bone inclination often present with reduced bone volume and structural challenges that may compromise implant stability. These characteristics should be carefully evaluated during preoperative planning to minimize failure risks. These findings underscore the importance of preoperative planning and adopting computer-guided surgical techniques. The observed differences in canal-crest distance between the groups were modest (<1 mm). However, analysis of the failed cases revealed that lower bone density and reduced canal-crest distance collectively contributed to the higher failure rate in the second molar group. Additional studies are needed to further explore these associations.

The reduced bone volume in the mandibular second molar region may increase the likelihood of implant deviation in angulation, thus elevating the risk of implant failure. These findings highlight the need for further studies, particularly using guided surgical techniques, to validate these observations. Literature supports the notion that inclination significantly impacts implant direction; smaller inclination may hinder the maintenance of an optimal implant angle, potentially affecting occlusal function and long-term stability [14,15]. Patients with failed implants in the mandibular second molar region had significantly lower preoperative alveolar bone inclination (mean: 71.15° ± 12.73°) compared to those with successful implants (mean: 77.65° ± 13.67°, p = 0.027). Although the correlation between low inclination and failure appears significant, further analysis revealed that other factors, such as marginal bone resorption and surgical deviations, collectively contributed to the higher failure rate. These findings highlight the multifactorial nature of implant failure and the importance of addressing all potential risks during treatment planning. However, the influence of other factors such as bone density, anatomical challenges, and surgical technique cannot be ruled out. Table 5 includes bone density and inclination data for both successful and failed cases, highlighting these potential correlations. Furthermore, post-extraction reduction in alveolar ridge height directly affects implant restoration, a phenomenon particularly pronounced in the second molar region [16,17].

Both this study and the systematic review by Fokas *et al*. [18] confirm the importance of preoperative CBCT imaging in ensuring accurate implant placement. These studies emphasize that reduced canal-crest distance and lower bone inclination are critical risk factors influencing implant deviation, consistent with our findings. Interestingly, Ritter *et al*.

[19] found that implant deviations were less common in regions with higher bone density, while our study revealed no significant differences in bone density between successful and failed implants. This discrepancy may stem from variations in sample demographics or surgical techniques, such as the use of guided implant placements in some cases. The importance of advanced imaging and precise surgical planning, particularly in complex anatomical regions, is also underscored by the collective insights in other studies. For instance, the use of digitally guided surgery, as suggested by Sener *et al*. [20], could address the limitations of freehand techniques observed in our study.

The study also showed a shorter canal-crest distance in the second-molar group, limiting implant length options. In complex anatomical regions, using shorter implants may be a reasonable choice to minimize pressure on the mandibular nerve and reduce the risk of complications [21,22].

Although bone density did not differ significantly between the two groups, implant deviation was notably higher in the second-molar group, particularly in the buccolingual and mesiodistal directions. This may be due to the complex anatomy of the mandibular second molar area and limited surgical visibility [23]. Deviations in implant positioning can compromise initial stability and increase the risk of implant failure and postoperative complications.

A six-month follow-up showed a higher implant failure rate and significantly increased marginal bone resorption in the second-molar group. These outcomes may be related to the unfavorable anatomical conditions in this region, especially for patients with lower preoperative alveolar bone inclination, who had a higher implant failure rate. Lower inclination increases the likelihood of implant deviation from the ideal angle and position, compromising implant stability and leading to long-term failure.

The higher failure rate in the mandibular second molar region underscores the importance of a comprehensive approach to implant planning. Factors such as anatomical constraints, reduced bone inclination, and variations in surgical technique all play significant roles. Future studies should explore advanced imaging techniques, patient-specific risk assessments, and the use of guided surgical systems to minimize deviations and optimize outcomes in complex regions like the mandibular second molar.

While this study provides preliminary data on the challenges of mandibular first and second molar implants, several limitations remain. First, the follow-up period was short, limited to six months, focusing on initial implant stability. However, long-term implant success often requires extended follow-up (e.g., 1–2 years) for comprehensive evaluation. Future studies should extend the follow-up period to further validate these results and assess the long-term survival rates and marginal bone changes around implants.

Second, although the sample size in this study was relatively large, the analysis of cases lost to follow-up and specific reasons for implant failure was insufficient. Future research should investigate additional factors associated with implant failure, such as general health status, postoperative care, occlusal force distribution, smoking, and medication use. Introducing multivariable analysis could help further understand how these factors influence the long-term stability of implants.

Moreover, future studies should consider comparing different implant techniques in complex anatomical regions. For example, comparing freehand placement with digitally guided implants to determine if the latter can effectively reduce deviations and improve initial and long-term stability [24,25]. Additionally, evaluating the soft tissue conditions in the implant site, particularly the thickness of soft tissue and the width of keratinized gingiva, is necessary, as these factors may play a vital role in the long-term success of implants [26].

This single-center design may limit generalizability to broader populations. Additionally, potential CBCT measurement errors and variability in surgeon experience could influence outcomes. Future multi-center studies with standardized protocols and extended follow-up periods are recommended.

In summary, future research should focus on extending follow-up duration, incorporating multidimensional analyses, and exploring new techniques to optimize implant strategies for mandibular second molars and enhance implant success rates [27,28].

Conclusions

This study demonstrates that the anatomical conditions in the mandibular second molar region are less favorable, resulting in greater implant deviation, lower success rates, and increased marginal bone resorption. However, as these observations are based on CBCT measurements and not direct intraoperative evidence, further studies are needed to validate these conclusions. Clinically, practitioners should pay special attention to alveolar bone inclination and width in the second molar region, selecting appropriate implant lengths and insertion angles to minimize implant deviation. Additionally, future studies should extend the follow-up period and employ multidimensional analyses of factors related to implant failure to further refine implant strategies, with the purpose of improving successful implant rates and long-term stability. Clinical practitioners are encouraged to explore the application of new techniques, such as digital navigation, which might provide more solutions for overcoming the challenges posed by complex anatomical regions.

Availability of Data and Materials

The data analyzed are available from the corresponding author upon reasonable request.

Author Contributions

ZBM designed the research study, performed the research, and took the lead in writing the manuscript. ZLD analyzed the data. WHZ, as the corresponding author, designed the research study and supervised the project, provided critical input on the study design, and contributed to the writing and revision of the manuscript. All authors contributed to important editorial changes in the manuscript. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

This study was conducted in accordance with the Declaration of Helsinki. The study was approved by the Medical Ethics Committee of Foshan Fosun Chancheng Hospital (CYEC-LCYJ-2024014-PJ-20240628). The principle of informed consent was followed throughout the experiment, with information about the study provided to patients or their families, and consent obtained.

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Conflict of Interest

The authors declare no conflict of interest.

References

[1] Oshida Y, Tuna EB, Aktören O, Gençay K. Dental implant systems. International Journal of Molecular Sciences. 2010; 11: 1580–1678. https://doi.org/10.3390/ijms11041580.

[2] Ikbal M, Shen YW, Ruslin M, Fuh LJ, Hsu JT. Assessment of sagittal root position, alveolar bone concavity, and labial bone perforation in the mandibular anterior tooth region for immediate implant placement. Journal of Dental Sciences. 2023; 18: 1227–1234. https://doi.org/10.1016/j.jds.2023.01.034.

[3] Yu SK, Kim S, Kang SG, Kim JH, Lim KO, Hwang SI, *et al*. Morphological assessment of the anterior loop of the mandibular canal in Koreans. Anatomy & Cell Biology. 2015; 48: 75–80. https://doi.org/10.5115/acb.2015.48.1.75.

[4] Teixeira LCL, da Silva BG, Couto MK, Tolentino EDS, da Silva MC. Bifurcation of the mandibular canal according to sex, age, and facial skeletal pattern: a morphological and morphometric study of cone beam computed tomography. Surgical and Radiologic Anatomy: SRA. 2024; 46: 1073–1080. https://doi.org/10.1007/s00276-024-03394-x.

[5] Ahmed AA, Ahmed RM, Jamleh A, Spagnuolo G. Morphometric Analysis of the Mandibular Canal, Anterior Loop, and Mental Foramen: A Cone-Beam Computed Tomography Evaluation. International Journal of Environmental Research and Public Health. 2021; 18: 3365. https://doi.org/10.3390/ijerph18073365.

[6] Alshomrani F. Cone-Beam Computed Tomography (CBCT)-Based Diagnosis of Dental Bone Defects. Diagnostics (Basel, Switzerland). 2024; 14: 1404. https://doi.org/10.3390/diagnostics14131404.

[7] Benavides E, Rios HF, Ganz SD, An CH, Resnik R, Reardon GT, *et al*. Use of cone beam computed tomography in implant dentistry: the International Congress of Oral Implantologists consensus report. Implant Dentistry. 2012; 21: 78–86. https://doi.org/10.1097/ID.0b013e31824885b5.

[8] Jain S, Choudhary K, Nagi R, Shukla S, Kaur N, Grover D. New evolution of cone-beam computed tomography in dentistry: Combining digital technologies. Imaging Science in Dentistry. 2019; 49: 179–190. https://doi.org/10.5624/isd.2019.49.3.179.

[9] Yeung AWK. Seminal Works and Historical Roots of Dental Implant Research with the Use of CBCT. The International Journal of Oral & Maxillofacial Implants. 2021; 36: 731–736. https://doi.org/10.11607/jomi.8669.

[10] Guzmán J, Abarca J, Navarro P, Garay I, Arnabat-Domínguez J, Betancourt P. Morphometric Analysis of the Mandibular Canal and Its Anatomical Variants in a Chilean Subpopulation: Cone Beam Computed Tomography Study. Diagnostics (Basel, Switzerland). 2024; 14: 1914. https://doi.org/10.3390/diagnostics14171914.

[11] Kong ZL, Wang GG, Liu XY, Ye ZY, Xu DQ, Ding X. Influence of bone anatomical morphology of mandibular molars on dental implant based on CBCT. BMC Oral Health. 2021; 21: 528. https://doi.org/10.1186/s12903-021-01888-3.

[12] Puri A, Verma P, Mahajan P, Bansal A, Kohli S, Faraz SA. CBCT Evaluation of the Vital Mandibular Interforaminal Anatomical Structures. Annals of Maxillofacial Surgery. 2020; 10: 149–157. https://doi.org/10.4103/ams.ams_144_19.

[13] Shelley AM, Ferrero A, Brunton P, Goodwin M, Horner K. The impact of CBCT imaging when placing dental implants in the anterior edentulous mandible: a before-after study. Dento Maxillo Facial Radiology. 2015; 44: 20140316. https://doi.org/10.1259/dmfr.20140316.

[14] Liu H, Wu X, Tan J, Li X. Safe regions of miniscrew implantation for distalization of mandibular dentition with CBCT. Progress in Orthodontics. 2019; 20: 45. https://doi.org/10.1186/s40510-019-0297-6.

[15] Chen Y, Liao Q, Wu Y, He R, Zhang N, Liao Y, *et al*. Study of the mandibular canal and its surrounding canals by multi-view cone-beam computed tomography. Insights into Imaging. 2024; 15: 103. https://doi.org/10.1186/s13244-024-01676-x.

[16] Gabay E, Katorza A, Zigdon-Giladi H, Horwitz J, Machtei EE. Histological and dimensional changes of the alveolar ridge following tooth extraction when using collagen matrix and collagen-embedded xenogenic bone substitute: A randomized clinical trial. Clinical Implant Dentistry and Related Research. 2022; 24: 382–390. https://doi.org/10.1111/cid.13085.

[17] Rosano G, Testori T, Torrisi P, Invernizzi M, Vercellini N, Del Fabbro M. Immediate placement and loading of implants with laser-microgrooved collar in combination with an anorganic porcine bone mineral matrix in the esthetic zone. Twelve-month results of a prospective multicenter cohort study. Clinical Implant Dentistry and Related Research. 2023; 25: 1164–1177. https://doi.org/10.1111/cid.13261.

[18] Fokas G, Vaughn VM, Scarfe WC, Bornstein MM. Accuracy of linear measurements on CBCT images related to presurgical implant treatment planning: A systematic review. Clinical Oral Implants Research. 2018; 29 Suppl 16: 393–415. https://doi.org/10.1111/clr.13142.

[19] Ritter L, Neugebauer J, Mischkowski RA, Dreiseidler T, Rothamel D, Richter U, *et al*. Evaluation of the course of the inferior alveolar nerve in the mental foramen by cone beam computed tomography. The International Journal of Oral & Maxillofacial Implants. 2012; 27: 1014–1021.

[20] Sener E, Onem E, Akar GC, Govsa F, Ozer MA, Pinar Y, *et al*. Anatomical landmarks of mandibular interforaminal region related to dental implant placement with 3D CBCT: comparison between edentulous and dental mandibles. Surgical and Radiologic Anatomy: SRA. 2018; 40: 615–623. https://doi.org/10.1007/s00276-017-1934-8.

[21] Promma L, Sakulsak N, Putiwat P, Amarttayakong P, Iamsaard S, Trakulsuk H, *et al*. Cortical bone thickness of the mandibular canal and implications for bilateral sagittal split osteotomy: a cadaveric study. International Journal of Oral and Maxillofacial Surgery. 2017; 46: 572–577. https://doi.org/10.1016/j.ijom.2016.12.008.

[22] Wu W, Song L, Liu J, Du L, Zhang Y, Chen Y, *et al*. Finite element analysis of the angle range in trans-inferior alveolar nerve implantation at the mandibular second molar. BMC Oral Health. 2023; 23: 928. https://doi.org/10.1186/s12903-023-03641-4.

[23] Schnutenhaus S, Wagner M, Edelmann C, Luthardt RG, Rudolph H. Factors Influencing the Accuracy of Freehand Implant Placement: A Prospective Clinical Study. Dentistry Journal. 2021; 9: 54. https://doi.org/10.3390/dj9050054.

[24] Qiao SC, Wu XY, Shi JY, Tonetti MS, Lai HC. Accuracy and safety of a haptic operated and machine vision controlled collaborative robot for dental implant placement: A translational study. Clinical Oral Implants Research. 2023; 34: 839–849. https://doi.org/10.1111/clr.14112.

[25] Chen S, Ou Q, Lin X, Wang Y. Comparison Between a Computer-Aided Surgical Template and the Free-Hand Method: A Systematic Review and Meta-Analysis. Implant Dentistry. 2019; 28: 578–589. https://doi.org/10.1097/ID.0000000000000915.

[26] Tahmaseb A, Wismeijer D, Coucke W, Derksen W. Computer technology applications in surgical implant dentistry: a systematic review. The International Journal of Oral & Maxillofacial Implants. 2014; 29 Suppl: 25–42. https://doi.org/10.11607/jomi.2014suppl.g1.2.

[27] Araujo-Corchado E, Pardal-Peláez B. Computer-Guided Surgery for Dental Implant Placement: A Systematic Review. Prosthesis. 2022; 4: 540–553. https://doi.org/10.3390/prosthesis4040044.

[28] Gargallo-Albiol J, Barootchi S, Marqués-Guasch J, Wang HL. Fully Guided Versus Half-Guided and Freehand Implant Placement: Systematic Review and Meta-analysis. The International Journal of Oral & Maxillofacial Implants. 2020; 35: 1159–1169. https://doi.org/10.11607/jomi.7942.