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Original Research Article

Closed (hydrodynamic) versus open (lateral sinus floor) subantral augmentation for single tooth replacement: criteria of decision-making and clinical efficacy

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Abstract – Introduction: This research aimed to study the impact of initial anatomical conditions on decision-making for subantral augmentation in a single tooth gap and to compare the clinical efficiency of closed hydrodynamic sinus lift and lateral sinus floor augmentation (LSFA) for single tooth restoration. **Materials and Methods:** This retrospective study included 96 patients who underwent subantral augmentation with simultaneous implantation in a single tooth gap. Patients were divided: 50 in the "Open" LSFA group and 46 in the "Closed" hydrodynamic lift group. A two-stage protocol was applied, with data on age, intervention site, implant dimensions, and bone height analyzed. **Results:** Mean residual bone height differed: 3.341 ± 1.433 mm in "Open" and 4.437 ± 1.741 mm in "Closed" ($p = 0.001$). Median bone height post-surgery was 9.5 mm in "Open" and 8.5 mm in "Closed" ($p = 0.0031$), with significant bone height increase ($p < 0.00001$). No implant or graft removals were needed. **Conclusion:** Residual alveolar ridge height, cortical bone thickness, and sinus wall thickness are key criteria in selecting a protocol. Both techniques achieved effective results, even with initial bone heights below 5 mm. LSFA led to greater bone height increase, while both approaches provide reliable options for stable implant integration.

Introduction

Teeth loss in the posterior maxilla remains a significant challenge in prosthetic dental rehabilitation. Several treatment approaches exist, in particular, the use of removable and nonremovable dentures as well as the implant supported prosthetic constructions [1]. In cases of single tooth gaps, however, the rehabilitation with dental implants is considered as the most appropriate option [2] due to the high clinical efficiency of this approach in long-term follow-up [1,3].

At the same time, dental implantation in the posterior maxilla is often a complex task especially in cases where available bone is limited due to the proximity of maxillary sinus floor and alveolar bone resorption, following tooth loss [4]. Depending on the amount and density of bone, the application of one of the sinus floor augmentation techniques may be indicated. This surgery involves the detachment of the maxillary sinus mucoperiosteal membrane in the dental implant area and creation of a space between the membrane and bone surface, which is filled with the bone grafting material (xenogeneic, autologous or synthetic) [5]. The procedure can be performed via the anterolateral maxillary sinus wall osteotomy (window) in case of lateral sinus floor augmentation (LSFA) or via transalveolar approach through the bone bed prepared for the implant placement (closed sinus lift procedure) [6–9]. Both open and closed sinus lifting procedures are reliable approaches for increasing the bone volume needed for implant positioning and osteointegration. However, the discussion on complication risks, postoperative morbidity, and indications for each of the techniques are still discussed in the literature. However, there is currently no substantial evidence to support a significant advantage of one surgical protocol over the other [10].

Therefore, the aim of the present research was to study the impact of initial anatomical conditions on decision-making regarding the method of subantral augmentation in a single tooth gap and to compare the clinical efficiency of different treatment protocols.

Material and methods

A retrospective cohort study was performed to evaluate the treatment results of 96 patients who underwent subantral augmentation with simultaneous dental implantation in a

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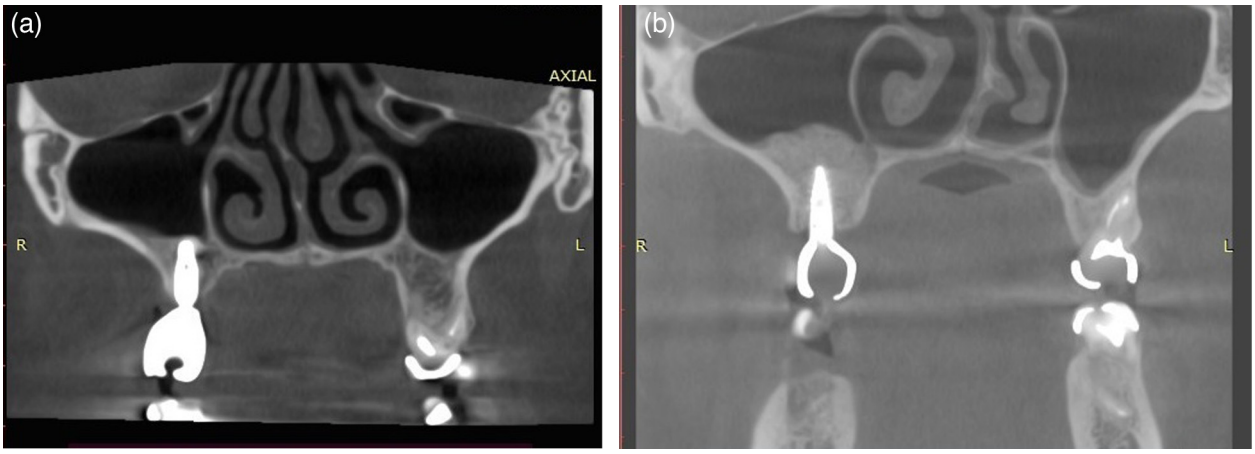

Fig. 1. Single tooth rehabilitation protocols at lateral region of the upper jaw: a — closed (hydrodinamic) subantral augmentation; b — subantral augmentation.

single tooth gap. All surgical interventions were performed at the Department of Maxillofacial Surgery and Innovative Dentistry, Bogomolets National Medical University, between January 2021 and April 2024. The research protocol was reviewed and approved by the bioethics committee of Bogomolets National Medical University, Kyiv, Ukraine (approval No. 163; November 07, 2022).

The inclusion criteria were: patients with single tooth gap in posterior maxilla (molars or premolars) with residual alveolar bone heights less than 6 mm who underwent sinus-lift procedures to create a sufficient bone volume; immediate implant placement in the area of augmented bone; loading of the integrated implant with single screw-retained prosthetic construction in terms from 4 to 7 months after the surgical intervention, the availability of computer tomography (CT) data before and after treatment, follow-up period of at least 12 months after prosthetic rehabilitation, and signed informed consent for the surgical and orthopedic treatment (Fig. 1).

Exclusion criteria were: age under 18 years, absolute and relative contraindications for subantral augmentation and dental implantation, lack of compliance and poor interaction with a physician, incomplete clinical and radiological documentation of the case, refusal to participate in the study.

Patients were selected at the stage of dental implant prosthetics according to the inclusion and exclusion criteria. Patients were divided into two groups depending on the applied method of subantral augmentation. "Open" group included 50 patients who underwent LSFA via conventoional lateral sinus wall osteotomy with creation of a bone window by dental diamond round-shaped burs for a surgical handpiece in the area of further implant installation. The maxillary sinus mucoperiosteum was detached and a space for osteoplastic material was formed. Using drills, a bone bed for the dental implant was created, the space in the augmentation area was filled with xenograft ("Osstem A-Oss" or "Dentegris CompactBone B." with particle size 1.0–2.0 mm), the dental implant was placed, and the wound was sutured.

"Closed" group included 46 patients who underwent a hydrodynamic transcrestal sinus lift [6,11,12]. After the detachment of the mucoperiosteum in the edentulous area using the OSTEM CAS (Creastal Approach — Sinus KIT) surgical kit for closed hydrodynamic sinus lift, the bed for the dental implant was created by subantral dissection of the bone using cylindrical blunt-ended drills with apical cutting edges. Then, the hydrodynamic maxillary membrane elevation was performed using a liquid column (0.9% NaCl solution) through the implant bed. A hydraulic test was performed for each patient to ensure the absence of perforations of the sinus mucosa (in case of the positive test liquid leaked back through the implant bed after depressurization of the syringe cannula and did not penetrate to the upper airways). If the test was positive, indicating no perforations, xenogenic bone material ("Osstem A-Oss" or "Dentegris CompactBone B." with particle size 1.0–2.0 mm) was inserted and the implant placed. Otherwise, if the patient reported liquid leakage through the nasal passage, the surgery was stopped and delayed for at least one month.

In a case of sinus septa presence, in the "Open" group a lateral sinus wall osteotomy was performed lateral to the septa projection, which was planned preoperatively based on the CT image. In the "Closed" group the technique allowed to ignore the presence of sinus septa.

A two-stage surgical protocol of the dental implantation was used for patients in both groups. The prosthetic stage of the treatment started 4–7 months after surgery. Standard healing caps were applied during the second surgical stage. Ti-based screw-retained oxidized zirconium prosthetic restorations were fixed in all cases, followed by CT control. The final follow-up was performed at 12 months or later.

In this study, data on age, intervention site, implant length and diameter, mucoperiosteum perforation, and implant osseointegration were analyzed. From presurgical CT scans, residual bone height, cortical bone thickness in the alveolar ridge area, and the thickness of the sinus lateral wall were identified in all patients included in the study.

Table I. Presurgical characteristics of the patients included to the study.

Parameter	Clinical groups		*p* value
	"Open" group (*n* = 50)	"Closed" group (*n* = 46)	
Age, years			
Me	45.5	50.5	0.131*
Q1–Q3	39–56	42–58	
Residual bone height, mm			
x ± SD	3.341 ± 1.433	4.437 ± 1.741	**0.001**£
Lateral sinus wall thickness in implant area, mm			
Me	1.5	2	0.436*
Q1–Q3	1.4–2	1.5–2	
Cortical bone thickness in the alveolar ridge area, mm			
Me	0.5	0.5	0.214*
Q1–Q3	0.5–1	0.5–1	

* Mann–Whitney *U* test.
£ — Independent samples *t*-test (Student's *t*-test).

Postoperative CT was performed before the prosthetic stage and the volume of the augmented bone (increase in alveolar bone heights after sinus lift procedure) was analyzed. For the "Open" group, the area of the bone window and its distance from the alveolar ridge (measured at the lowest point) were measured.

Statistical analysis included the calculation of mean (x) and standard deviation (SD) for parametric values, and median (Me) and interquartile range (Q1—Q3) for nonparametric values. Quantitative data were analyzed using the independent samples *t*-test (Student's *t*-test) for parametric values and the Mann–Whitney U test for nonparametric values. Qualitative data were assessed using Pearson's chi-squared test (with Yates's correction if necessary) or the Fisher exact test. Analysis was conducted using R software (version 4.2.2, R Core Team) with a significance level of $p < 0.05$.

The sample size calculation was based on the anticipated mean increase in bone height of 5 ± 1 mm for the "Open" group and 4 mm for the "Closed" group. Thus, for a type I/II error rate of 0.05 at a power level of 95%, at least 26 patients were required in each group (total: 52) for sufficient study power (Figs. 1a and 1b).

Results

The median age of the patients in "Open" group and "Closed" group were 50.5 years (IQR 43–58) and 45.5 years (IQR 39–56), respectively ($p = 0.131$) (Tab. I). The single tooth gap in both groups was associated predominantly with the loss of the first molar, (70% of cases in "Open" group and 65.2% of cases in "Closed" group). The presurgical anatomic conditions in both groups are presented in Table I. The mean residual bone height significantly differed between the groups. It consisted 3.341 ± 1.433 mm in "Open" group and 4.437 ± 1.741 mm in "Closed" group ($p = 0.001$). The mean area of the bone window in "Open" group was 36.04 ± 2.6 mm^2, and the mean distance from the alveolar ridge to the window was 4.3 ± 2.1 mm. The lateral sinus wall thickness in the implant area and the cortical bone thickness in the alveolar ridge area were similar in "Open" group and "Closed" group (1.5 mm, IQR 1.4–2 versus 2 mm, IQR 1.5–2 and 0.5 mm, IQR 0.5–1 versus 0.5 mm, IQR 0.5–1, respectively), with no significant differences observed ($p > 0.05$).

The clinical and radiological outcomes of subantral augmentations are presented in Table II. The median total bone height after surgery was 9.5 mm (IQR 8.22–10.07) in the "Open" group and 8.5 mm (IQR 8–9.5) in the "Closed" group ($p = 0.0031$). Bone height increase also differed significantly between the groups ($p < 0.00001$). The median length of installed dental implants was 8 mm (IQR 7–8.5) in "Open" group and 7.5 mm (IQR 7.5–8.5) in "Closed" group ($p = 0.0004$), whereas the median diameter was similar for both groups (4.5 mm; $p = 0.245$). Although the mucoperiosteum perforation rate and frequency of inflammatory complications were higher in "Open" group (18% and 12%, respectively) than in "Closed" group (8.7% and 4.3%), this difference was not significant ($p > 0.05$). However, no cases of implant or graft material removal were observed in either group. All 96 implants were integrated and withstand the masticatory loads for at least 12 months.

Discussion

Subantral augmentation in single tooth gaps is a challenging task despite its apparent simplicity. The implementation of conventional open sinus lift approaches has

Table II. Clinical and radiological outcomes of subantral augmentation.

Parameter	Clinical groups		*p* value
	"Open" group (n=50)	"Closed" group (n=46)	
Total bone height after augmentation, mm			
Me	9.5	8.5	**0.0031***
Q1–Q3	8.22–10.07	8–9.5	
Bone height increase, mm			
Me	6.01	4.5	<**0.00001***
Q1–Q3	4.96–7.15	3.5–5.5	
Dental implant diameter, mm			
Me	4.5	4.5	0.245*
Q1–Q3	4–4.5	4.5–4.5	
Dental implant height, mm			
Me	8	7.5	**0.0004***
Q1–Q3	7–8.5	7.5–8.5	
Mucoperiosteum perforation rate, %	18.0 (*n* = 9)	8.7 (*n* = 4)	0.302¥
Inflammatory complications rate (acute or chronic sinusitis), %	12.0 (*n* = 8)	4.3 (*n* = 2)	0.175¥

* Mann–Whitney *U* test.
¥ Pearson's chi-squared test.

significant anatomic limitations, determined by the proximity of the dental roots, intraosseous vessels, and by the topography of the lateral sinus wall, and alveolar recess [13,14]. These factors influence the optimal size and configuration of the bone window, thereby impairing orientation and impeding the performance of technical manipulations during surgery. In contrast, the only limitations of closed sinus lift methods are the augmentation height and complicated detection of Schneiderian membrane perforations [2].

The choice of the subantral augmentation method is based on several considerations. The most important is presurgical residual bone heights which determines the required amount of augmentation material and possibility of simultaneous implant placement as well as primary stability of the implant [10,14,15]. The last parameter depends on the bone tissue density, the ratio of cortical bone to cancellous bone, and their volume. Personal experience and surgical skills also influence the chosen method [14,15].

Closed or transcrestal subantral augmentation is performed using special osteotomes, compactors, drills, and other instruments [8,9,16]. This method was proposed to reduce the operation trauma, because it avoids the creation of an additional window during dental implantation. According to the literature, the possible augmentation height for this method ranges from 2 to 8 mm. However, according to recent publications transcrestal procedures were less predictable, and associated with non-uniform distribution of the grafting material as well as with significant risks of hidden perforations of the sinus mucosa [10,17]. In recent decades, the technique of hydrodynamic sinus lift has been suggested as a means of mitigating these risks. In this technique, after implant bed formation, the mucoperiosteum is detached using pressure created by a liquid column, which hermetically fills the implant bone bed [9,12,16,18].

According to Lyu's M *et al.* study [4], the use of the conventional lateral approach is preferable in cases of substantial bone deficits as it allows more significant increase in vertical bone height, but it is also associated with higher morbidity and complication rates. The open sinus lift technique provides good visual control of the mucoperiosteum integrity during its detachment and the possibility to eliminate perforations if they occur [4,8,15,19]. In contrast, closed sinus lift methods are attractive for their lower injury and the lack of need for extensive mucoperiosteal flap detachment. However, visual control of the integrity of the mucoperiosteum and precise placement of the osteoplastic material are not possible [9,16].

The residual height of the alveolar ridge in the implantation is regarded as a primary criterion that determines the indications for the subantral augmentation method. The greater the bone tissue deficiency, the fewer indications for closed methods of subantral augmentation [19,20]. However, the initial volume of bone tissue at the site of dental implantation is more significant for the primary stability of the implant than for subantral augmentation. Furthermore, the need for single restorations in the presence of vertical bone tissue deficiency obscures the criteria for applying of a particular augmentation method, which is directly related to the initial anatomical conditions. According to research by Mingyue Lyu (2023), significant thickness of the lateral wall of

the maxillary sinus is considered a risk factor for LSFA complications [4]. In contrast, significant cortical bone thickness at the top of the alveolar ridge, along with the volume of bone tissue proximal to the roots of adjacent teeth, enables sufficient primary stability during implantation. However, the roots of adjacent teeth limit the clinician's ability to create a sufficiently large bone window during lateral augmentation, which can affect the visualization of the operation area [4,8,15,21,22].

In our study, the closed sinus lift was preferred in cases with significantly higher residual bone heights, which favors the use of shorter dental implants, whereas the implant diameter was similar to that in the open sinus lift group. In this study, all cases of dental implants were successfully integrated, and prosthetic rehabilitation was achieved with a follow-up period of at least 12 months, similar to the study of Krennmair *et al.* (2008) [1]. Subantral augmentation was performed simultaneously with dental implantation in all patients. In both groups, the average initial bone volume was less than 5 mm, consistent with the findings of the multicenter study by Felice *et al.* (2014) [23]. The success of the implantation may be due to the sufficient thickness of the cortical plate at the top of the alveolar ridge, which provided the primary stability for the implant, despite the variation in the thickness between the two groups.

Similarly, to several other studies, significantly greater bone augmentation was achieved in "Open" group: the obtained bone height was almost 33% greater than that in "Closed" group, where closed subantral augmentation was performed. However, this difference did not significantly affect the success of dental implantation or the frequency of complications. Therefore, it can be concluded that the factors influencing the choice of subantral augmentation method at the presurgical stage were either the initial level of bone or the surgeon's personal preferences and his experience with a particular technique.

Mucoperiosteal perforations occurred in both groups, with a significantly higher frequency during the open sinus lift procedure, consistent with data from similar studies [15,21,24,25]. Perforations in "Closed" group required a delay in subantral augmentation and implant placement. Surgical intervention in these patients was postponed until at least one month after the initial procedure. For the patients in "Open" group, visual control allowed perforations to be covered or isolated from the implantation zone, which, in turn, reduced the rehabilitation time. The perforations were repaired using an internally placed membrane following a parachute technique [26]. Inflammatory complications occurred more frequently in the open sinus lift group (12% *vs*. 4% in closed group). However, this difference was not statistically significant, and these complications were acute but resolved with conservative treatment.

Conclusion

The residual alveolar ridge height, cortical bone thickness, and anterior wall thickness of the maxillary sinus in the area planned for subantral augmentation with simultaneous dental implantation are regarded by surgeons as key criteria when choosing a surgical protocol, however further investigations are required for deeper clarification of the indications. In the case of a single prosthetic restoration supported by a dental implant, both hydrodynamic closed sinus lift and LSFA provided similar results even when the initial alveolar bone heights was below 5 mm. LSFA facilitated a significantly greater increase in alveolar bone height, however without affecting the outcome of the final integrated result of treatment.

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Conflicts of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Data availability statement

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

Ethics approval

The research protocol was reviewed and approved by the bioethics committee of Bogomolets National Medical University, Kyiv, Ukraine (approval No. 163; November 07, 2022).

Informed consent

Written informed consent was obtained from all patients.

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