Journal of Dental Sciences

Volume 21 | Issue 2 Article 45

2026

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Journal of Dental Sciences 21 (2026) 1053—1065

Available online at https://jds.ads.org.tw/journal/

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Original Article

Late implant loss and complications of one-step implant therapy in severely atrophic posterior maxilla

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Received 18 November 2025; Final revision received 30 November 2025
Available online 1 April 2026

KEYWORDS
Bone substitutes;
Dental implant;
Lateral window sinus augmentation;
Maxillary sinus

Abstract *Background/purpose:* Successful long-term outcomes of one-step implant placement in the atrophic maxilla have rarely been reported. This retrospective study aimed to evaluate the long-term efficacy of the one-step lateral sinus floor elevation and simultaneous implant placement (LSFESI) in severely atrophic posterior maxilla, and to identify the risk factors for marginal bone loss (MBL) and late implant failure (LIF).
Materials and methods: Clinical data were obtained from Taipei Tzu Chi Hospital. One-step, non-submerged LSFESI was performed at sites with a remaining bone height (RBH) $<$ 5 mm and an insertion torque $>$ 15 N. The clinical and radiographic outcomes, including MBL and LIF, were assessed. The effects of patient- and implant-related factors on MBL were assessed using Generalized Estimating Equation to account for the clustering of multiple implants within the same patient. Chi-square or Fisher's exact tests were used to determine significant

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https://doi.org/10.1016/j.jds.2025.12.002

differences in the distribution of variables between patients with and without LIF.
Results: A total of 122 implants were placed in 60 patients across 73 sinuses to support fixed prosthetic reconstructions. The mean duration was 10 years. Implant survival rates were significant associated with several factors, including keratinized tissue (KT) < 2 mm, poor oral hygiene (OH), the presence of complications, and RBH. The overall LIF rate was 12.3 %. Female, poor OH, KT < 2 mm, and sinus perforation in combination with either sinus infection or infection of adjacent teeth had greater incidence of LIF.
Conclusion: This study demonstrated that one-step LSFESI can be a predictable approach with favorable long-term outcomes.

Introduction

Implant rehabilitation on atrophic posterior maxilla is always challenging. Several surgical techniques and materials have been tested to assess their effectiveness on the reconstruction of posterior maxilla, including LSFESI.[1,2] In the past, LSFESI was recommended to be performed at the sites with RBH > 5 mm.[3] Successful long-term outcomes of both one- and two-stage implant placement in the atrophic maxilla have been reported, even with RBH of 1–3 mm.[4–15] It is important to note, however, that in these studies, LSFESI was typically performed using a submerged technique, which necessitates a second-stage surgery.

Both submerged and non-submerged implant placement approaches have demonstrated similarly clinical outcomes.[16,17] The cost-effective LSFESI approach offers several clinical benefits, including reduced chair time, lower overall treatment costs, and the elimination of the need for a second surgical procedure. In a 12- to 36-month retrospective study, Chaushu et al. reported that submerged and non-submerged healing demonstrated comparable marginal bone loss (MBL) following LSFESI, provided the RBH exceeded 5 mm and insertion torque was > 25 N/cm.[18] Other studies have reported a short-term non-submerged LSFESI approach in the atrophic posterior maxilla.[19,20] However, long-term implant outcomes from these studies remain limited.

Several risk factors have been identified for late implant failure (LIF) and peri-implantitis for LSFESI, including smoking, history of periodontitis, RBH <3 mm, certain implant brand, and surgical complications.[4,9,12,14,21] However, limited longitudinal studies were available. Moreover, most studies have excluded patients with systemic and local conditions that might compromised treatment outcomes. Knowledge of the factors influencing long-term clinical outcomes and LIF of non-submerged LSFESI under challenging systemic and local conditions remains limited. Therefore, this retrospective study aimed to evaluate the longitudinal efficacy and to identify the risk factors for MBL and LIF associated with the one-step LSFESI approach in severely atrophic posterior maxilla of patients with compromised systemic and local conditions.

Materials and methods

Study population

All patients managed with one-step LSFESI at the Department of Dentistry, Taipei Tzu Chi Hospital, between 2006 and 2024 were retrospectively selected for a long-term follow-up study. The study was conducted following the Declaration of Helsinki. This data is approved by the Institutional Review Board at the Taipei Tzu Chi Hospital (#13-IRB 76). One-step LSFESI was performed at sites with RBH less than 5 mm. The choice between a one- and two-stage sinus floor elevation was determined by achieving primary stability (N > 15N) rather than a specific minimum RBH.[19] Insertion torque for dental implants was measured either manually using a torque wrench or automatically by the surgical drilling device. Patients with conditions, including uncontrolled diabetes mellitus (DM, glycated hemoglobin > 8 %), heavy smoking (≥ 10 cigarettes per day), bisphosphonate use, and dental infections adjacent to implants, potentially affecting implant survival, were included to minimize bias in assessing risk factors for late implant loss in one-stage, non-submerged LSFE.[22] Exclusion criteria included patients with untreated periodontitis, active alcohol or drug abuse, pregnancy, sinusitis, or systemic diseases contraindicating oral surgery.

Preoperative and surgical procedures

All patients were treated at the hospital dental clinic. Preoperative and surgical procedures for one-step LSFESI were performed in accordance with our previous study (for detailed information, see Dung, 2015).[20] The implant bed was underprepared using a final drill of a smaller diameter and condensed to achieve higher implant primary stability.[23]

After LSFESI, the sinus window was covered with a resorbable membrane. Transmucosal healing abutments

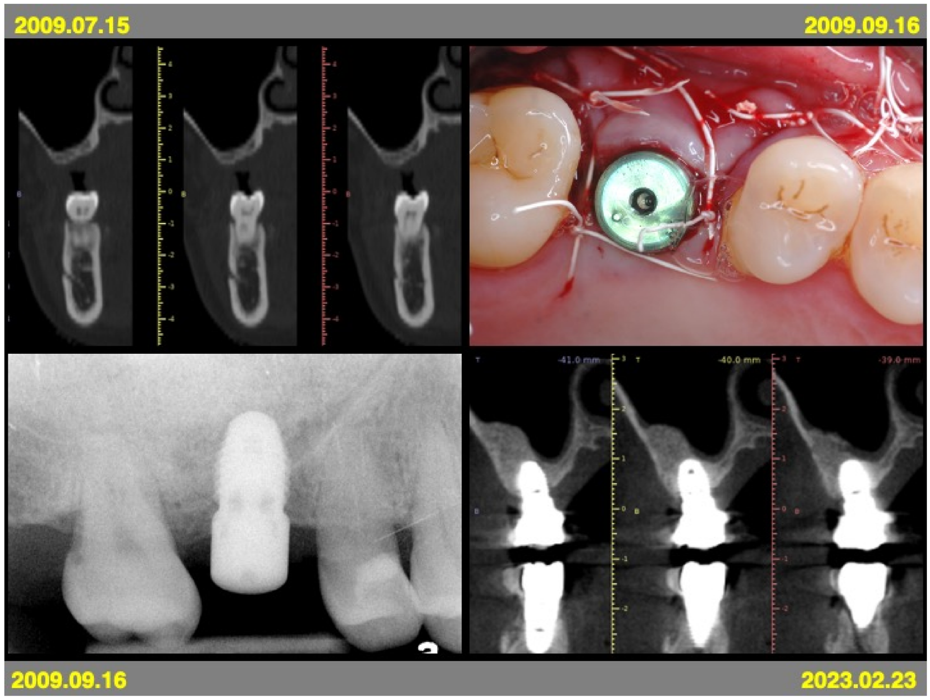

Figure 1 Clinical photographs and radiographs of one-step lateral sinus floor elevation and simultaneous implant placement with long-term follow-up.

were immediately placed to enable non-submerged healing once minimum primary stability (at least 15 N) was achieved (Fig. 1). Implant and sinus healing was evaluated using periapical radiographs every 6 months.

Prosthodontic procedures and follow-up

Approximately 107 implants were loaded with a fixed implant-supported prosthesis. Non-functional and progressive loading were applied to minimize the risk of delayed healing or overloading.[24] The typical loading protocol for provisional implant restorations was carried out in accordance with our previous study.[20] Twenty implant crowns and fifty-three bridges were restored.

Clinical and radiographic outcome assessment

The clinical and radiographic outcomes, including surgical complications, MBL, implant survival rates, and LIF were assessed. Preoperative and follow-up evaluations included periapical radiography and cone-beam computed tomography of the posterior atrophic maxilla. MBL and RBH were measured on periapical radiographs of edentulous posterior regions using digital software (Infinitt Radiology PACS, Taipei, Taiwan).

The MBL was measured from the crown margin to the top of the bone crest, following the methodology described in our previous study (Fig. 2).[25] During follow-up visits, supportive periodontal and peri-implant care (SPC) was provided, occlusion was rechecked, and abutment stability was confirmed.

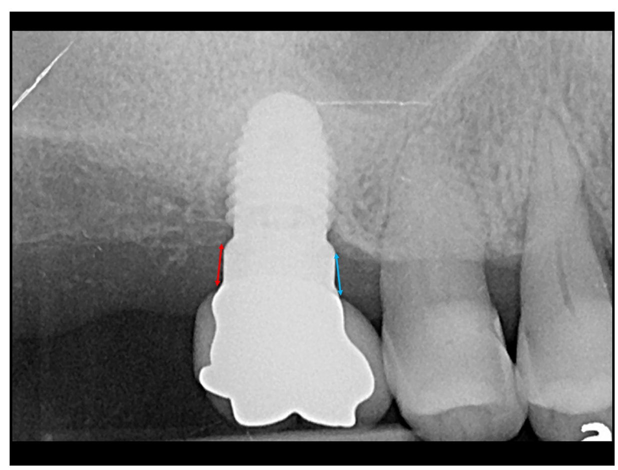

Figure 2 The measurement of marginal bone level. The measurement of marginal bone level. Marginal bone level was measured from the crown margin to the bone crest. Both mesial and distal implant bone levels at crown deliver (a, b) and follow up date (c, d) were measured. Mean of mesial and distal bone level were calculated as average bone level of each implant. Average total bone loss was measured by deduction of the baseline mean bone level (a+b/2) from the last follow-up bone level (c+d/2).

Risk factors for marginal bone loss, late implant failure and implant survival

Possible patient- and implant-related risk factors were assessed, including gender, history of periodontitis, smoking, DM, oral hygiene (OH), compliance with SPC, RBH, lack of keratinized tissue (KT) (defined as KT $<$ 2 mm), complications, and years of follow-up. Implants exhibiting no pain or mobility at the final examination were considered surviving, according to the criteria by Misch et al.[26] LIF is defined as implant loss occurring after occlusal loading.[22] Compliance and OH performance was assessed based on the methodology described previously.[25,27]

Statistical analysis

This study examined potential patient- and implant-related risk factors for MBL, implant survival, and late implant loss. Implant survival analyses were conducted based on KT $<$ 2 mm, OH, periodontitis, presence of complications, and RBH. Implant survival was evaluated using Kaplan—Meier curves, and differences between the survival curves were assessed using the log-rank test.

Continuous variables are presented as mean $\pm$ standard deviation, while categorical variables are expressed as frequencies and percentages. Two-sample t-tests and Wilcoxon rank-sum tests were used to assess the impacts of a history of periodontitis, implant insertion torque, and RBH on MBL. Depending on the data type, two-sample t-tests or Pearson's chi-square tests (or Fisher's exact test when more than 25 % of cells had expected values $<$5) were applied to evaluate the effects of RBH and implant diameter on insertion torque.

To account for the clustering of multiple implants within the same patient, the Generalized Estimating Equation method was employed to evaluate the effects of both patient-related and implant-related factors on MBL. Chi-squared or Fisher's exact tests were used to determine significant differences in the distribution of variables between patients with and without LIF. Statistical analyses were performed using SAS software (version 9.4; SAS Institute, Cary, NC, USA).

Results

Clinical and radiographic assessments of 122 implants were performed in 60 patients and 73 sinuses. Twenty-two percent (13) of patients underwent LSFESI in both sinuses. Implant distribution per sinus was as follows: 28 sinuses received a single implant, 42 received two, and three received three implants. The mean follow-up duration was 10 years (range, 4—16 years). Table 1 presents a descriptive summary of patient- and implant-related risk factors. The study population consisted of equally distributed male and female patients. A history of periodontitis was present in 88.3 % of the patients. Additionally, 10 % of the participants were smokers, 10 % had DM, and 13.3 % had good OH. Approximately 73.3 % of patients received SPC $\geq$ 2 times per year.

Overall, 65 implants (59.0 %) were placed in sinuses with RBH of 1—3 mm. Forty-nine implant sites (49.2 %) had a KT $<$ 2 mm. The follow-up period exceeded 7 years in 83.6 % of patients. Complications occurred at 24.6 % of the implant sites, including sinus membrane perforation in 15 sites (12.3 %), perforation with sinusitis in four sites (3.3 %), adjacent tooth infection in six sites (4.9 %), perforation with adjacent tooth infection in three sites (2.5 %), and bisphosphonate use in two implants (1.6 %). In this study, 18 implants (16.8 %) had an MBL of $>$ 1 mm.

Table 1 Patient- and implant-related factors.

Patient-related factors	N = 60 (%)
Gender	
Male	30 (50.0 %)
Female	30 (50.0 %)
Periodontitis	
Yes	53 (88.3 %)
No	7 (11.7 %)
Smoking	
Yes	6 (10.0 %)
No	54 (90.0 %)
Oral hygiene	
Good	8 (13.3 %)
Medium	26 (43.3 %)
Poor	26 (43.3 %)
Compliance	
High	23 (38.3 %)
Medium	21 (35.0 %)
Low	16 (26.7 %)
Diabetes	
Yes	6 (10.0 %)
No	54 (90.0 %)
Implant-related factors	**N = 122 (%)**
Remaining bone height	
1—3 mm	72 (59.0 %)
4—5 mm	50 (41.0 %)
Implant insertion torque	
N > 15	44 (36.1 %)
N > 35	32 (26.2 %)
N > 45	46 (37.7 %)
Marginal bone loss >1 mm	
Yes	18 (14.8 %)
No	104 (85.3 %)
Keratinized tissue <2 mm	
Yes	49 (40.2 %)
No	73 (59.8 %)
Complications	
Sinus perforation	15 (12.3 %)
Sinustitis + perforation	4 (3.3 %)
Infection + perforation	3 (2.5 %)
Bisphosphonates	2 (1.6 %)
Infection (adjacent tooth)	6 (4.9 %)
None	92 (75.4 %)
Tissue recession	
Recession	28 (23.0 %)
Creeping	27 (22.1 %)
None	67 (54.9 %)
Follow-up years	
4—7	20 (16.4 %)
7—10	49 (40.2 %)
>10	53 (43.4 %)
Implant loss	
Yes	15 (12.3 %)
No	107 (87.7 %)

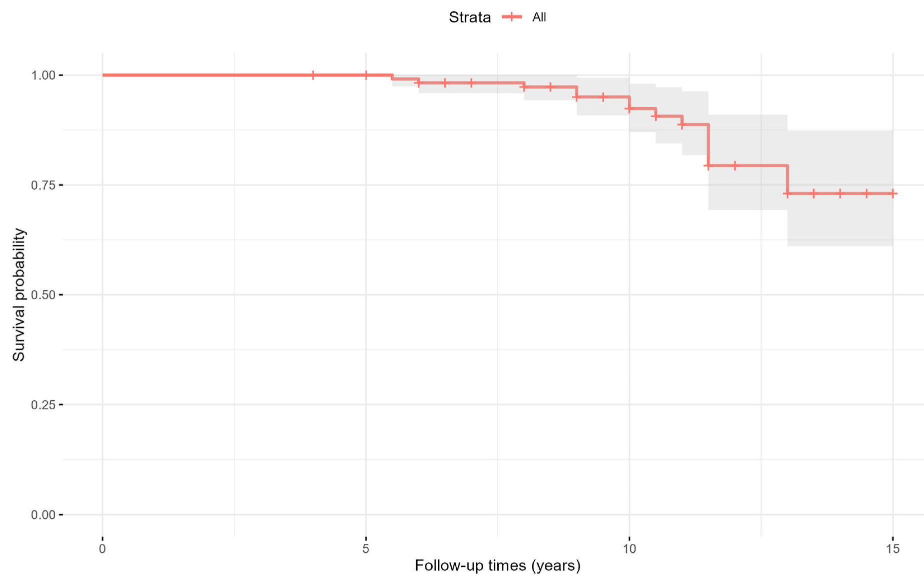

Figure 3 Overall survival curve of implant loss.

Table 2 Log-rank test for strata homogeneity between survival curves.

Strata	Log-rank test *P*-value
Keratinized tissue <2 mm	<0.001
Oral hygiene	<0.001
Periodontitis	0.436
Complications	<0.001
Remaining bone height	0.054

**P*-value <0.05 indicates significant association of the variables on LIF. From results above we see that the survival curves stratified by keratinized tissue <2 mm, oral hygiene, complications, and remaining bone height differed significantly, suggesting these factors influenced LIF.

Fifteen implants were lost during the follow-up period, resulting in an overall 12.3 % of LIF rate. All lost implant sites (100 %) had a KT $<$ 2 mm. The Kaplan—Meier 15-year implant survival curve is illustrated in Fig. 3. Log-rank test results revealed that the survival curves stratified by KT $<$ 2 mm, OH, complications, and RBH differed significantly, suggesting these factors influenced LIF (Table 2).

Forty-nine implants (40.2 %) were placed in areas with KT $<$ 2 mm, while 73 implants (59.8 %) were placed in areas with KT $\geq$ 2 mm. Implant survival rates during the follow-up period were 73.5 % and 100.0 %, respectively, with a statistically significant difference ($P < 0.001$) (Fig. 4). Fifty-four implants (44.3 %) were placed in patients with poor OH, whereas 68 (55.7 %) patients demonstrated moderate or good OH. Implant survival rates were 72.2 % and 100.0 %, respectively, with a significant difference ($P < 0.001$) (Fig. 5). Of the implants, 111 (91.0 %) were placed in patients with stage III or IV periodontitis and 11 (9.0 %) in those without periodontitis. The implant survival rates were 86.5 % and 100.0 %, respectively, although the difference was not statistically significant ($P = 0.436$) (Fig. 6). Thirty implants (24.6 %) were placed at sites with complications, and 92 (75.4 %) at sites without complications. The corresponding implant survival rates were 66.7 % and 94.6 %, respectively, with a statistically significant difference ($P < 0.001$) (Fig. 7).

Survival curves stratified by RBH exhibited a statistically borderline significance ($P = 0.05$), suggesting that RBH may moderately influence implant survival. Interestingly, implants in sites with RBH of 4—5 mm exhibited a higher loss rate than those in sites with RBH of 1—3 mm during follow-up (Table 2, Fig. 8).

Table 3 summarizes the effects of history of periodontitis, implant insertion torque, and RBH on the MBL. Mean MBL was 0.38 $\pm$ 0.74 mm in patients with a history of periodontitis and 0.21 $\pm$ 0.46 mm in those without. There was no significant association found between MBL and a history of periodontitis or between MBL and insertion torque ($P > 0.05$). No significant difference was observed in MBL between implants with RBH 4—5 mm (0.47 $\pm$ 1.02 mm) and those with RBH 1—3 mm (0.45 $\pm$ 0.84 mm) ($P > 0.05$).

Table 4 presents the impact of RBH and implant diameter on the insertion torque. Implants in sites with RBH 1—3 mm demonstrated significantly lower insertion torque (>15 N) than those in sites with greater RBH. Tables 5 and 6 displays patient- and implant-related risk factors associated with MBL. Univariate logistic regression analysis using the GEE method revealed that poor OH ($P < 0.001$), DM ($P < 0.001$), KT $<$ 2 mm ($P = 0.009$), and complications ($P < 0.001$) were significantly associated with an increased MBL. Tables 7 and 8 outlines patient- and implant-related factors significantly associated with LIF. Female ($P = 0.013$), poor OH levels ($P < 0.001$), KT $<$ 2 m m ($P < 0.001$), and sinus perforation in combination with either sinus infection or infection of adjacent teeth ($P < 0.001$) had greater incidence of LIF. No significant risk was found for sinus perforation with no infection on LIF. Two implants with bisphosphonates were excluded in order to differentiate the risk of sinus perforation with infection from those with no infection on LIF.

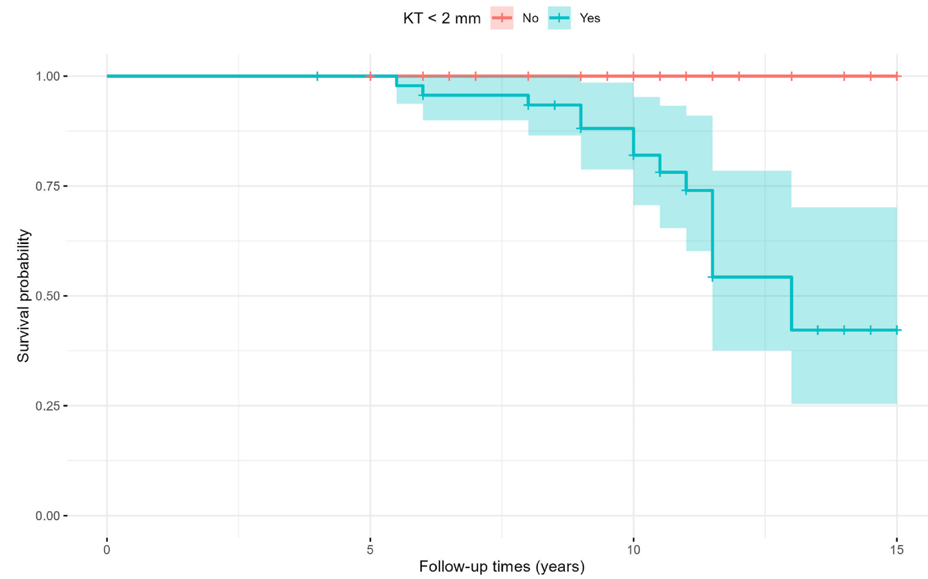

Figure 4 Survival curve of implant loss by keratinized tissue (KT) < 2 mm.

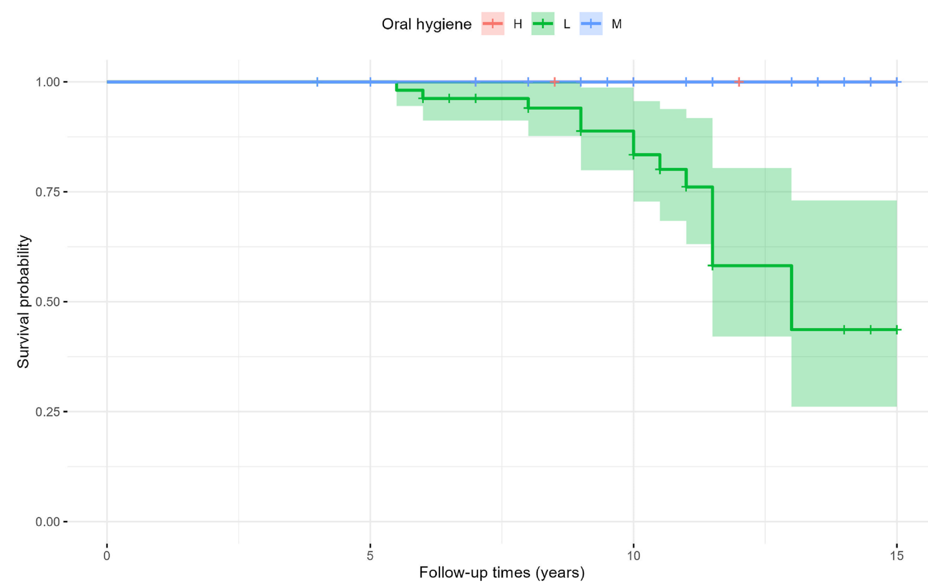

Figure 5 Survival curve of implant loss by oral hygiene.

Discussion

To the best of our knowledge, this is the first report of long-term late implant complications following one-step LSFESI in the severely atrophic maxilla. The results of the present retrospective study indicate that the one-step LSFESI, combining sinus augmentation and non-submerged implant placement in a severely atrophic maxilla, was predictable and can be maintained for the long term. Consistent with previous studies, the present study confirms that primary stability can be achieved in atrophic maxilla with RBH less than 5 mm.[7,10,13,19] This one-step LSFESI therapy reduces the number of surgical procedures, overall treatment time, and therapeutic expenses.

Few longitudinal studies have evaluated the clinical outcomes of the non-submerged, one-step approach to LSFESI in severely atrophic maxilla. In this study, the overall implant survival rate after a mean follow-up period of 10 years was 87.7 %, even in patients with challenging systemic or local conditions. In a retrospective analysis of submerged LSFESI in the severely atrophic maxilla with a 10-year follow-up, Valentini et al. reported a late implant survival rate of 83.1 %.[10] The main risk factor associated with negative outcomes was the long-term development of peri-implantitis, which subsequently resulted in LIF.

Other studies on submerged LSFESI in atrophic maxilla with a RBH < 5 mm reported 5-year implant survival rates ranging from 96 % to 99 %.[4,5,9–13,15] Similar survival rates have been observed in two non-submerged LSFESI studies,

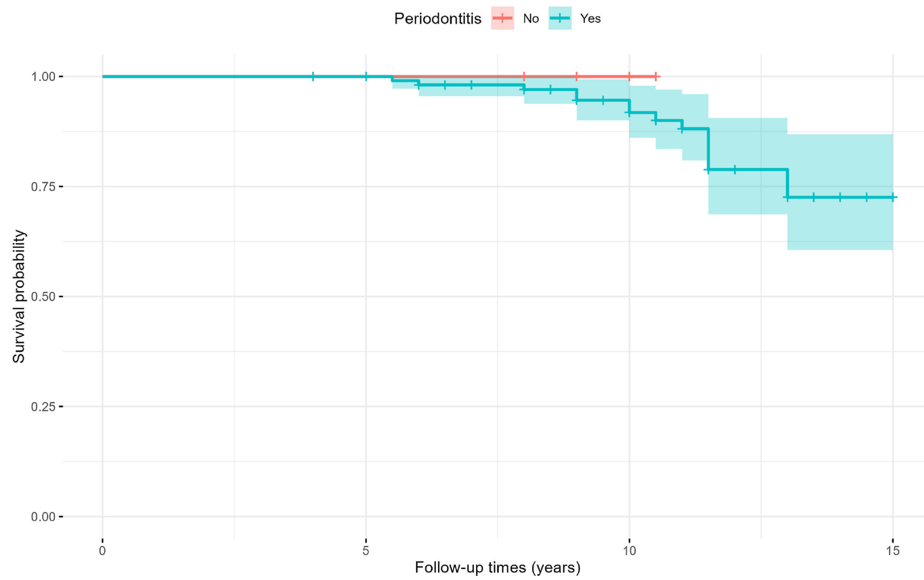

Figure 6 Survival curve of implant loss by periodontitis.

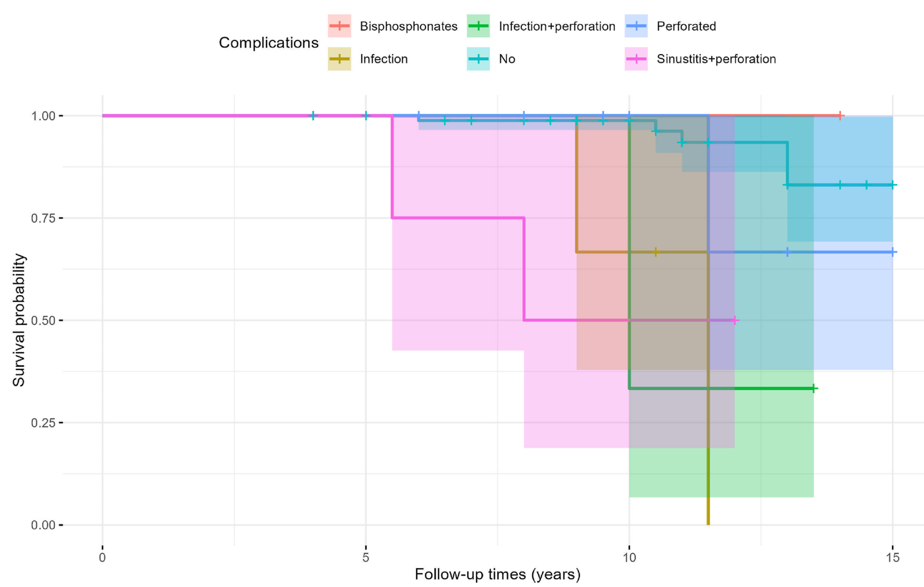

Figure 7 Survival curve of implant loss by complications.

both reporting a 5-year implant survival rate of 98 %.[19,20] The short-term implant survival rate using the non-submerged, one-step LSFESI approach was high and comparable to that of the submerged or staged approach in severely atrophic maxillary sinuses. However, similar to a previous study, the 10-year survival rate of implants placed using the LSFESI approach in this study decreased by approximately 10 %.[10] Most implants in this study failed after 5 years. The primary causes of LIF in this long-term study were peri-implantitis associated with smoking, uncontrolled DM, progressive periodontitis, and dental infections adjacent to the implants. Whether peri-implant bone loss progresses more rapidly in severely atrophic augmented sinuses than in native bones remains unclear. However, further studies are warranted to explore this issue.

No significant differences in MBL were observed over the 10-year study period for non-submerged one-step LSFESI in patients, regardless of a history of periodontitis or smoking status. Contrary to the findings of this study, Krennmair et al., in a 5-year prospective study, evaluated factors affecting peri-implant MBL for implants placed in staged maxillary sinus augmentation.[4] MBL increased over time and was negatively affected by a history of periodontitis. Stacchi et al. and other studies discovered that patients with a history of periodontitis and the LSFESI approach were significantly associated with peri-implantitis.[21,22,28—31] The high prevalence (88 %) of stages III—IV periodontitis in this cohort may have complicated the identification of a correlation with MBL. Further controlled clinical trials are required to clarify this issue.

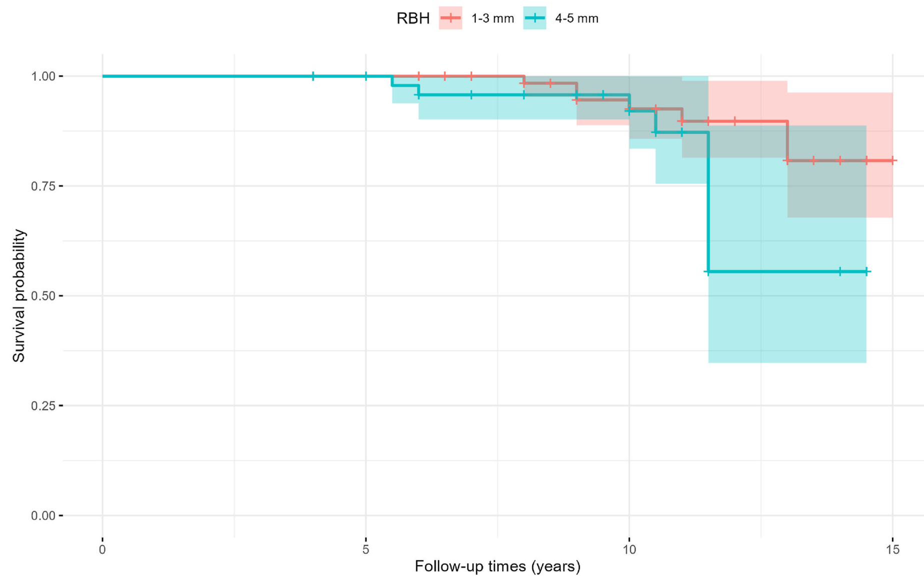

Figure 8 Survival curve of implant loss by remaining bone height (RBH).

Table 3 A history of periodontitis, insertion torque, and remaining bone height (RBH) on marginal bone loss (MBL) (N = 107).

Variables	Changes of MBL Mean±SD	*P*-value (t-test or ANOVA)	*P* -value (Wilcoxon or Kruskal–Wallis)
Periodontitis			
With	0.485 ± 0.943	0.121	0.290
Without	0.214 ± 0.456		
Insertion torque			
N > 15	0.534 ± 1.171	0.731	0.986
N > 35	0.463 ± 0.813		
N > 45	0.369 ± 0.627		
RBH			
1–5 mm (all implant sites)	0.457 ± 0.908		
1–3 mm	0.449 ± 0.839	0.904	0.947
4–5 mm	0.470 ± 1.015		

**P*-value <0.05 indicates significant association of the variables on implant insertion torque. From results above we see that remaining bone height 1–3 mm has significant associations with less insertion torque.

The impact of smoking on implant health remains controversial.[28,29,31,32] Our previous short-term study involving non-submerged, one-step LSFESI, demonstrated that smoking was associated with early MBL.[20] Krennmair et al. also demonstrated that MBL for implants placed in staged maxillary sinus augmentation was negatively affected by smoking status.[4]

DM and poor OH were significantly associated with MBL.[29,33–36] In this study, all six patients with DM had a history of periodontitis, peri-implantitis, or implant loss. This may explain the elevated risk of peri-implantitis and implant loss in patients with DM. Data from this study confirmed that non-submerged one-step LSFESI was significantly associated with MBL in patients with poor OH. Numerous studies have demonstrated that poor OH is a major risk factor for peri-implant diseases.[29,33–36] Further studies with larger sample sizes are needed to minimize bias from the small number of participants. Furthermore, peri-implant MBL may be influenced by several patient factors, which can interact synergistically or require longer follow-up to fully assess their impact on implant outcomes, warranting further investigation.

Literature on the effects of varying insertion torques and RBH on MBL of implants using the one-step LSFESI approach remains limited. This study on non-submerged, one-step LSFESI is likely the first to demonstrate that there were no significant long-term differences in MBL among implants with different insertion torques and RBH. At a 10-year follow-up of two-stage implant placement after sinus grafting, Urban reported minimal complications and MBL, with no significant differences in MBL between severely (RBH: 0.1–3.5 mm) and moderately (RBH: 3.5–7 mm) atrophic maxilla.[5] In a long-term comparative study of dental implants placed in severely atrophic maxilla using LSFESI, Virnik et al.[11] demonstrated no significant

Table 4 Remaining bone height (RBH) and implant diameter on implant insertion torque.

Variables	Insertion torque			*P*-value
	>15 N	>35 N	>45 N	
RBH				
1—5 mm (all implant sites)	44	32	46	
1—3 mm	37	17	18	<0.001*
4—5 mm	7	15	28	
Implant diameter				
3.5 mm	3	1	2	0.520
4.3 mm	10	7	8	
5 mm	27	22	26	
6 mm	4	2	10	
Implant diameter (binary)				
3.5/4.3 mm	13	8	10	0.695
5/6 mm	31	24	36	

*Chi-square test or Fisher exact test if over 25 % of cells have expected counts less than 5.
**P*-value <0.05 indicates significant association of the variables on implant insertion torque. From results above we see that remaining bone height 1—3 mm has significant associations with less insertion torque.

differences in the occurrence of peri-implantitis between sites with RBH < 3 mm and those with RBH ≥ 3 mm.

The existing evidence on the prevalence of peri-implantitis in long-term non-submerged LSFE is rare. In four long-term (> 5 years) retrospective studies of submerged, one-stage LSFE, peri-implantitis affected 5.0—16.8 % of implants.[9—11,15] The high prevalence of patients with periodontitis, along with the extended follow-up period in this study using non-submerged LSFESI, may have contributed to the notable LIF associated with peri-implantitis. However, the impact of submerged versus non-submerged techniques on the prevalence of peri-implantitis in one-stage LSFE remains difficult to assess due to limited evidence and inconsistent case definitions of peri-implantitis. Further studies on this topic are warranted.

Table 5 Patient-related variables affecting marginal bone loss (Univariate) (N = 107).

Patient-related factors	*Coef.*	*95 % C.I.*	*P*-value
Gender			
Female (ref.)			
Male	0.234	(-0.214, 0.681)	0.306
Periodontitis			
No (ref.)			
Yes	0.247	(-1.874, 0.682)	0.265
Smoking			
No (ref.)			
Yes	0.548	(-0.322, 1.418)	0.217
Oral hygiene			
Good (ref.)			
Medium	0.086	(-0.170, 0.342)	0.511
Poor	0.900	(0.439, 1.362)	<0.001*
Compliance			
High (ref.)			
Medium	−0.148	(-0.664, 0.367)	0.573
Low	0.135	(-0.445, 0.715)	0.648
Diabetes			
No (ref.)			
Yes	1.952	(1.237, 2.667)	<0.001*

*Generalized estimating equations (GEE) taking into account of the clustering of implants within patient.
**P*-value <0.05 indicates significant associations of the variables on marginal bone loss. From results above we see that poor oral hygiene and patients with diabetes have significant associations on marginal bone loss.

Data from the present study indicated that complications such as bisphosphonate use and infections of adjacent teeth were significantly associated with increased peri-implant MBL. Two implants involving one patient taking bisphosphonates exhibited severe peri-implant MBL, the cause of which remained unclear but may have been related to other risk factors such as poor oral hygiene. The influence of adjacent endodontic infections on peri-implant MBL has rarely been reported. Daubert et al. described two cases of peri-implant bone loss adjacent to teeth with endodontic—periodontic lesions, which resolved following endodontic therapy or tooth extraction.[37] In this study, implants adjacent to infected teeth demonstrated either severe MBL or late implant loss. Thus, periodontal or endodontic infections in neighboring teeth may increase the risk of implant complications and warrant careful monitoring.

This study is also the first to demonstrate that KT < 2 mm in implants placed via a non-submerged, one-step LSFESI approach is significantly associated with increased MBL. Previous studies have reported conflicting findings regarding the association between KT and peri-implant MBL.[28,36,38] The lack of buccal KT appears to be linked to unstable implant outcomes such as increases of BOP and MBL, although the association was weak. However, KT was significantly associated with reduced MBL.[36] Previous studies have demonstrated that insufficient KT is a risk indicator for peri-implantitis, and therefore, adequate width of KT has been highly recommended around dental implants to maintain peri-implant health.[29,34,39]

Table 6 Implant-related variables affecting marginal bone loss (Univariate) (N = 107).

Implant-related factors	*Coef.*	*95 % C.I.*	*P*-value
Remaining bone height			
1–3 mm (ref.)			
4–5 mm	−0.178	(-0.545, 0.189)	0.342
Insertion torque			
N > 15 (ref.)			
N > 35	0.015	(-0.426, 0.456)	0.948
N > 45	−0.026	(-0.453, 0.402)	0.906
Keratinized tissue <2 mm			
No (ref.)			
Yes	0.404	(0.100, 0.709)	0.009*
Complications			
None (ref.)			
Bisphosphonates, infection	2.520	(1.943, 3.097)	<0.001*
Sinusitis, perforation, sinustitis + perforation, infection + perforation	0.081	(-0.368, 0.530)	0.724
Tissue recession			
None (ref.)			
Recession	0.289	(-0.113, 0.691)	0.159
Creeping	−0.039	(-0.314, 0.235)	0.779
Follow-up years			
4-7 (ref.)			
7–10	0.122	(-0.138, 0.381)	0.982
>10	0.069	(-0.032, 0.964)	0.066

*Generalized estimating equations (GEE) taking into account of the clustering of implants within patient.
**P*-value <0.05 indicates significant associations of the variables on marginal bone loss. From results above We see that keratinized tissue <2 mm, use of bisphosphonates, and infection of the adjacent tooth have significant associations on marginal bone loss.

Table 7 Patient-related characteristics and implant loss.

Patient-related factors	Implant loss		*P*-value
	No	Yes	
Gender			
Female	49	12	0.013*
Male	58	3	
Periodontitis			
No	11	0	0.193
Yes	96	15	
Smoking			
No	93	13	0.979
Yes	14	2	
Oral hygiene			
Good	19	0	<0.001*
Medium	49	0	
Poor	39	15	
Compliance			
High	46	10	0.174
Medium	37	2	
Low	24	3	

*Chi-square test or Fisher exact test if over 25 % of cells have expected counts less than 5.
**P*-value <0.05 indicates significant difference in distribution of the variables between patients with and without implant loss. From results above we see that gender and oral hygiene have significant associations with implant loss.

Previous long-term studies on the risk factors for LSFE in sites with RBH less than 5 mm employed either a two-stage approach or a one-stage submerged approach.[4,5,9–12,15] The present long-term study is the first to demonstrate that female sex, poor OH, KT < 2 mm, and complications due to adjacent dental infections were significantly associated with increased LIF. All seven cases of late implant loss occurred in patients had a history of Stage III or IV periodontitis, KT < 2 mm, and poor oral hygiene. Twelve implants were lost in five female patients. The reason for the significant association between female sex and LIF was unclear and may be related to the small sample size, warranting further investigation. Six implants in three female patients failed due to severe peri-implantitis associated with periodontal–endodontic infections in adjacent teeth. Two patients had diabetes-one female and one male, with the latter also being a smoker. Cha et al.[9] and Fu et al.[12] both found smoking was a potential cause of LIF.

Data from the present study was the first to show that no significant risk of implant insertion torque on LIF in implants placed via a non-submerged, one-step LSFESI approach. Log-rank test results of the present study revealed that the survival curves stratified by RBH < 3 mm and RBH 4–5 mm differed significantly, suggesting RBH influenced LIF. Why RBH 4–5 mm had lower survival rate than RBH < 3 mm is unclear. Fu et al. assessed risk factors for LIF in LSFESI among 618 patients with 936 implants in a 2–10-year retrospective study.[12] Contrary to our findings, RBH < 3 mm was independent risk factor for LIF. In addition,

Table 8 Implant-related characteristics and implant loss.

Implant-related factors	Implant loss		*P-value*
	No	Yes	
Remaining bone height			
1—3 mm	65	7	0.299
4—5 mm	42	8	
Insertion torque			
N > 15	40	4	0.153
N > 35	30	2	
N > 45	37	9	
Keratinized tissue <2 mm			
No	73	0	<0.001*
Yes	34	15	
Complications			
None	87	5	<0.001*
Sinus perforation (no infection)	13	2	
Sinus perforation + sinusitis, sinus perforation + infection of adjacent teeth, infection of adjacent teeth	5	8	
Follow-up years			
Mean	10.04	10.07	0.975
SD	2.87	2.24	

*Chi-square test or Fisher exact test if over 25 % of cells have expected counts less than 5. T-test used for continuous variable.
**P*-value <0.05 indicates significant difference in distribution of the variables between patients with and without implant loss. From results above we see that keratinized tissue <2 mm and complications have significant associations with implant loss.

smoking and certain implant brands also showed higher risk for LIF. Whether implant insertion torque and RBH< 3 mm had higher risk for LIF is inconclusive and deserves further evaluations.

The present study found sinus perforation in combination with sinus infection and infection of adjacent teeth significantly impact LIF. However, no significant risk was found for sinus perforation with no infection on LIF. In a long-term evaluation of implant survival using submerged and one- or two-stage approaches in patients with severely atrophic maxilla, Cho-Lee et al. demonstrated that complications, including membrane perforation, sinusitis, and peri-implantitis, appeared to influence implant loss.[14] Fifteen implants (79 %) were lost during the first year and were related to membrane perforation or sinusitis. LIF (21 %) were caused by peri-implantitis and implant fractures. The reasons for the differing results reported by Cho-Lee et al. compared to others are unknown and may be related to implant overloading or unhealed bone due to a sinus infection. Other previous studies showed no significant relationship between sinus membrane perforation, sinusitis, and LIF.[9,32,40—43] In a 5-year prospective study, Cha et al. evaluated factors associated with LIF in 207 consecutive sinus lifts and 462 implants placed in sites with RBH < 4 mm.[9] Membrane perforation did not compromise implant success when the membrane was repaired. Hsu et al. evaluated 99 patients with 427 implants placed in LSFE sites and showed that sinus membrane perforation did not impact peri-implant MBL and implant survival rate.[32] In order to avoid sinus infection and infections adjacent to sinuses related LIF, careful monitoring the health of the adjacent teeth and consultation with ENT specialist are strongly recommended both before surgical intervention and for postoperative complications.[44]

The critical determinants of success for the one-step LSFESI approach in this study were initial implant stability, appropriate loading time, meticulous plaque control, and regular SPC. Finally, retrospective cohort studies are limited by factors such as the timing of data collection, selection bias, variable choice, and potential underreporting of complications. These factors contribute to a low internal validity and limit the ability to establish causality. Given the limited sample sizes, these findings should be interpreted with caution when making broad generalizations.

This study demonstrated that, with careful case selection and adherence to proper implant protocols, non-submerged LSFESI for sites with RBH less than 5 mm is a predictable approach with favorable long-term outcomes. Implant survival rates were significant associated with several factors, including KT < 2 mm, poor OH, the presence of complications, and RBH. The overall LIF rate was 12.3 %. Female sex, poor OH, KT < 2 mm, and sinus perforation in combination with sinus infection and infection of adjacent teeth were significantly associated with increased risk of LIF. Further prospective controlled clinical studies with larger sample sizes are needed to validate our findings.

Declaration of competing interest

The authors declare no conflicts of interest.

Acknowledgments

This study was supported by a grant from the Taipei Tzu Chi Hospital, Buddhist Tzu Chi Medical Foundation, Taiwan (TCRD-TPE-114-37).

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