SJIF Impact Factor (2025): 8.688| ISI I.F. Value: 1.241| Journal DOI: 10.36713/epra2016 ISSN: 2455-7838(Online)
EPRA International Journal of Research and Development (IJRD)
Volume: 10 | Issue: 10 | October 2025 - Peer Reviewed Journal

MORPHOMETRIC ASSESSMENT OF CRESTAL BONE AFTER OPEN AND CLOSED SINUS LIFTING BASED ON CONE-BEAM COMPUTED TOMOGRAPHY (CBCT) DATA

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Article DOI: https://doi.org/10.36713/epra24591
DOI No: 10.36713/epra24591

ANNOTATION

Purpose of the study. *Comparative morphometric evaluation of the crestal bone condition in patients after open and closed sinus lifting using cone-beam computed tomography (CBCT).*

Material and methods. *The study included 78 patients who underwent dental implantation with two types of sinus lifting: open (n = 40) and closed (n = 38). CBCT was performed with a slice thickness of 0.1 mm and voxel size of 0.15 mm. The following parameters were analyzed: crestal bone height, cortical plate thickness, bone density (HU), contour symmetry index (%), and frequency of microresorption (%). Statistical analysis was performed using the Student's t-test ($p < 0.05$).*

Research results. *Morphometric analysis revealed significantly better parameters of crestal bone after closed sinus lifting compared to the open technique: bone height - 3.42 ± 0.30 mm vs. 2.85 ± 0.35 mm ($p < 0.01$); cortical thickness - 0.96 ± 0.09 mm vs. 0.83 ± 0.08 mm ($p < 0.05$); density - 1015 ± 40 HU vs. 945 ± 45 HU ($p < 0.01$); and microresorption frequency - 8.1% vs. 17.5% ($p < 0.05$).*

Conclusions. *Closed sinus lifting ensures greater preservation of the crestal bone, higher mineral density, and reduced microresorption rates compared to the open approach. The obtained results confirm the biomechanical and clinical advantages of the closed method in ensuring long-term implant stability and predictable osteointegration.*

KEYWORDS. *Sinus lifting, crestal bone, CBCT, morphometry, bone density, microresorption, osteointegration, dental implantology.*

TOPICALITY

The preservation of crestal bone is one of the most critical factors determining the long-term stability and success of dental implants. Bone remodeling in the crestal zone is influenced by multiple surgical and biomechanical factors, including the method of sinus lifting. Open sinus lifting, although effective in creating sufficient bone volume, is associated with higher surgical trauma, increased risk of microresorption, and delayed osteointegration [1-3].

In contrast, closed sinus lifting represents a less invasive alternative that promotes more favorable bone regeneration, preservation of cortical integrity, and faster recovery of bone density [4,5]. Recent studies have shown that maintaining crestal bone height and density directly affects implant survival and reduces the incidence of marginal bone loss and peri-implant inflammation [6,7].

Despite the growing popularity of cone-beam computed tomography (CBCT) as a diagnostic tool, comparative morphometric data on crestal bone after open and closed sinus lifting remain limited. Therefore, conducting a detailed CBCT-based morphometric evaluation of crestal bone parameters-such as bone height, cortical thickness, and density-will provide objective insights into the regenerative potential of each method.

Thus, the study of crestal bone morphology after different sinus lifting techniques is relevant and timely. It helps optimize surgical decision-making, minimize postoperative bone loss, and ensure the biomechanical stability and longevity of dental implants, which is essential for improving clinical outcomes in modern implantology.

PURPOSE OF THE STUDY

To evaluate the morphometric parameters of crestal bone after open and closed sinus lifting using cone-beam computed tomography (CBCT)

RESEARCH MATERIALS AND METHODS

The study included 78 patients aged 35-65 years who underwent dental implantation in the lateral regions of the upper jaw using open (n = 40) and closed (n = 38) sinus lifting techniques. All participants had satisfactory osseointegration and no acute

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inflammatory or systemic contraindications. Cone-beam computed tomography (CBCT) was performed using a Planmeca ProMax 3D Mid (Finland) system with a slice thickness of 0.2 mm, reconstruction step 0.1 mm, and voxel size 0.15 mm. Morphometric analysis was carried out at three levels of the implant-crestal bone interface (1 mm, 3 mm, and 5 mm from the bone crest).

The following parameters were evaluated: Average crestal bone height (mm); Thickness of the cortical plate (mm); Bone density in Hounsfield Units (HU); Symmetry index of the bone contour (%); Frequency of microresorption (%). All measurements were performed in Planmeca Romexis 6.0 software. The statistical analysis was conducted using Student's t-test at a significance level of $p < 0.05$, and the results were presented as M ± m.

RESEARCH RESULTS

At the first stage, a subgroup analysis of morphometric changes in the crestal bone was carried out depending on the type of sinus lifting technique (open or closed). According to CBCT data, patients who underwent closed sinus lifting demonstrated significantly better preservation of crestal bone morphology compared to those after the open approach (Table 1).

Table 1

Morphometric Evaluation of Crestal Bone According to CBCT Data in Patients After Implant Placement

Parameter	Group I (Open sinus lifting, n = 40)	Group II (Closed sinus lifting, n = 38)	t	p
Mean height of crestal bone (mm, M ± m)	2.85 ± 0.35	3.42 ± 0.30	2.98	< 0.01
Thickness of cortical plate (mm, M ± m)	0.83 ± 0.08	0.96 ± 0.09	2.74	< 0.05
Density of crestal bone (HU, M ± m)	945 ± 45	1015 ± 40	3.21	< 0.01
Symmetry index of bone contour (%)	86.4 ± 4.2	91.8 ± 3.9	2.83	< 0.05
Frequency of microresorption (%)	17.5 ± 3.6	8.1 ± 2.9	2.41	< 0.05

Note. Statistical significance was determined using Student's *t*-test ($p < 0.05$; $p < 0.01$). Measurements were performed using CBCT (slice thickness = 0.1 mm) at the implant–crestal bone interface at 1, 3, and 5 mm from the alveolar crest. Bone density was expressed in Hounsfield Units (HU). The symmetry index reflects the homogeneity of the bone contour and uniformity of regeneration along the buccal and oral walls.

Morphometric evaluation (Table 1) demonstrated a statistically significant improvement in the parameters of crestal bone among patients who underwent closed sinus lifting compared to those treated with the open approach. The mean height of the crestal bone in Group II was 3.42 ± 0.30 mm, versus 2.85 ± 0.35 mm in Group I ($p < 0.01$), indicating a less invasive nature of the procedure and better preservation of peri-implant structures. The thickness of the cortical plate was also significantly higher in Group II (0.96 ± 0.09 mm) compared to Group I (0.83 ± 0.08 mm, $p < 0.05$), while bone density measured in Hounsfield Units reached 1015 ± 40 HU versus 945 ± 45 HU ($p < 0.01$).

The frequency of microresorption (localized areas of decreased bone density) in the implant neck region was almost twice lower in the closed technique group (8.1% vs. 17.5%, $p < 0.05$), confirming the reduced surgical trauma and better adaptation of the implant to the bone bed. The obtained data are consistent with previous studies (Amato M.B.P., 2020; Nguyen J., 2025) showing that preservation of crestal bone is a key predictor of successful osseointegration and long-term implant stability. Thus, the closed sinus lifting technique provides superior morphometric characteristics of the crestal bone-greater height, density, and contour symmetry-with a lower incidence of microresorption ($p < 0.05$-0.01), making it a preferable approach when sufficient residual bone volume is available.

Determination of the Relationship Between Implant Length and Clinical Crown Height (Crown/Implant Ratio, C/I Ratio)

Table 2

Relationship Between Implant Length and Clinical Crown Height (C/I Ratio) Based on CBCT Data

Parameter	Group I (Open sinus lifting, n = 40)	Group II (Closed sinus lifting, n = 38)	t	p
Mean implant length (mm, M ± m)	10.8 ± 0.7	9.6 ± 0.6	3.82	< 0.001
Mean clinical crown height (mm, M ± m)	12.7 ± 0.9	11.1 ± 0.8	3.45	< 0.01
Crown/Implant ratio (C/I ratio, M ± m)	1.18 ± 0.10	1.03 ± 0.08	3.26	< 0.01
Frequency of C/I > 1.2 (%)	27.5 ± 4.6	10.5 ± 3.1	2.99	< 0.01
Mean load on implant (chewing simulation, N)	72.4 ± 6.3	64.1 ± 5.9	2.68	< 0.05
Frequency of bone microresorption at C/I > 1.2 (%)	19.6 ± 3.7	8.4 ± 2.8	2.87	< 0.01

Note. Statistical significance was determined using Student's *t*-test ($p < 0.05$; $p < 0.01$; $p < 0.001$). The C/I ratio was calculated as the ratio of clinical crown height (mm) to the length of the installed implant (mm). Values of C/I > 1.2 are associated with an increased risk of implant overload and marginal bone resorption. Load distribution data were obtained using chewing simulation on the PingVin device with a force of 60-80 N.

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The analysis (Table 2) revealed a significant dependence between implant length, clinical crown height, and the C/I ratio**,** indicating that biomechanical balance plays a critical role in peri-implant bone preservation. In the open sinus lifting group**,** the C/I ratio averaged 1.18 ± 0.10**,** which was significantly higher compared to the closed sinus lifting group (1.03 ± 0.08; $p < 0.01$). This difference reflects the anatomical limitations of residual alveolar bone height in the open approach, necessitating the use of longer clinical crowns, which in turn increases the mechanical load on the implant system**.** A higher C/I ratio was associated with a marked increase in the frequency of microresorption (19.6% vs. 8.4%; $p < 0.01$) and a greater mean occlusal load recorded during chewing simulation (72.4 ± 6.3 N **vs.** 64.1 ± 5.9 N, $p < 0.05$). These findings confirm that excessive crown height relative to implant length contributes to marginal bone stress and reduced osseointegration stability. The results highlight that the optimal C/I ratio range is 0.9-1.1, ensuring favorable load distribution and minimizing the risk of biomechanical overload and bone resorption**.**

Therefore, maintaining a C/I ratio ≤ 1.1-1.2 is crucial for long-term implant success, especially in posterior maxillary regions where bone density and height are naturally reduced.

These findings support the superiority of the closed sinus lifting technique, which provides a more balanced C/I ratio, lower stress concentration, and improved longevity of prosthetic restorations.

DISCUSSION

The present study provides a detailed morphometric and biomechanical assessment of peri-implant bone parameters following open and closed sinus lifting, emphasizing the influence of implant-crown proportion on long-term stability. The findings confirm that subtle anatomical and procedural differences can significantly affect peri-implant bone preservation and functional outcomes. From a clinical perspective, the preservation of crestal bone height and density remains a cornerstone of successful osseointegration. Numerous studies have shown that excessive crown height and unfavorable crown-to-implant ratios increase marginal stress and microresorption risk due to biomechanical overload at the implant-bone interface (Misch, 2020; Pommer, 2023). Our results align with this concept, highlighting that optimizing implant placement depth and minimizing prosthetic leverage are critical to maintaining bone integrity over time. Biomechanically, the closed sinus lifting technique demonstrates greater structural preservation due to minimal disruption of the Schneiderian membrane and reduced intraoperative trauma. This approach provides a more uniform stress distribution along the implant axis, which is particularly relevant in posterior maxillary regions where trabecular bone is less dense. The improved symmetry and homogeneity of the crestal contour observed after the closed approach support the hypothesis that limited surgical manipulation favors natural bone remodeling. In contrast, open sinus lifting, while allowing for greater vertical augmentation, remains more invasive and is associated with higher risks of early marginal bone remodeling and delayed stabilization. However, in cases of severely reduced residual height, it remains the only viable option to achieve primary implant stability. Therefore, careful case selection and precise biomechanical planning-guided by CBCT and finite element analysis-are essential to minimize postoperative complications. The correlation between the C/I ratio and peri-implant microresorption underlines the importance of prosthetic design optimization. Maintaining a C/I ratio below 1.1 not only reduces stress concentration but also ensures better load transfer to the bone. The implementation of digital treatment planning and individualized abutment angulation can further mitigate overload risks and promote uniform bone adaptation.

Overall, this study supports the growing body of evidence that minimally invasive sinus augmentation, coupled with rational prosthetic biomechanics, enhances both functional and morphological outcomes. Continuous long-term monitoring and the integration of CBCT-based morphometric assessment into clinical protocols will enable early detection of unfavorable remodeling and improve the predictability of implant success.

CONCLUSION

The conducted study demonstrated that the choice of sinus lifting technique plays a decisive role in determining the morphometric characteristics and long-term stability of peri-implant bone. The closed sinus lifting technique provides superior outcomes, characterized by greater crestal bone height and density, a lower incidence of microresorption, and a more favorable crown-to-implant ratio (C/I ≤ 1.1-1.2). These parameters collectively contribute to optimal load distribution, reduced biomechanical stress, and enhanced osseointegration stability.

The open sinus lifting approach, while necessary in cases of significant residual bone deficiency, is associated with a higher risk of marginal bone resorption and mechanical overload. Therefore, careful patient selection and the use of digital planning based on CBCT imaging and biomechanical modeling are essential for achieving predictable and long-term successful outcomes.

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