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Lateral sinus floor elevation in patients with sinus floor defects: A retrospective study with a 1- to 9-year follow-up

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Abstract

Objectives: We aimed to retrospectively evaluate the long-term clinical outcomes of lateral sinus floor elevation (LSFE) in patients with sinus floor defects.

Materials and Methods: Between 2008 and 2020, patients with sinus floor defects were recruited after confirmation on preoperative cone-beam computed tomography (CBCT). The split-thickness flap technique with a palatal crestal incision was used to manage tissue adhesion in the bone defects area. A resorbable collagen membrane was used to close the sinus floor defects from the crestal side before bone substitute placement. Of 58 implants, 47 (81.0%) were placed after an 8-month healing period, whereas 11 were placed simultaneously. Patients were followed up by radiography and clinical examination for 1–9 years. Finally, the cumulative survival rate (CSR) of implants, surgical complications, and marginal bone loss (MBL) were recorded and analyzed.

Results: In total, LSFE was performed in 36 sinuses (35 patients) with sinus floor defects, of which surgery was completed in 35 sinuses (97.2%) in the first attempt. Schneiderian membrane perforations (SMP) occurred in 10/36 (27.8%) sinuses; nine were repaired carefully, whereas one surgery was suspended due to complicated SMP, and successful re-entry LSFE was performed 4 months later. After a follow-up period of 1–9 years, the CSR was 96.5% at the 1-year, 3-year, 5-year, and 7-year follow-ups and 64.3% at the 8-year follow-up.

Conclusion: Within the limitations of this study, sinus floor defects seem not to compromise LSFE therapy after appropriate management and long-term clinical outcomes are predictable.

KEYWORDS
dental implant, lateral sinus floor elevation, maxillary sinus, sinus floor defects, split-thickness flap

1 | INTRODUCTION

Maxillary sinus floor defects or discontinuities can occur because of various potential factors, including traumatic bone loss after tooth extraction and the combination of sinus pneumatization and extreme alveolar bone resorption. The prevalence of sinus floor defects according to previous studies was 2%–4.35% (Wang et al., 2019; Zijderveld et al., 2008). Under these extreme anatomical conditions, adhesion between the Schneiderian membrane and mucoperiosteal flap may lead to large perforations at sites with

poor visual and surgical access during the process of lateral sinus floor elevation (LSFE) (Zijderveld et al., 2008). In addition, bone defects in the sinus floor introduce the risk of bone graft displacement and contamination owing to gravity (Jensen, 2019). Therefore, sinus floor defects were considered a relative contraindication to LSFE in some cases in the past (van den Bergh et al., 2000). Cortes et al's. (2015) case–control study also indicated that sinus floor defects were a factor that could increase the risk of SMP, which may compromise treatment outcomes and also lead to implant loss (Al-Moraissi et al., 2018; Tükel & Tatli, 2018).

Lateral sinus floor elevation has been proven to be a predictable treatment procedure for providing sufficient bone height in the case of severely atrophied posterior maxillae (Del Fabbro et al., 2013; Jensen, 2019). Several retrospective studies have evaluated the clinical prognosis of 1-stage or 2-stage LSFE in patients with extremely insufficient initial residual bone height (RBH <4 mm) (Kim et al., 2020; Pistilli et al., 2022; Tsai et al., 2020). The reported cumulative survival rate (CSR) of the implants in this situation was 92.8% at the 10-year follow-up (Kim et al., 2020) and 100% at the 5-year follow-up (Pistilli et al., 2022). However, specifics regarding the management of sinus floor defects during LSFE have rarely been reported in the literature. A previous case report has suggested the use of the split-thickness flap technique to resolve this problem (Nevins & Wang, 2019; Testori et al., 2022). Moreover, long-term clinical outcomes have not yet been reported, and the technical details of this procedure are yet to be described systematically.

Therefore, the present study aimed to retrospectively evaluate the long-term clinical outcomes and radiographic changes following LSFE in patients with sinus floor defects, to summarise the clinical characteristics, and to describe the technical details of this procedure.

2 | MATERIALS AND METHODS

2.1 | Study design and ethical approval

Due to the rarity of cases, this study was organized as a retrospective, single-arm, longitudinal cohort study. This study was approved by the local ethics committee (Institutional Review Board of Peking University School and Hospital of Stomatology; approval number: PKUSSIRB-202277080) and was registered in the Chinese Clinical Trial Registry (registration number: ChiCTR2200063807; http://www.chictr.org.cn/listbycreater.aspx).

In this retrospective study, patients who were scheduled to undergo LSFE at the Department of Oral Implantology, Peking University Hospital of Stomatology, China, between January 2008 and December 2020, were screened for sinus floor defects. Patients with sinus floor defects were identified from among 1831 consecutive patients (2039 maxillary sinus) via a preoperative CBCT examination. The demographic information, clinical characteristics, and radiographic measurements were recorded. The surgical complications and CSR of the implants were also recorded and analyzed.

2.2 | Inclusion and exclusion criteria

The inclusion criteria were as follows: (a) preoperative cross-sectional CBCT images show sinus floor defects, (b) completed LSFE followed by dental implant placement, (c) radiographic examination after 6 months of postoperative healing, (d) well-documented medical charts reporting details regarding intra- and postoperative complications.

The exclusion criteria were as follows: (a) incomplete or low-quality clinical and radiographic documentation, (b) refusal to undergo the LSFE procedure and selection of nonimplant restoration; (c) untreated periapical disease or periodontal disease; (d) acute and chronic inflammation in the maxillary sinus; (e) uncontrolled diabetes; (f) systemic factors interfering with bone or soft tissue healing, such as a history of bisphosphonate medication use and osteoporosis; (g) a history of radiotherapy administered in the head and neck region; (h) pregnancy or lactation; and (i) severe alcoholism/drug abuse.

2.3 | Description of the clinical procedure

2.3.1 | Perioperative management

Before surgery, the patients underwent clinical and radiographic examinations for an evaluation of the maxillary sinus cavity conditions and the sinus floor defects (Figure 1). In some cases, the Schneiderian membrane was unexpectedly depressed (Figure 1d) or abnormally thickened, which may be signs of sinus floor defects.

Prophylactic oral premedication was administered routinely (cefuroxime axetil tablets 250 mg twice/day for 7 days; tinidazole tablets, 500 mg/day for 5 days; dexamethasone tablets, 1.5 mg twice/day for 2 days; and ibuprofen, 600 mg every 12 h for 3 days).

2.3.2 | Surgical and restoration procedures

Under local anesthesia, a crestal incision was introduced slightly palatal to the sinus floor defects area, guided by the preoperative CBCT and combined with additional proximal and distal vertical incisions (Figure 2a). Blunt and sharp separations were combined during flap reflection. The scar-like adhesion tissue was dissected using a 15-blade instead of a periosteum elevator to raise the split-thickness flap in the bone defect area. When elevating the flap, extreme care was taken to avoid SMP. Because it is difficult to find the boundary between the periosteal layer of the Schneiderian membrane and the submucosa of the mucoperiosteal flap, the blade was used to split the flap more laterally while paying great attention in order to avoid perforation.

Subsequently, a lateral antrostomy was created using a conventional approach. The inferior cut was made at least 3–4 mm away from the sinus floor. The bone bridge between the lateral window and bone defect area was left as wide as possible to prevent fracture and absorption (Figure 2b). Using blunt instruments, the

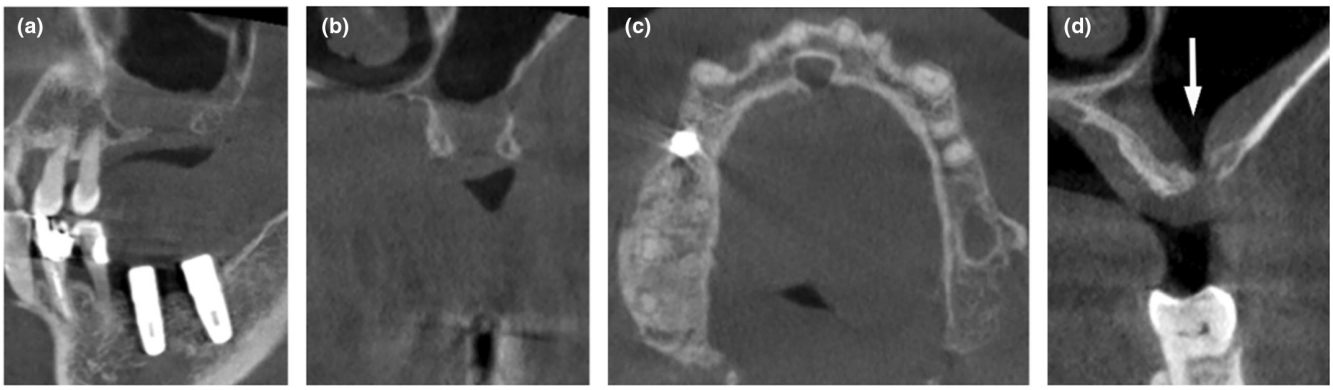

FIGURE 1 Representative cone-beam computed tomography cross-sectional views show sinus floor defects at the edentulous site. (a) Mesiodistal extension of the bone defects, (b) buccolingual extension of the bone defects, (c) the general shape of the bone defects, (d) the arrow shows the Schneiderian membrane depressed unexpectedly in the sinus floor defect area.

Schneiderian membrane was lifted along with scar-like tissue from the access of the lateral window. A resorbable collagen membrane (Bio-Gide, Geistlich Pharma AG) was placed over the sinus floor from the outside to close the bone defect when its diameter was larger than 2 mm; the membrane was sometimes fixed with titanium pins to keep it stable (Figure 2c). Another resorbable collagen membrane (Bio-Gide, Geistlich Pharma AG) was placed under the Schneiderian membrane to prevent possible perforation, and the created space was filled with bone substitutes (Bio-Oss, diameter 1–2 mm; Geistlich Pharma AG) (Figure 2d).

The mucoperiosteal flap was repositioned and sutured using 4–0 absorbable sutures (Vicryl Rapid; Ethicon, Johnson & Johnson). CBCT was performed immediately after the surgery to verify the position of the bone graft (Figure 2e). Implant placement was scheduled for 8 months later after confirming that the local graft had healed well (Figure 2f,g). Under certain conditions, simultaneous implant placement was performed when the range of the sinus floor defects in the implant site was smaller than the implant diameter, and when the RBH and bone density provided sufficient primary implant stability.

Restoration was scheduled at approximately 6 months after implant placement in the second-stage procedure, and at about 12 months in the first-stage procedure. Before restoration, radiographs were obtained to verify the osseointegration of the implants. All the implants were prosthetically restored (Figure 2h), apart from two that were lost early. Patients were followed up at 6 months and annually after prosthetic loading.

2.4 | Data acquisition and measurements

2.4.1 | Clinical characteristics and outcomes

The basic clinical features of the sinus floor defects were documented and analyzed and the radiographic incidence of sinus floor defects was calculated.

The CSR of the implants was considered the primary outcome of this research. The success criteria of the implants were adopted from the Pisa Consensus Conference (Misch et al., 2008), according to which there are four approved clinical categories: conditions of implant success, satisfactory survival, compromised survival, and failure.

Intraoperative (SMP or bleeding) and postoperative complications (wound dehiscence, infection, acute maxillary sinusitis, or implant failure) were captured from the medical history and were analyzed.

2.4.2 | Radiographic assessment

The image analysis software application, Planmeca Romexis (Planmeca Dental Imaging Oy), was used for measurements with an accuracy of 0.1 mm. Panoramic and cross-sectional views of the maxilla were reconstructed. Two independent observers performed all measurements in the cross-sectional views at the planned implant sites. Internal calibration was performed based on the known implant length to address panoramic distortions. Specifically, all data measured from radiographs during the follow-up period, apart from those measured from CBCT, were adjusted with a coefficient derived from the ratio of true implant length to radiographic implant length. For the calibration and evaluation of intraobserver reliability, measurements were performed in 15 CBCT images twice on 2 nonconsecutive days. The mean difference was 0.04–0.15 mm/image.

1. Bone defect areas in the maxillary sinus floor

The size of the sinus floor defects was estimated by multiplying the maximum mesiodistal length in the sagittal view by the maximum buccolingual width in the coronal view in the CBCT image using a unified approach. If the maxillary sinus floor had more than one bone defect, the sum of the sizes and the number of defects were recorded.

2. Residual bone height (RBH)

The RBH was measured at all the planned implant sites located in the sinus, parallel to the longitudinal axis of the implant. If the

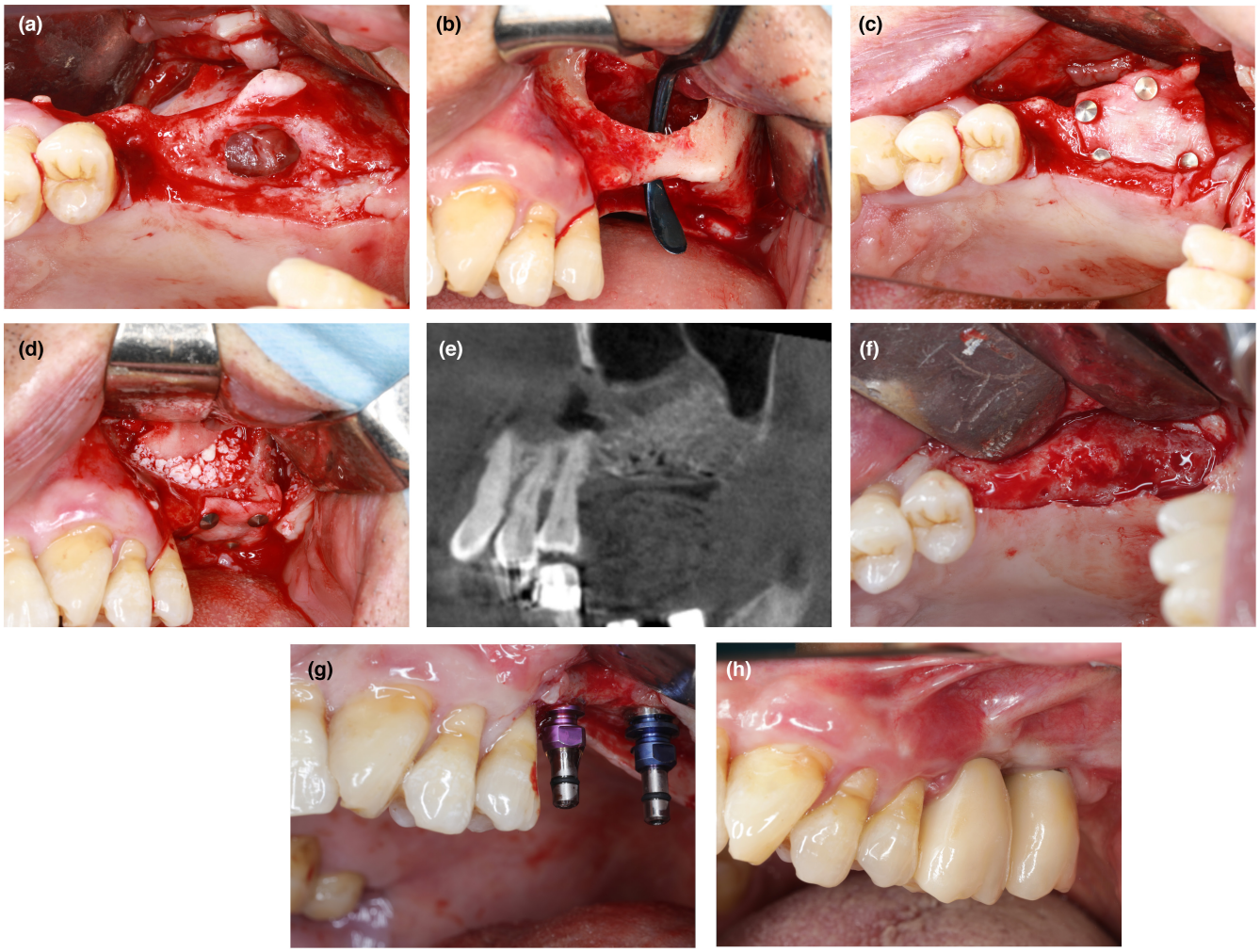

FIGURE 2 Surgical procedure. (a) A crestal incision was introduced slightly palatal to the sinus floor defect area. The split-thickness flap technique was applied to complete flap reflection. (b) The bone beam between the lateral window and sinus floor defects was wide enough. (c) A resorbable collagen membrane was placed on the outside to close the bone defect prior to graft insertion and was fixed with titanium pins. (d) The created space was filled with bone substitutes. (e) Immediate postoperative CBCT confirmed the position of the bone graft. (f) The local graft healed well 8 months after LSFE. (g) Two-stage implant placement. (h) The splinted restoration was delivered.

planned implant site was located in the sinus floor defects area, the RBH was recorded as the peripheral RBH (pRBH) around the sinus floor defects (Figure 3).

3. Mean Schneiderian membrane thickness (mMT)

The thickness of the Schneiderian membrane was measured at three points: the buccal conjunction point (MTb), the middle point of the sinus floor (MTm), and the palatal conjunction point (MTp) (Figure 4). The thickness of the Schneiderian membrane at the site of sinus floor defects was specifically defined as MTf. Measurements were performed perpendicularly from the mucosal surface to the underlying bone plate of the sinus or sinus floor line between both sides of the sinus floor defect. The average of the three values was recorded as the mMT.

4. Height of the bone graft gained (HBG)

Height of the bone graft gained values were measured from the sinus floor to the top of the bone graft at the planned implant site and parallel to the longitudinal axis of the implant at least 8 months after LSFE surgery.

5. Marginal bone loss (MBL)

In the last X-ray examination, MBL was measured between the platform and the first bone-to-implant contact at the last available timepoint. The values of the mesial and distal aspects were averaged into a single value for each implant.

2.5 | Statistical analysis

All relevant data were recorded using Excel 2016 (Microsoft). Data analysis was performed using the SPSS software (IBM Corp. Released 2020. IBM SPSS Statistics for Macintosh, Version 27.0. Armonk, NY: IBM Corp). The primary parameter measured in this study was the CSR of the implants, which was estimated using the Kaplan–Meier method. Descriptive statistics were presented as mean ± standard

deviation or median ± interquartile range (IQR) for continuous variables after checking for normality with the Shapiro–Wilk test and were presented as frequency and percentage for categorical variables.

Based on the normality results, the differences in pRBH, MTf, mMT, bone defect area, and age between the SMP and non-SMP (n-SMP) subgroups were evaluated using the Mann–Whitney *U* test. Differences in sex, smoking habits, history of periodontitis, diabetes mellitus, history of sinus cyst removal surgery, and sinus septa were evaluated between the two groups using Fisher's exact test. The maximum value of bone defect area as well as the mean value of pRBH and MTf were taken when multiple bone defects existed on one sinus floor. Also, the mean value of mMT was taken when multiple implant sites existed on one sinus. And to control the intraclass correlation within the patient, one of the double sinuses in a particular patient was randomly removed for sensitivity analysis. The level of statistical significance was set at $p < 0.05$. Incomplete data were excluded from the analyses.

3 | RESULTS

3.1 | Demographic and clinical characteristics

From January 2008 to December 2020, 1831 patients (2039 maxillary sinuses) were scheduled to undergo LSFE at the Department of Oral Implantology, Peking University Hospital of Stomatology. Thirty-seven patients (38 sinuses) had sinus floor defects on preoperative CBCT. The incidence of radiographic sinus floor defects was 2.0% in the patients and 1.9% in the sinuses. Among them, 35 patients (36 sinuses) underwent LSFE, while the remaining two patients chose nonimplant restorations. Consequently, 36 sinuses with sinus floor defects were included in this study (Figure 5).

Finally, 35 patients (36 sinuses), 22 men and 13 women, were enrolled in this study; their mean age was 49.9 ± 11.2 years at the time of surgery. Twelve patients had lesions on the right maxilla, 22 on the left, and only one patient on both sides. The loss of a single tooth was seen in the case of 36% (13/36), whereas the loss of multiple teeth was seen in the remaining 64% (23/36). Sinus floor defects were found at 37 implant sites, with 25 in the maxillary first molar (17 on the left and 8 on the right). Only one sinus had septa on the maxillary sinus floor. A history of maxillary sinus surgery for antral pseudocyst removal was seen in the case of four sinuses. The demographic and clinical characteristics of the patients are presented in Table 1.

In total, 47 implants were placed after an average 9-month healing period according to the local anatomical conditions, and 11 implants were placed simultaneously with submerged healing in 10 of them. Restorations were completed at an average of 6 months after implant placement in the secocnd-stage procedure and after an average of 11 months in the first-stage procedure. When it comes to implant types, 22 were Camlog implants, 32 were Nobel implants, and 4 were Ankylos implants. The following types of prostheses were used in the 45 sites with multiple missing teeth: single crown, 16.3% (7/43); splinted restoration, 62.8% (27/43); crown and bridge, 13.9% (6/43); and provisional restoration, 7.0% (3/43). All three provisional restorations were placed in one completely edentulous patient with sinus floor defects in the right sinus. A full-arch provisional prosthesis was delivered after the implantation.

3.2 | Clinical outcomes

After a mean follow-up period of 4 years (range 1–9 years), the CSR was 96.5% at the 1-year, 3-year, 5-year, and 7-year follow-up timepoints and 64.3% at the 8-year follow-up timepoint. Detailed information is presented in the form of a Kaplan–Meier curve (Figure 6). Forty-eight out of 58 (82.7%) implants were classified as Group I (success), 7 out of 58 (12.1%) implants as Group II (satisfactory survival), 3 out of 58 (5.2%) implants as Group IV (failure). Two of the three lost implants in the two sinuses of two patients were withdrawn because of osseointegration failure before functional loading without subsequent implant replacement. A single implant at another site in the abovementioned sinus was lost due to peri-implantitis after 7 years of functional loading in a patient with poor oral hygiene. A new implant was inserted, and the prosthesis was delivered 8 months later. At the final follow-up visit, no other implants were lost or had failed.

During the procedure, SMP occurred in 10/36 (27.8%) of the treated sinuses. It was possible to complete the surgical procedure in nine cases with membrane perforations ≤10 mm in size; perforations were managed using extreme care while continuing the membrane detachment procedure and applying absorbable collagen membranes (Bio-Gide). Surgery was suspended in only one case due to complicated membrane perforation, and successful re-entry LSFE was performed after 4 months, with desirable bone healing 12 months before implant placement.

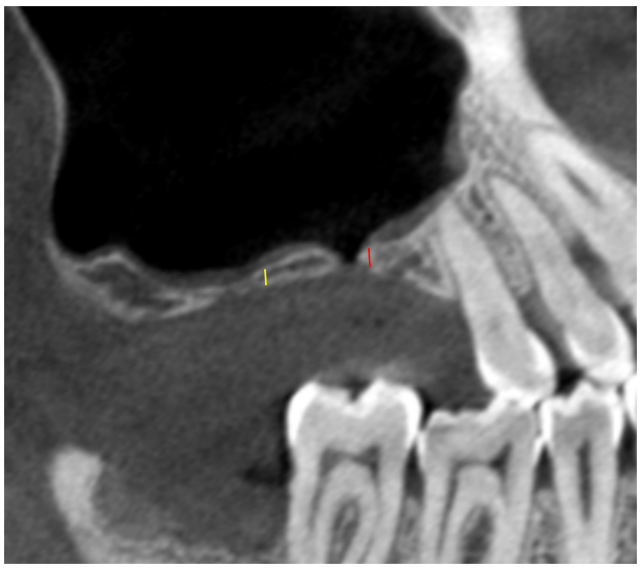

FIGURE 3 Residual bone height (RBH) and periphery RBH (pRBH). The yellow line indicates RBH, and the red line indicates pRBH.

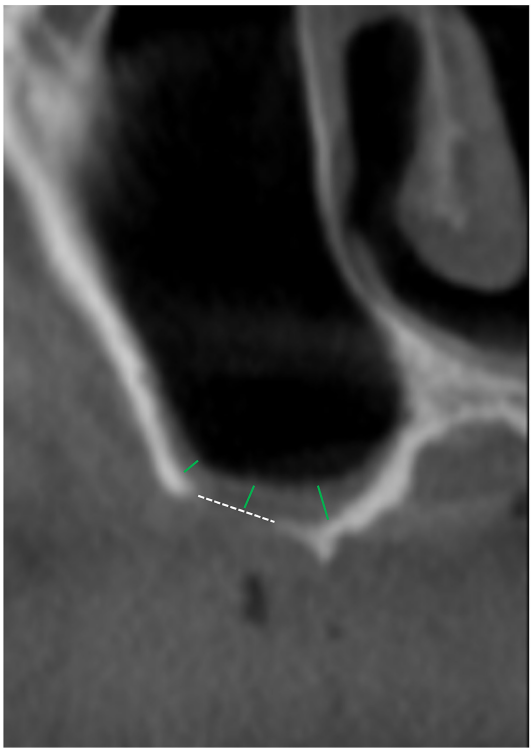

FIGURE 4 Sinus floor thickness. The green lines indicate membrane thickness at the buccal, middle, and palatal points of the sinus floor.

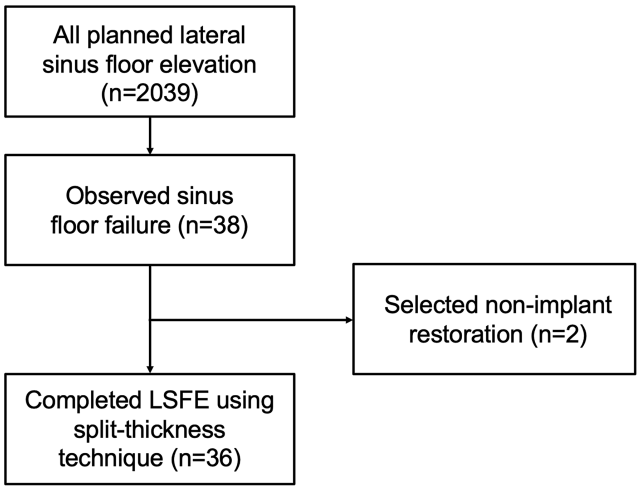

FIGURE 5 Workflow of patient enrolment.

No postoperative wound dehiscence, infection, or acute maxillary sinusitis was observed. All the patients healed uneventfully.

The results of the Mann–Whitney *U* test and Fisher's exact test showed that pRBH, MTf, mMT, bone defect area, age, sex, smoking habits, history of periodontitis, diabetes mellitus, history of sinus cyst removal surgery, and sinus septa did not reach statistical significance between the SMP and n-SMP groups. After sensitivity analysis, the results were consistent. Detailed information is presented as descriptive statistics in Table 2.

TABLE 1 Summary of the demographic and clinical characteristics.

	N (%)/mean ± SD
Age (years)	49.9 ± 11.2
Gender	
Male	22 (62.9%)
Female	13 (37.1%)
Sinus bone defect site	
Right	13 (36.1%)
Left	23 (63.9%)
Tooth missing	
Single	14 (38.9%)
Multiple	22 (61.9%)
Septa	
Yes	1 (2.8%)
No	35 (97.2%)
Cyst	
Yes	4 (11.1%)
No	32 (88.9%)

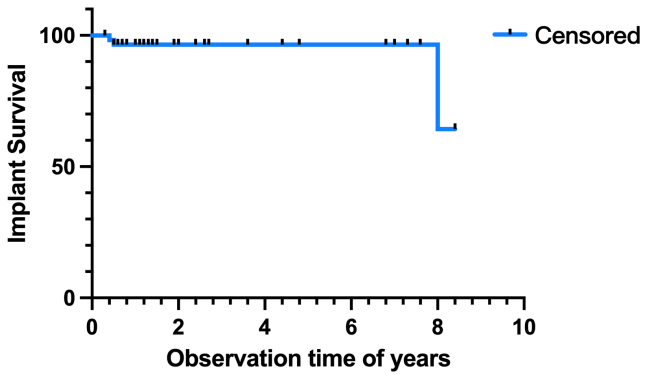

FIGURE 6 Cumulative survival rate of the implants.

3.3 | Radiographic outcomes

The mean and median (IQR) of the bone defect areas were 17.5 mm^2 and 7.1 (1.9–18.2) mm^2, respectively. Six of these areas measured >40 mm^2. While 86.1% (31/36) of the sites had only one sinus floor defect per site, 11.1% (4/36) had two sinus floor defects per site, and only 1 site had three sinus floor defects.

The average RBH in each implant site was 2.2 mm, and the median RBH was 1.7 mm (IQR: 1.2–2.8 mm). Additionally, the median pRBH was 1.4 mm (IQR: 1.0–2.2 mm).

The median mMT was 1.3 mm (IQR: 0.9–4.1 mm). Among the 174 MTb, MTm, and MTp sites, there were 67 sites (38.5%) with mucosal thickness ≥2 mm and 52 sites (29.9%) with mucosal thickness <1 mm.

After LSFE, the median HBG was 11.6 mm (IQR: 10.2–13.3 mm), and the median HBG in the apical portion of the implant was 2.2 mm (IQR: 1.3–3.8 mm).

The median MBL was 0.3 mm (IQR: 0.0–0.8 mm). The radiographic outcomes are summarized in Table 3.

4 | DISCUSSION

Owing to various improvements in surgical techniques and instruments, anatomical variations, such as sinus septa and variant posterior superior alveolar artery, can be managed appropriately (Maridati et al., 2014; Okada & Kawana, 2019). However, sinus floor defects remain a challenging issue to manage, particularly when the buccal flap and Schneiderian membrane are largely adherent (Testori et al., 2022). In addition, the incidence of radiographic sinus floor defects in this study was 1.9% (38/2039), which is comparable to that reported by Zijderveld et al. (2008) (2%, 2/100). This anatomical variation is rare, but unavoidable, in cases requiring LSFE.

The CSR of the implants was 96.5% during the first 7 years of the follow-up and 64.3% at the 8-year follow-up, which was comparable to that in cases with RBH <4 mm reported in a long-term retrospective study (Kim et al., 2020). Moreover, no postoperative complications were observed in our study. Despite careful management, SMP still occurred in 10/36 cases (27.8%), which is higher than the incidence (21/197, 10.7%) reported in the study on LSFE with RBH <4 mm (Kim et al., 2020). This result is consistent with that of a previous study, suggesting that sinus floor defects increase the risk of SMP (Cortes et al., 2015). However, whether there are significant influences in terms of bone formation and implant survival rates, which differ between the postrepair group and nonperforation group, is controversial (Becker et al., 2008; Froum et al., 2013). No postoperative biological complications were observed. Moreover, the median MBL was 0.3 mm (IQR: 0.0–0.8 mm), which is comparable to that in previous studies (Filipov et al., 2021). Therefore, despite the limitations associated with these findings, sinus floor defects do not seem to compromise LSFE therapy after appropriate management.

Previous studies have shown that the split-thickness flap is reliable and reproducible in re-entry LSFE; however, the same problem of the adhesion of the Schneiderian membrane and mucoperiosteal flap arises in the case of bone dehiscence (Lin et al., 2010). In this procedure, should bone defects be present at the crestal level, it is necessary to modify the flap reflection to a split-thickness design and move the crestal incision toward the palate (1–2 mm away from the bone defects), guided by preoperative CBCT. In recent years, several researchers have also used this technique in a few cases with sinus floor defects (Nevins & Wang, 2019; Testori et al., 2022).

In the present study, lateral osteotomy was selected as the routine procedure. With this procedure, a larger amount of cortical bone could be preserved on the sinus floor to facilitate subsequent implant placement. Previous research by Winter et al. (2003) and Soardi et al. (2020); Soardi and Wang (2012) indicates that crestal window sinus elevation (CWSE) is a feasible procedure. It can be implemented to minimize surgical trauma and retain the osteogenic potential of the bony walls. However, it has limited indications in patients with sinus floor defect areas that are large enough for good access and no SMP during flap reflection. In addition, the membrane detachment force, angle of the instrument, and elasticity assessment during CWSE are different from those during LSFE. Coupled with the fusion of the mucoperiosteal flap and Schneiderian membrane, there is an increase in surgical difficulties and the requirement for better surgical skills. Therefore, lateral osteotomy was chosen to limit the size of the lateral window.

When the diameter of the defect was more than 2 mm, a sufficiently large resorbable collagen membrane fixed with titanium pins was used to close the bone defect and reconstruct the sinus floor before bone substitute placement was recommended. The function of the barrier membrane is to keep the blood clot and bone substitutes stable and to avoid unwanted, fast-growing tissues, which is conducive to new bone formation at the crestal level. This results in solid wound closure, which could aid in managing possible dehiscence.

Given the extensive alveolar loss, 47/58 (81.0%) implant placements were scheduled 8 months after LSFE in the second stage. The healing period was longer than that in other studies (Chao et al., 2010; Peleg et al., 1999). Previous histological studies have confirmed that

TABLE 2 Associations between Schneiderian membrane perforations (SMP) and the potential risk factors.

	SMP	n-SMP	*p*-Value
pRBH (mm), median [IQR]	1.4 [0.9–2.3]	1.6 [1.1–2.3]	.460
MTf (mm), median [IQR]	1.5 [0.3–4.4]	1.4 [0.3–3.0]	.843
Bone defect area (mm^2), median [IQR]	3.1 [1.3–9.8]	11.5 [2.5–38.4]	.065
mMT (mm), median [IQR]	1.2 [0.3–3.0]	1.5 [0.9–3.9]	.270
Age (years), mean ± SD	47.8 ± 4.5	51.0 ± 12.9	.255
Gender: fem, *n* (%)	4 (40.0%)	9 (36.0%)	1.0
Smoking habits +, *n* (%)	1 (10.0%)	2 (9.5%)	1.0
History of periodontitis +, *n* (%)	7 (70.0%)	12 (48.0%)	.285
Diabetes mellitus +, *n* (%)	0 (0.0%)	1 (4.8%)	1.0
Cyst +, *n* (%)	0 (0.0%)	4 (16.0%)	.303
Septa +, *n* (%)	1 (10.0%)	0 (0.0%)	.286

TABLE 3 Radiographic measurements.

	Median [IQR]
Bone defect area (mm^2)	7.1 [1.9–18.2]
RBH (mm)	1.7 [1.2–2.8]
mMT (mm)	1.3 [0.9–4.1]
HBG (mm)	11.6 [10.2–13.3]
MBL (mm)	0.3 [0–0.8]

Abbreviations: HGB, Height of the bone graft gained; MBL, marginal bone loss; mMT, Mean Schneiderian membrane thickness; RBH, residual bone height.

new bone formation is initiated from the surrounding bony walls (Pignaton et al., 2020; Scala et al., 2010). The lateral window combined with sinus floor defects may decrease the osteogenic potential and lead to slow bone formation. Besides, existing research has shown that the bone formed after 8 months exhibited a larger number of bone trabeculae and decreased space between the trabeculae than that seen in the case of biopsy samples harvested after 5 months (Liu et al., 2020). The healing time after LSFE in this study was prolonged, as well as the time for implant integration, which is consistent with the previous opinion that the total healing period may still exceed 1 year in some extreme situations with slower resorbing graft material (Jensen, 2019). In reality, some patients cannot attend appointments as planned because of their personal schedules and distant residential locations. As a result, the implant was usually placed approximately 9 months after LSFE, and restoration was performed after an average of 6 months in the second-stage procedure in this study. Immediate implant insertion can only be performed when initial stability can be achieved. This is a highly experience-based decision because RBH is extremely low, and in some cases, the implant neck might not be completely surrounded by the residual bone.

The strengths of this study include the relatively large number of rare cases and the long follow-up period. However, some limitations must be acknowledged. First, its retrospective nature resulted in incomplete data extraction and different lengths of follow-up periods. Hence, there is limited generalisability and the risk of recall bias. Second, several different surgeons performed surgical procedures on different patients. Individual heterogeneity exists even if a standardized procedure was followed. Third, measurement and estimation errors were unavoidable, and more accurate methods should be adopted in future research. Additionally, in the statistical analysis, the internal correlation between the two sinuses in the same patient was ignored in the Mann–Whitney *U* test and Fisher's exact test. Therefore, the probability of class I errors was increased, and the risk factors for SMP in LSFE in patients with sinus floor defects might have been overestimated. So, one of the double sinuses in a particular patient was randomly removed for sensitivity analysis and the results still did not reach statistical significance, which was consistent and robust. Last, due to insufficient sample size and a low rate of implant failure, the results are not sufficiently robust to assess the risk factors affecting implant survival in LSFE in patients with sinus floor defects. Further research is required in this area. Therefore, the data and results should be interpreted with caution.

Overall, based on the results of this study, the outcomes of implementing LSFE in patients with sinus floor defects are predictable, as assessed during the long-term follow-up period. Future studies with improved study designs and larger sample sizes are necessary to clinically and histologically confirm our findings and may provide further insights into the relationship between the size of sinus floor defects and osteogenesis in the sinus elevation space.

5 | CONCLUSION

Despite the limitations of this study, the results suggest that the long-term clinical outcomes of LSFE in patients with sinus floor defects are predictable. Special attention should be paid to the preoperative CBCT evaluation and surgical method.

AUTHOR CONTRIBUTIONS

Yifan Wen: Methodology; Data curation; Software; Formal analysis; Writing – original draft; Project administration; Conceptualization. **Donghao Wei:** Writing -– review & editing; Validation. **Xi Jiang:** Conceptualization; Methodology; Writing – review & editing. **Yu Zhang:** Supervision; Writing – review & editing. **Ping Di:** Supervision; Conceptualization; Writing – review & editing. **Ye Lin:** Supervision; Writing – review & editing; Conceptualization; Validation; Data curation.

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CONFLICT OF INTEREST STATEMENT

The authors declare no potential conflict of interest with respect to the authorship and/or publication of this article.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ETHICS STATEMENT

This study was approved by the local ethics committee (Institutional Review Board of Peking University School and Hospital of Stomatology; approval number: PKUSSIRB-202277080).

PERMISSION TO REPRODUCE MATERIALS FROM OTHER SOURCES

This study did not include materials reproduced from other sources.

CLINICAL TRIAL REGISTRATION

This study was registered in the Chinese Clinical Trial Registry (registration number: ChiCTR2200063807; http://www.chictr.org.cn/listbycreater.aspx).

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