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Factors Associated with Early and Late Complications After Lateral Window Sinus Elevation: A Two-Year Retrospective Cohort Study

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Research Article

History

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ABSTRACT

Objectives: To evaluate early postoperative complications and 1- and 2-year implant-related outcomes following lateral window maxillary sinus floor augmentation by correlating CBCT-based anatomical parameters with surgical and prosthetic variables.

Materials and Methods: This retrospective single-center cohort study included 128 patients who underwent lateral window sinus augmentation between 2020 and 2023. Preoperative CBCT imaging was used to assess residual bone height, lateral wall thickness, palatal–nasal recess angle, ostium diameter, Schneiderian membrane thickness (<3 mm or ≥3 mm), presence of septa, sinus pathology, and alveolar antral artery (AAA) diameter (≤2 mm or >2 mm). Early postoperative complications were recorded within the first month. Implant-related outcomes at 1 and 2 years were classified as implant failure or peri-implant crestal bone resorption (CBR). Statistical analyses included univariate tests and multivariable logistic regression for 1-year CBR outcomes ($p < 0.05$).

Results: Early postoperative complications were rare and mainly consisted of graft exposure/infection and bleeding/hematoma. A significantly higher incidence of early complications was observed in cases with AAA diameter >2 mm, with bleeding/hematoma occurring exclusively in this group ($p = 0.006$). Other anatomical parameters, including ostium diameter, showed no significant association with early complications. At 1 year, implant outcomes were significantly associated with prosthetic superstructure type, residual crestal bone height, intraoperative complications—particularly Schneiderian membrane perforation—and postoperative complication management strategy. These associations were primarily driven by increased CBR rather than implant failure. At 2 years, prosthetic superstructure type and Schneiderian membrane thickness ≥3 mm showed significant associationsin univariate analyses; however, no independent predictors were identified in multivariable modeling. Implant failure remained infrequent throughout the follow-up period.

Conclusions: Lateral window sinus augmentation yielded predictable short- and mid-term outcomes when guided by CBCT-based presurgical assessment and structured postoperative management. Vascular anatomy, particularly AAA diameter, was the main factor realated to early bleeding-related complications, whereas prosthetic design was the most consistent factor influencing long-term crestal bone changes.

Keywords: Cone-beam computed tomography, crestal bone resorption, lateral window, maxillary sinus augmentation, prosthetic design

Lateral Pencere Tekniği ile Sinüs Elevasyonu Sonrası Erken ve Geç Komplikasyonların Belirleyicileri: İki Yıllık Retrospektif Kohort Çalışması

Araştırma Makalesi

Süreç

Geliş: 27/01/2026
Kabul: 12/03/2026

ÖZ

Amaç: Lateral pencere tekniği ile maksiller sinüs tabanı yükseltimi sonrası erken postoperatif komplikasyonlar ile 1 ve 2 yıllık implant ilişkili sonuçları, CBCT temelli anatomik parametrelerin cerrahi ve protetik değişkenlerle birlikte değerlendirilmesi yoluyla incelemektir.

Gereç ve Yöntemler: Bu retrospektif, tek merkezli kohort çalışmaya 2020–2023 yılları arasında lateral pencere sinüs augmentasyonu uygulanan 128 hasta dahil edilmiştir. Preoperatif CBCT görüntüleri kullanılarak rezidüel kemik yüksekliği, lateral duvar kalınlığı, palatal–nazal reses açısı, ostium çapı, Schneiderian membran kalınlığı (<3 mm veya ≥3 mm), septa varlığı, sinüs patolojisi ve alveolar antral arter (AAA) çapı (≤2 mm veya >2 mm) değerlendirilmiştir. Erken postoperatif komplikasyonlar ilk ay içinde kaydedilmiştir. İmplant ilişkili sonuçlar 1. ve 2. yıllarda implant kaybı veya peri-implant krestal kemik rezorpsiyonu (CBR) olarak sınıflandırılmıştır. İstatistiksel analizlerde tek değişkenli testler ve 1. yıl CBR sonuçları için çok değişkenli lojistik regresyon analizi kullanılmıştır ($p < 0,05$).

Bulgular: Erken postoperatif komplikasyonlar nadir görülmüş ve çoğunlukla greft açığa çıkması/enfeksiyon ile kanama/hematom şeklinde ortaya çıkmıştır. AAA çapının >2 mm olduğu olgularda erken komplikasyon sıklığı anlamlı derecede daha yüksek bulunmuş, kanama/hematom yalnızca bu grupta gözlenmiştir ($p = 0,006$). Ostium çapı dahil diğer anatomik parametreler ile erken komplikasyonlar arasında anlamlı ilişki saptanmamıştır. Birinci yılda implant sonuçları; protetik üst yapı tipi, rezidüel krestal kemik yüksekliği, özellikle Schneiderian membran perforasyonu olmak üzere intraoperatif komplikasyonlar ve postoperatif komplikasyon yönetimi ile anlamlı ilişki göstermiştir. Bu ilişkiler esas olarak implant kaybından ziyade artmış CBR ile ilişkilidir. İkinci yılda ise tek değişkenli analizlerde protetik üst yapı tipi ve Schneiderian membran kalınlığı ≥3 mm anlamlı bulunmuş; ancak çok değişkenli modellemede bağımsız bir prediktör saptanmamıştır. Takip süresi boyunca implant kaybı nadir olarak izlenmiştir.

Sonuçlar: CBCT temelli cerrahi planlama ve düzenli postoperatif takip ile lateral pencere sinüs elevasyonu kısa ve orta dönemde öngörülebilir sonuçlar sağlamaktadır. Erken kanama ilişkili komplikasyonlarda vasküler anatomi belirleyici olurken, uzun dönem krestal kemik değişikliklerinde protetik tasarımın daha etkili olduğu görülmüştür.

Anahtar Kelimeler: Krestal kemik rezorpsiyonu, konik ışınlı bilgisayarlı tomografi, lateral pencere, maksiller sinüs augmentasyonu, protetik tasarım

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Introduction

Alveolar ridge resorption and maxillary sinus pneumatization following tooth loss in the posterior maxilla frequently result in insufficient vertical bone height for implant placement. Consequently, maxillary sinus lifting (MSL) procedures have become a widely adopted approach in implant treatment planning.[1] The lateral window technique is among the preferred methods, particularly in cases with limited residual crestal bone height (CBH) <5 mm, as it provides a wide surgical field and allows controlled elevation of the Schneiderian membrane.[2,3] Nevertheless, intraoperative and postoperative complications—most notably membrane perforation and infection—remain clinically significant concerns.

Successful sinus elevation largely depends on meticulous preoperative assessment. Patient-related factors such as systemic health status, sinus pathology, history of previous nasal or sinus surgery, and smoking habits should be thoroughly evaluated.[4] Preoperative cone-beam computed tomography (CBCT) examination is indispensable for assessing existing bone volume, excluding sinus pathology, and evaluating anatomical features that may influence surgical risk, including lateral sinus wall thickness (LWT), membrane thickness, presence of sinus septa, ostium patency, and the localization of the alveolar antral artery (AAA).[5,6] In addition, CBH, the degree of sinus pneumatization, and the tension potential of the sinus membrane may directly influence surgical difficulty and the risk of membrane perforation.[7]

Although numerous studies on maxillary sinus floor augmentation have evaluated individual anatomical variations, investigations that comprehensively assess these parameters in conjunction with intraoperative findings, surgical technique–related variables, preprosthetic site characteristics, and long-term implant outcomes remain limited. Therefore, the aim of the present study was to give a comprehensive evaluation of the associations between preoperative anatomical characteristics, surgical and prosthetic variables, and the occurrence of intraoperative, postoperative, and early- and late-stage implant-related complications in patients undergoing MSL using the lateral window technique.

Materials and Methods

Study Design

This study was designed as a retrospective, single-center observational cohort study evaluating patients who underwent maxillary sinus floor augmentation using the lateral window technique. The study was reported with reference to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) recommendations for observational studies.[8]

The study was conducted in accordance with the principles of the Declaration of Helsinki and was approved by the Institutional Review Board of Istinye University Human Research Ethics Committee (Meeting Date: 07 March 2025; Meeting No: 2025/01; Protocol No: 25-07).

Study Population and Patient Selection

Clinical records of patients who underwent maxillary sinus augmentation via the lateral window approach between June 1, 2020 and June 1, 2023 were retrospectively reviewed.

Initially, 144 patients were screened. After applying predefined inclusion and exclusion criteria, 16 patients were excluded due to incomplete clinical or radiographic records, inadequate CBCT image quality, previous sinus or nasal surgery, uncontrolled systemic disease (ASA class III or higher), or inability to reliably assess the predefined anatomical parameters. A total of 128 patients constituted the final study population and were included in all clinical, radiographic, and statistical analysis (Figure 1).

Inclusion Criteria

- Age ≥ 18 years
- Being ASA I-II
- Maxillary sinus floor augmentation performed using the lateral window technique
- Availability of preoperative CBCT imaging
- Availability of clinical and radiographic follow-up data at 1 and 2 years

Exclusion Criteria

- History of prior sinusitis or active sinus pathology (n = 2)
- History of previous sinus or nasal surgery (n = 2)
- Poor-quality CBCT scans or presence of radiographic artifacts impairing accurate assessment (n = 2)
- Inability to visualize or reliably measure predefined anatomical parameters (n = 2)
- Conditions associated with increased intracranial pressure in the early postoperative period (e.g., air travel or diving) (n = 1)
- Incomplete intraoperative or postoperative records, including insufficient documentation of the surgical procedure, complications, or their management (n = 7)

Demographic and Systemic Variables

The following patient-related variables were recorded:

- Age
- Sex
- Smoking status
- American Society of Anesthesiologists (ASA) classification

Surgical Procedure

All surgeries were performed by single operator (IN Guldiken–Corresponding author) using the lateral window sinus elevation technique under local anesthesia, following a standardized clinical protocol. After crestal and vertical releasing incisions, a full-thickness mucoperiosteal flap was elevated to expose the lateral wall of the maxillary sinus. A bony window was outlined at the planned augmentation site and created using rotary instruments. The Schneiderian membrane was carefully elevated from the sinus floor and walls to form a compartment for augmentation.

Depending on the planned treatment strategy and residual bone height, implants were placed either simultaneously with sinus elevation (one-stage approach) or in a delayed manner after graft maturation (two-stage

approach). Augmentation was performed using the grafting approach recorded in the clinical files (autograft/allograft/xenograft or graftless), and the use and positioning of a collagen barrier membrane over the lateral window were documented.

Intraoperative complications (e.g., bleeding/hematoma and Schneiderian membrane perforation) and their management were recorded. Hemorrhage was managed using local hemostatic measures. Membrane perforations were addressed according to intraoperative findings, most commonly via repair using a resorbable collagen membrane; when required, additional surgical modifications (e.g., creation of an additional access window) were performed to allow safe continuation of membrane elevation and graft placement. Standard postoperative instructions and pharmacological management were provided, and early postoperative complications and their management were documented during follow-up.

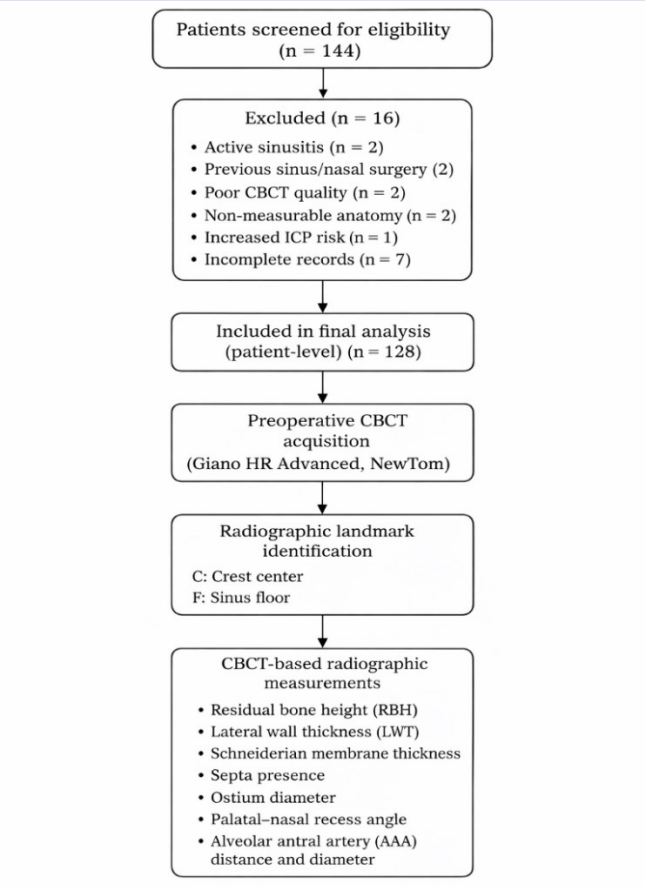

Figure 1. Flow diagram of patient selection and CBTC-based radiographic assessment. The unit of analysis was the patient (n = 128).

Radiographic Evaluation

Preoperative CBCT examinations were performed using the Giano HR Advanced NewTom system (NewTom, Italy), with a voxel size ranging from 0.125 to 0.30 mm. The field of view was adjusted to include the maxillofacial region, and scans were acquired using 90–110 kVp with automatic exposure control under standardized head positioning.

All CBCT datasets were evaluated using the manufacturer's proprietary software on a calibrated 23.6-inch LED monitor. Measurements were obtained using the integrated digital caliper tool. All radiographic assessments were performed by a calibrated oral and maxillofacial radiologist.

The following anatomical landmarks were identified:

- C: center of the alveolar crest
- F: base of the maxillary sinus floor

Based on these landmarks, the following radiographic parameters were assessed (Figure 2):

- Residual bone height (RBH): linear distance between points C and F
- Lateral sinus wall thickness (LWT): measured on implant-matched coronal sections, 4–6 mm above point F at the planned window level, sampling the thinnest portion of the lateral wall along a perpendicular cortex-to-sinus trajectory
- Palatal–nasal recess angle (PNR angle)
- Schneiderian membrane thickness: categorized as <3 mm (normal) or ≥3 mm (thickened)
- Presence of sinus septa
- Ostium diameter, measured at its narrowest point
- Presence of radiographic sinus pathology (mucosal thickening, cysts, or signs of sinusitis)

- AAA diameter, categorized as ≤2 mm (normal) or >2 mm (wid)

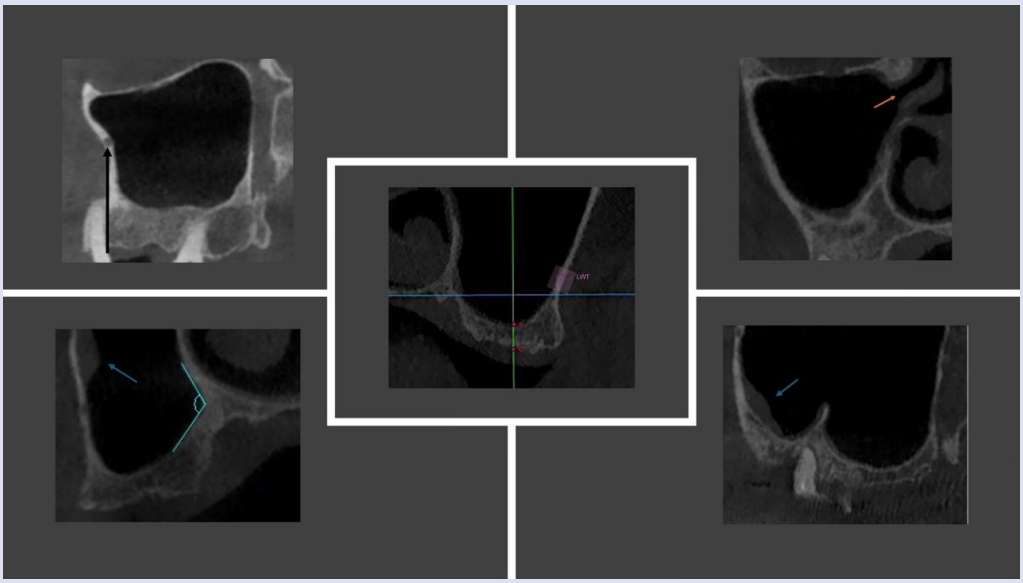

Figure 2. Radiographic evaluation of maxillary sinus–related anatomical parameters on preoperative CBCT images (Upper left: Identification and measurement of the posterior superior alveolar artery (AAA) diameter within the lateral sinus wall (black arrow). Lower left: Measurement of the palatal–nasal recess (PNR) angle and concurrent assessment of Schneiderian membrane thickness (outlined angle and blue arrow). Lower right: Illustration of Schneiderian membrane thickening and the presence of an intra-sinus septum (blue arrow). Upper right: Measurement of the maxillary sinus ostium diameter at its narrowest point (orange arrow). Center: Measurement of lateral sinus wall thickness (LWT) on implant-matched coronal sections at the planned lateral window level, performed 4–6 mm above the sinus floor, sampling the thinnest portion of the lateral wall along a perpendicular cortex-to-sinus trajectory.

Intraoperative Variables

The following surgical variables were recorded:

- Grafting approach (autograft, allograft, xenograft, or graftless technique)
- Use of barrier (collagen) membranes and their placement
- Intraoperative complications and their management (e. g., hemorrhage control, membrane repair, opening extra window)

Postoperative and Implant-Related Outcomes

Postoperative and long-term outcomes included:

- Early postoperative complications (e. g., pain, infection, sinusitis, bleeding/hematoma, graft exposure)
- Implant survival at 1 and 2 years (failure vs. survival)
- Peri-implant crestal bone resorption (CBR) at 1 and 2 years (classified as minimal, moderate, or severe)
- Prosthetic rehabilitation type (single crown, fixed partial prosthesis, full-arch restoration)
- Prosthetic material (metal–ceramic, all-ceramic, zirconia)

Crestal bone level changes were evaluated using standardized periapical radiographs obtained at the 1- and 2-year follow-up visits. Radiographs were acquired using a parallel technique with individualized positioning devices to ensure reproducibility and minimize projection distortion. Measurements were performed using calibrated digital software by comparing the distance from the implant platform to the first bone-to-implant contact.

CBR was categorized as follows: minimal (<0.5 mm), moderate (0.5–1.0 mm), and severe (>1.0 mm). For regression analysis, CBR was further dichotomized as absent (<0.5 mm) versus present (≥0.5 mm). In patients receiving multiple implants, the highest observed CBR category was used for patient-level classification.

Statistical Analysis

Statistical analyses were performed using SPSS software (Version 22.0) and R software. Continuous variables were expressed as mean ± standard deviation or median (minimum–maximum), depending on data distribution. Categorical variables were presented as frequencies and percentages. Group comparisons were conducted using Pearson's chi-square test or Fisher's exact test, as appropriate. The strength of association between categorical variables was assessed using Cramer's V coefficient.

All analyses were performed at the patient level (n = 128). For patients receiving multiple implants, outcomes were summarized per patient. For crestal bone resorption (CBR), the highest observed CBR category within each patient was used for classification.

To identify independent factors associated with 1-year CBR, multivariable binary logistic regression analysis was performed after excluding patients with implant failure

and dichotomizing CBR as absent (0) versus present (≥0.5 mm). Variables included in the model were selected based on clinical relevance and univariate screening results, while considering event-per-variable limitations to avoid overfitting. Adjusted odds ratios (ORs) with 95% confidence intervals (CIs) were calculated. Model fit was assessed using the Hosmer–Lemeshow test.

For 2-year outcomes, a similar regression model was constructed; however, no independent predictors were identified. Due to the limited number of implant failures, multivariable modeling was not performed for failure outcomes.

A p-value <0.05 was considered statistically significant.

Results

Study Population

A total of 128 patients who underwent maxillary sinus floor augmentation using the lateral window technique were included in the final analysis.

Early Postoperative Complications

Early postoperative complications were evaluated within the immediate postoperative period (within the first month following the procedure). The majority of patients did not experience any early complications. Among patients with complications, graft exposure and bleeding/hematoma were the most frequently observed events.

No statistically significant associations were identified between early postoperative complications and sex, ASA classification, smoking status, graft material, use of a collagen membrane over the lateral window, implant protocol, surgical side, number of implants, prosthetic superstructure, type of edentulism, LWT, CBH, number of lateral windows, Schneiderian membrane thickness, presence of septa, preoperative sinus pathology, ostium diameter, palatal–nasal recess angle, or intraoperative complications.

In contrast, AAA diameter showed a statistically significant association with early postoperative complications ($p = 0.006$). Bleeding or hematoma was observed exclusively in cases with a AAA diameter ≥2 mm; however, the number of bleeding events was limited.

Additionally, a statistically significant association was observed between the type of early postoperative complication and the corresponding management strategy ($p < 0.001$). Surgical debridement with or without soft tissue closure (performed using a buccal advancement flap and, when required, the buccal fat pad) was mainly employed in cases of graft exposure and infection, whereas conservative management was more frequently used for bleeding or hematoma (Table 1).

One-Year Postoperative Outcomes

At the 1-year follow-up, implant-related complications were categorized as implant failure or peri-implant CBR. The majority of implants remained functional without complications.

A significant association was observed between prosthetic superstructure type and 1-year implant outcomes ($p < 0.001$), with full-arch restorations showing a higher prevalence of peri-implant crestal bone resorption (CBR). Residual crestal bone height was also significantly related to 1-year outcomes ($p = 0.020$), with higher CBR rates observed in sites with shorter and moderate baseline bone height. In addition, intraoperative complications—particularly Schneiderian membrane perforation—were significantly associated with unfavorable outcomes at 1 year ($p = 0.037$). Postoperative complication management was likewise significantly associated with 1-year outcomes ($p = 0.007$), with surgically managed cases demonstrating higher rates of CBR (Table 2).

No significant associations were found between 1-year outcomes and sex, ASA status, smoking, graft material, membrane use over the lateral window, implant protocol, surgical side, number of implants, LWT, number of windows, membrane thickness, presence of septa, preoperative sinus pathology, ostium diameter, palatal–nasal recess angle, or AAA diameter.

In multivariable binary logistic regression analysis performed for 1-year crestal bone resorption (CBR), after excluding implant failures and dichotomizing CBR as absent (<0.5 mm) versus present (≥0.5 mm), prosthetic superstructure type (adjusted OR: 1.23; 95% CI: 1.01–1.50; $p = 0.037$) and intraoperative complications (adjusted OR: 1.67; 95% CI: 1.16–2.39; $p = 0.006$) remained independently associated with increased odds of CBR. The regression model demonstrated overall statistical significance (Omnibus test $p = 0.006$) and acceptable goodness-of-fit (Hosmer–Lemeshow test $p = 0.833$; Table 3).

Two-Year Postoperative Outcomes

At the 2-year follow-up, implant-related outcomes included implant survival, implant failure, and peri-implant CBR.

A statistically significant association was again observed between prosthetic type and 2-year outcomes ($p = 0.003$). Full-arch restorations demonstrated the highest rates of peri-implant CBR, whereas implant failure remained infrequent. Additionally, Schneiderian membrane thickness showed a statistically significant association with 2-year outcomes ($p = 0.005$). Patients with a membrane thickness ≥3 mm exhibited a higher prevalence of peri-implant CBR compared with those with membrane thickness <3 mm (Table 4).

No statistically significant associations were detected between 2-year outcomes and sex, systemic status, smoking, graft material, membrane use over the lateral window, implant protocol, surgical side, number of implants, type of edentulism, LWT, residual CBH, number of windows, presence of septa, preoperative sinus pathology, ostium diameter, palatal–nasal recess angle, AAA diameter, intraoperative complications, or complication management strategy.

Table 1. Association between early postoperative complications and selected patient-, surgical-, and radiographic-related variables

Variable	Category	No complication n (%)	Graft exposure n (%)	Bleeding/hematoma n (%)	p
Sex	Female	59 (90.8)	5 (7.7)	1 (1.5)	0.879
	Male	55 (88.7)	6 (9.7)	1 (1.6)	
ASA	ASA I	80 (89.9)	8 (9.0)	1 (1.1)	0.870
	ASA II	34 (89.5)	3 (7.9)	1 (2.6)	
Smoking	Non-smoker	94 (91.3)	7 (6.8)	2 (1.9)	0.310
	Smoker	20 (83.3)	4 (16.7)	0 (0.0)	
Biomaterial	Allograft	51 (89.5)	5 (8.8)	1 (1.8)	1.000
	Xenograft	46 (88.5)	5 (9.6)	1 (1.9)	
	Graftless	17 (94.4)	1 (5.6)	0 (0.0)	
Implant protocol	7 months	37 (88.1)	4 (9.5)	1 (2.4)	0.872
	9 months	40 (93.0)	3 (7.0)	0 (0.0)	
	Simultaneous	37 (88.1)	4 (9.5)	1 (2.4)	
Prosthetic design	Single/short-span	48 (84.2)	7 (12.3)	2 (3.5)	0.271
	Long-span	38 (90.5)	4 (9.5)	0 (0.0)	
	Full-arch	27 (100.0)	0 (0.0)	0 (0.0)	
LWT	<1.5 mm	57 (87.7)	7 (10.8)	1 (1.5)	0.799
	1.5–2.5 mm	47 (92.2)	3 (5.9)	1 (2.0)	
	>2.5 mm	8 (88.9)	1 (11.1)	0 (0.0)	
RBH	<2 mm	19 (95.0)	0 (0.0)	1 (5.0)	0.355
	2–4 mm	32 (88.9)	4 (11.1)	0 (0.0)	
	4–7 mm	62 (88.6)	7 (10.0)	1 (1.4)	
Membrane thickness	<3 mm	92 (92.0)	6 (6.0)	2 (2.0)	0.113
	≥3 mm	21 (80.8)	5 (19.2)	0 (0.0)	
Sinus pathology	Absent	82 (89.1)	9 (9.8)	1 (1.1)	0.675
	Sinus cyst	8 (88.9)	1 (11.1)	0 (0.0)	
	Mucosal thickening	5 (83.3)	1 (16.7)	0 (0.0)	
Ostium diameter	<1 mm	15 (78.9)	4 (21.1)	0 (0.0)	0.300
	1–3 mm	94 (91.3)	7 (6.8)	2 (1.9)	
	>3 mm	5 (100.0)	0 (0.0)	0 (0.0)	
AAA diameter	≤2 mm	106 (90.6)	11 (9.4)	0 (0.0)	0.006*
	>2 mm	8 (80.0)	0 (0.0)	2 (20.0)	
Intraoperative complications	None	91 (91.0)	8 (8.0)	1 (1.0)	0.121
	Bleeding	3 (75.0)	0 (0.0)	1 (25.0)	
	Membrane perforation	19 (86.4)	3 (13.6)	0 (0.0)	
Postoperative management	None	97 (100.0)	0 (0.0)	0 (0.0)	<0.001*
	Surgical + soft tissue	0 (0.0)	2 (100.0)	0 (0.0)	
	Conservative	17 (89.5)	0 (0.0)	2 (10.5)	
	Surgical debridement	0 (0.0)	9 (100.0)	0 (0.0)	

**Statistically significant (p < 0.05)*

Table 2. Factors associated with 1-year implant outcomes

Variable	No complication n (%)	Failure n (%)	CBR n (%)	p
Prosthetic design				<0.001*
Single/short-span (1–3 units)	44 (78.6)	2 (3.6)	10 (17.9)	
Long-span (4–7 units)	37 (88.1)	0	5 (11.9)	
Full-arch (12–14 units)	17 (63.0)	0	10 (37.0)	
Residual bone height				0.020*
<2 mm	14 (66.7)	3 (14.3)	4 (19.0)	
2–4 mm	25 (69.4)	1 (2.8)	10 (27.8)	
4–7 mm	58 (84.1)	0	11 (15.9)	
Intraoperative complications				0.037*
None	82 (82.8)	2 (2.0)	15 (15.2)	
Membrane perforation	12 (54.5)	1 (4.5)	9 (40.9)	
Bleeding	4 (100)	0	0	
Postoperative management				0.007*
None	81 (83.5)	1 (1.0)	15 (15.5)	
Conservative	13 (68.4)	1 (5.3)	5 (26.3)	
Surgical debridement	4 (50.0)	1 (12.5)	3 (37.5)	

**Statistically significant (p < 0.05)*

Table 3. Multivariable logistic regression analysis for 1-year crestal bone resorption (CBR)

Variable	Adjusted OR	95% CI	p
Prosthetic superstructure	1.23	1.01–1.50	0.037*
Intraoperative complications	1.67	1.16–2.39	0.006*

Model statistics: Omnibus p = 0.006; Hosmer–Lemeshow p = 0.833
**Statistically significant (p < 0.05)*

Table 4. Factors associated with 2-year implant outcomes

Variable	No complication n (%)	Failure n (%)	CBR n (%)	p
Prosthetic design				0.003*
Single/short-span	48 (85.7)	1 (1.8)	7 (12.5)	
Long-span	37 (88.1)	0	5 (11.9)	
Full-arch	21 (77.8)	0	6 (22.2)	
Membrane thickness				0.005*
<3 mm	87 (87.0)	0	13 (13.0)	
≥3 mm	18 (69.2)	3 (11.5)	5 (19.2)	

**Statistically significant (p < 0.05)*

A multivariable logistic regression model constructed for 2-year CBR did not demonstrate overall statistical significance (Omnibus test p = 0.465), and no independent predictors were identified. Given the limited number of implant failure events, multivariable modeling was not performed for failure outcomes.

Detailed results of all tested variables are provided in Table 5.

Table 5. Complete 1-year implant outcomes

Variable	Category	No complication n (%)	Failure n (%)	CBR n (%)	p
Sex	Female	51 (79.7)	1 (1.6)	12 (18.8)	0.629
	Male	47 (74.6)	3 (4.8)	13 (20.6)	
ASA	ASA I	70 (79.5)	1 (1.1)	17 (19.3)	0.151
	ASA II	28 (71.8)	3 (7.7)	8 (20.5)	
Smoking	Non-smoker	83 (79.8)	4 (3.8)	17 (16.3)	0.134
	Smoker	15 (65.2)	0 (0.0)	8 (34.8)	
Biomaterial	Allograft	45 (80.4)	1 (1.8)	10 (17.9)	0.772
	Xenograft	39 (73.6)	3 (5.7)	11 (20.8)	
	Graftless	14 (77.8)	0 (0.0)	4 (22.2)	
Implant protocol	7 months	37 (88.1)	1 (2.4)	4 (9.5)	0.065
	9 months	31 (72.1)	3 (7.0)	9 (20.9)	
	Simultaneous	30 (71.4)	0 (0.0)	12 (28.6)	
Prosthetic design	Single/short-span	44 (78.6)	2 (3.6)	10 (17.9)	<0.001*
	Long-span	37 (88.1)	0 (0.0)	5 (11.9)	
	Full-arch	17 (63.0)	0 (0.0)	10 (37.0)	
LWT	<1.5 mm	52 (80.0)	4 (6.2)	9 (13.8)	0.144
	1.5–2.5 mm	38 (74.5)	0 (0.0)	13 (25.5)	
	>2.5 mm	6 (66.7)	0 (0.0)	3 (33.3)	
RBH	<2 mm	14 (66.7)	3 (14.3)	4 (19.0)	0.020*
	2–4 mm	25 (69.4)	1 (2.8)	10 (27.8)	
	4–7 mm	58 (84.1)	0 (0.0)	11 (15.9)	
Membrane thickness	<3 mm	79 (79.0)	1 (1.0)	20 (20.0)	0.055
	≥3 mm	18 (69.2)	3 (11.5)	5 (19.2)	
Sinus pathology	Absent	70 (76.1)	2 (2.2)	20 (21.7)	0.150
	Sinus cyst	6 (66.7)	1 (11.1)	2 (22.2)	
	Mucosal thickening	5 (83.3)	1 (16.7)	0 (0.0)	
Intraoperative complications	None	82 (82.8)	2 (2.0)	15 (15.2)	0.037*
	Bleeding	4 (100.0)	0 (0.0)	0 (0.0)	
	Membrane perforation	12 (54.5)	1 (4.5)	9 (40.9)	
Postoperative management	None	81 (83.5)	1 (1.0)	15 (15.5)	0.007*
	Surgical + soft tissue	0 (0.0)	0 (0.0)	2 (100.0)	
	Conservative	13 (68.4)	1 (5.3)	5 (26.3)	
	Surgical debridement	4 (50.0)	1 (12.5)	3 (37.5)	

Discussion

The present retrospective cohort study evaluated early and late complications following lateral window sinus elevation by integrating anatomical, surgical, and prosthetic variables. The main findings indicate that early postoperative complications were primarily associated with AAA diameter and complication

management strategy, whereas 1- and 2-year implant outcomes showed significant associations with prosthetic superstructure design, residual crestal bone height, Schneiderian membrane perforation, and membrane thickness.

Early Postoperative Complications: AAA Diameter & Management Strategy, Ositum, Complication Type & Management Strategy

In the present cohort, early postoperative bleeding/hematoma was significantly associated with a wider alveolar antral artery (AAA) diameter (>2 mm), highlighting the importance of preoperative CBCT-based vascular assessment before lateral window osteotomy.[4,9] Although bleeding events were infrequent, this association is biologically plausible, as larger-caliber intraosseous vessels traversing the lateral sinus wall are more prone to injury during window preparation.[9] Previous studies have also linked postoperative sinus complications to impaired drainage related to ostio-meatal complex variations;[6] however, ostium diameter was not significantly associated with early complications in the present study, likely due to differences in study design and the predominance of local surgical and vascular events. Finally, the observed relationship between complication type and management strategy reflects pragmatic clinical decision-making, with surgical intervention reserved mainly for graft exposure or infection, whereas conservative measures were sufficient for most bleeding or hematoma cases.[4]

Schneiderian Membrane and 1-Year–2-Year Outcomes

In the present study, Schneiderian membrane perforation was significantly associated with unfavorable 1-year outcomes; however, this association was primarily driven by increased peri-implant crestal bone resorption rather than implant failure. This finding aligns with growing evidence indicating that membrane perforation, when properly managed, does not inevitably compromise implant survival. In line with this, a recent systematic review and meta-analysis by Schiavo-Di Flaviano et al.[10] reported comparable implant survival rates between perforated and non-perforated sinuses (97.1% vs. 97.7%), concluding that membrane perforation should not be considered an absolute contraindication or a reason to abort sinus augmentation procedures.

Beyond membrane integrity, preoperative Schneiderian membrane thickness appears to exert a more time-dependent biological effect. While previous systematic reviews and meta-analyses have reported inconclusive associations between membrane thickness and early complications or perforation risk, our findings suggest that a membrane thickness ≥3 mm may be more relevant to long-term peri-implant bone behavior.[11,12] Specifically, thicker membranes were associated with increased crestal bone resorption at later follow-up intervals rather than with early postoperative complications.

Overall, these findings support the interpretation of Schneiderian membrane perforation and mucosal thickening as modifiable biological risk indicators rather than deterministic predictors of failure. When identified through careful CBCT-based presurgical evaluation and managed with appropriate surgical judgment and experience, these factors do not necessarily lead to catastrophic outcomes but underscore the importance of individualized risk stratification and long-term monitoring of peri-implant bone stability.

Prosthetic Superstructure as the Strongest Association at 1- and 2-Year Follow-Up

Prosthetic superstructure design emerged as the most consistent factor of late implant-related complications in the present study, with full-arch restorations demonstrating significantly higher rates of peri-implant crestal bone resorption at both 1- and 2-year follow-up. Notably, studies specifically evaluating the relationship between prosthetic design and implant behavior in lateral window sinus–augmented sites remain scarce.

Although prosthetic design may not represent a direct causal factor, the biological environment of grafted sinus sites differs from native bone, with prolonged remodeling and altered bone density potentially increasing susceptibility to sustained mechanical loading. In this context, extensive restorations may act as amplifying factors through increased occlusal load, hygiene-related challenges, and possible cantilever effects.[13]

Previous clinical and meta-analytic studies have largely focused on surgical techniques and implant survival, generally reporting favorable outcomes when prosthetic protocols are controlled.[14,15] However, marginal bone changes appear more sensitive to biomechanical and prosthetic variables over time.[16] Taken together, these findings suggest that prosthetic planning in sinus-augmented sites should be considered a long-term biological factor rather than a purely restorative decision.

Importantly, multivariable analysis demonstrated that prosthetic superstructure design remained independently associated with 1-year CBR after adjustment for other clinically relevant variables. Although cantilever extensions were not used and occlusal schemes were standardized across cases, full-arch restorations—representing larger prosthetic spans—were associated with increased crestal bone changes. This finding suggests that, particularly in sinus-augmented sites, biomechanical load distribution and prosthetic span may influence early peri-implant bone remodeling.

Non-Significant Variables: Possible Explanations

Several patient-related, anatomical, and surgical variables—including smoking status, ASA classification, graft material, membrane coverage of the lateral

window, ostium diameter, presence of sinus septa, and lateral wall thickness—were not significantly associated with early or late complications in the present study. Although these factors have been variably reported as potential risk modifiers, the available evidence regarding their isolated impact on clinical outcomes remains inconsistent.[17,18]

The absence of significant associations in this cohort may reflect standardized surgical protocols, careful patient selection, and comprehensive CBCT-based presurgical planning. Previous studies suggest that anatomical features such as membrane thickness or septa may increase technical complexity but do not necessarily lead to higher complication or implant failure rates when appropriately managed.[17,18]

Moreover, uniform postoperative care and consistent complication management may have mitigated the influence of individual risk factors. This finding is in line with reports indicating that long-term implant behavior is more strongly influenced by cumulative biomechanical and inflammatory factors than by isolated patient- or anatomy-related variables.[19,20]

Strengths and Limitations of the Study

The strengths of this study include its comprehensive CBCT-based anatomical assessment, enabling detailed evaluation of vascular, mucosal, and bony sinus parameters. The integration of anatomical, surgical, and prosthetic variables within a single analytical framework provides a more holistic understanding of complication patterns following lateral window sinus elevation. Furthermore, the inclusion of both 1- and 2-year follow-up data allows differentiation between early biological responses and late biomechanically driven outcomes, which is particularly relevant for implant dentistry in augmented sites.

Certain limitations should be acknowledged. The retrospective design and single-center setting may limit the generalizability of the findings. In addition, the relatively low incidence of some complications may have reduced statistical power to detect weaker associations. Histological confirmation of mucosal conditions was not available, and radiographic assessments were relied upon as surrogate markers of sinus health. Nevertheless, the study reflects real-world clinical practice and provides clinically meaningful insights derived from routine workflows rather than highly controlled experimental conditions. Additionally, due to the limited number of implant failures, multivariable modeling focused primarily on CBR outcomes, and the findings should be interpreted with caution in relation to rare adverse events.

Clinical Implications and Future Directions

From a clinical perspective, the findings emphasize the importance of thorough CBCT-based presurgical evaluation, particularly with respect to alveolar antral artery diameter and Schneiderian membrane thickness. Equally important, prosthetic planning should be incorporated early into treatment decision-making, as superstructure design appears to exert a sustained influence on peri-implant bone behavior. Future prospective, multicenter studies with larger cohorts and standardized prosthetic loading protocols are warranted to further elucidate the complex interactions between sinus anatomy, surgical variables, and long-term prosthetic biomechanics.

Conclusions

Lateral window sinus elevation demonstrated predictable outcomes when guided by careful CBCT-based anatomical assessment and integrated prosthetic planning. Early postoperative complications were mainly influenced by vascular anatomy, whereas ostium diameter showed no significant effect. Prosthetic superstructure design was the strongest factor associated with 1- and 2-year outcomes, with full-arch restorations associated with greater peri-implant crestal bone resorption. Schneiderian membrane perforation and increased membrane thickness affected peri-implant bone behavior rather than implant survival. Multivariable analysis particularly highlighted prosthetic design and intraoperative complications as independent contributors to peri-implant crestal bone changes at 1 year. From a clinical perspective, when a lateral window sinus augmentation approach is planned, careful consideration of prosthetic span and load distribution during the first postoperative year appears critical. Increasing implant support rather than relying on limited-point support for extensive restorations may contribute to improved peri-implant bone stability in augmented sites. These findings emphasize the importance of individualized risk assessment and long-term monitoring rather than exclusion based on isolated intraoperative findings.

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Conflicts of Interest Statement

None.

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