

# Complications in sinus lifting procedures: Classification and management

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## 1 | INTRODUCTION

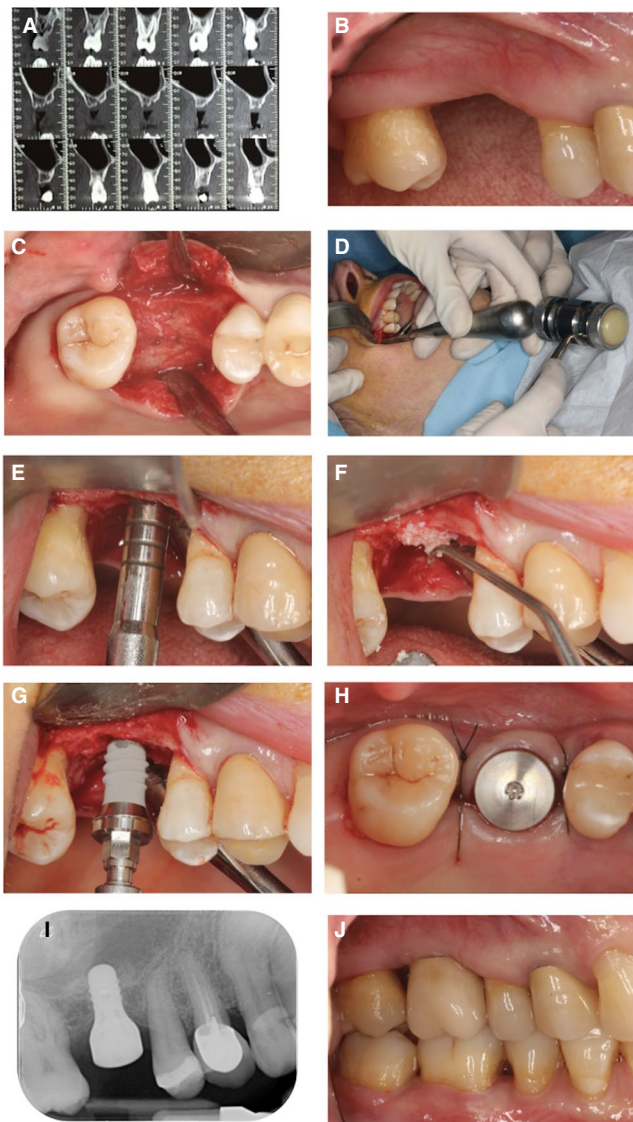
The maxillary sinus, the largest of all paranasal sinuses, is shaped like a pyramid, with dimensions of approximately 2.5 cm in width, 3.75 cm in height, and 3 cm depth.<sup>1</sup> When patients lose teeth in the posterior maxilla, alveolar bone resorption follows, both centripetal, as a consequence of the physiological bone remodeling following tooth loss, and also from sinus cavity pneumatization toward the alveolar crest.<sup>2</sup> These two processes usually result in limited bone availability for implant placement, hence requiring a regenerative procedure, the so-called maxillary sinus lifting procedure. Sinus lifts are currently considered a safe treatment modality with a low complication rate.<sup>3,4</sup> The procedure is referred to in different ways in the literature, as sinus lift, sinus augmentation, sinus floor elevation, or augmentation of an atrophic maxillary sinus. Since the objective of this regenerative intervention is to provide sufficient bone height and width for appropriate implant placement, dental implants may be placed at the same time as the sinus augmentation procedure ("one-stage" technique). The alternative is a staged procedure, where the bone is augmented during the first surgical intervention and then the dental implants are placed after the appropriate bone volume has been created ("two-stage" technique).<sup>5</sup>

The classical sinus lift procedure was first described in the 1970s by Tatum<sup>3,6</sup> and consisted of combining a crestal incision with a mesial and a distal vertical incision that allows the elevation of a buccal flap to expose the lateral bone wall of the sinus. Afterwards, a trapdoor osteotomy (window) is created in the lateral wall to access the Schneiderian membrane and the sinus cavity. The membrane is then carefully dissected and elevated in an apical direction, with

special attention paid to maintain its integrity. The displacement of the membrane will create space for the graft material. In situations where there is enough basal alveolar bone for stable implant installation, implants are placed protruding through the sinus cavity and are protected at their apical end by the intact sinus membrane. All the remaining space around the implant within the sinus cavity is usually filled by a bone replacement graft, and the opening of the window is closed by a barrier membrane, before closing the flaps with the appropriate suturing. When there is insufficient basal bone to provide primary stability for the implant, the two-stage technique is required, and dental implants should only be placed when the space under the sinus lifting has been regenerated with mature bone.

Various different biomaterials have been used as bone replacement grafts in maxillary sinus lifting procedures, ranging from autologous bone obtained from the iliac crest, chin, mandibular ramus, or other intraoral sites, to the use of bone substitutes, synthetic biomaterials, or combinations thereof.<sup>7</sup>

In patients with appropriate residual bone height, augmentation of the sinus floor can also be accomplished via the transalveolar approach using the osteotome technique. This less-invasive procedure introduced by Tatum in 1976<sup>6</sup> consists of elevating the maxillary sinus floor through the alveolar crest when drilling for the placement of the implant. In 1994, Summers modified this approach by using concave-tipped tapered osteotomes, which fracture the maxillary floor and elevate the sinus membrane.<sup>8</sup> This modification is less invasive, less time consuming, and allows for better bone density and implant stability through the lateral compression exerted by the osteotomes (Figure 1). In both procedures, after lifting the



**FIGURE 1** Closed sinus lift for implant placement. A, Computed tomography image of available residual bone: 4 mm in height and 10 mm in width. B, Intraoral exam of the baseline situation. C, Bone crest after raising full-thickness flap. D, Bone condensation in the apical and lateral directions with the use of osteotomes and a mallet. E, Image showing the introduction of the osteotome into the bone to the level of the desired implant length (8 mm in this case). F, Bone fill with bovine hydroxyapatite. G, Implant placement. H, Flap suturing following a one-stage healing protocol. I, Periapical radiograph immediately after implant placement. J, Prostheses loading

Schneiderian membrane, various types of bone grafting materials have been used to fill the resulting space;<sup>9</sup> however, the need for using a graft has been questioned by other authors, claiming that after the elevation of the sinus floor the stabilization of the blood clot will provide new bone formation around the implant.<sup>10-13</sup> Since both the sinus floor lifting and the bone grafting procedure are conducted blindly, this increases the risk of complications.

The survival rate of implants placed in conjunction with sinus augmentation procedures has been evaluated in several systematic

reviews and has demonstrated predictable results (greater than 90%) after medium and long-term follow-up.<sup>4,5,7,14-20</sup>

Implant survival with the transalveolar technique has also been shown to be higher, ranging from 92.7% to 97.2% and with an annual failure rate of 2.48%.<sup>9,16,21,22</sup> One possible confounding factor is whether or not there was a need for grafting. Though there is limited evidence on this subject, one systematic review reported no differences between the survival of implants placed in the sinus with or without grafts.<sup>16</sup> Another controversial issue with the transalveolar approach relates to the required bone height, with most of studies reporting values ranging between 4 and 6 mm.<sup>23-25</sup> In one systematic review, implant survival increased to 96.9% when the residual bone was 5 mm or greater, compared with 92.7% when the residual bone was less than 5 mm.<sup>22</sup> The rationale for this surgical approach may, therefore, be considered questionable, since with this amount of bone height there are less-invasive alternatives for implant placement, such as the use of short implants. Indeed, when dental implant placement in conjunction with sinus lifting procedures was compared with short implants in cases of this minimum height of alveolar bone, no significant differences were observed in terms of implant survival or prosthesis failure. However, the reported complication rates was greater (odds ratio: 4.77) in sinus lifting procedures.<sup>4</sup> When dental implants in conjunction with sinus lifting procedures were compared with dental implants placed in native bone there were no significant differences in implant survival observed, although the variability was greater for grafted sites.<sup>17</sup>

## 2 | FACTORS INFLUENCING THE OUTCOME OF DENTAL IMPLANTS PLACED IN REGENERATED BONE FOLLOWING SINUS LIFT SURGERY

Several factors that may influence the outcome of dental implants in regenerated bone in the posterior maxilla have been studied:

1. Grafting the surgically created antral cavity. There are no significant differences in implant survival when comparing grafting vs no grafting, with a mean survival rate of 96%-97% when no graft was used and 94%-99.6% for implants placed in grafted sinuses, according to two systematic reviews with meta-analysis.<sup>18,20</sup>
2. Type of bone replacement graft. There are no significant differences in implant survival or bone gain when comparing autologous bone grafts alone, bone substitutes alone, or their combination.<sup>4,5,16,19</sup> However, a significant higher implant failure has been reported for implants placed after sinus lifting with the use of bone blocks, when compared with the use of particulate bone grafts (83.3% vs 92.3% implant survival rates, respectively).<sup>5,7,19</sup>
3. Barrier membranes. The use of a membrane to cover the lateral window has been associated with higher implant survival rates, with data from a systematic review reporting 88.7% implant survival when no membrane was placed vs 93.6% with the use of a

barrier membrane covering the window.<sup>5,16</sup> If not used, the graft material may also be displaced out of the sinus (Figure 2).

4. The use of biologicals (platelet derivatives). Added value has not been demonstrated in terms of implant survival or bone gain,<sup>14,15,26,27</sup> although their application improves the handling of the bone graft,<sup>14</sup> and short-term bone formation and increased radiographic density<sup>15</sup> have been reported.
5. The use of cell therapies and recombinant human bone morphogenetic protein-2 in an absorbable collagen sponge carrier has not offered a significant added benefit.<sup>15,28</sup> One systematic review even found that in those cases in which the initial bone height was up to 4 mm, bone gain was higher for the use of autologous bone alone.<sup>29</sup>
6. Implant surface. Dental implants with modified surfaces (moderate roughness) have been associated with a lower risk of implant failure (84% vs 91.6% implant survival in machined vs rough surfaces), and significant higher implant survival in the long term (greater than 3 years; odds ratio: 6.61).<sup>5,16</sup>
7. Initial bone height. This factor has not been shown to have an impact on long-term implant survival after open sinus lifting, with similar survival rates for residual ridge heights of less than 5 mm and 5 mm or greater (95.21% vs 95.23% implant survival rate, respectively).<sup>16</sup>

### 3 | PREVALENCE/INCIDENCE OF COMPLICATIONS (EARLY/LATE) ASSOCIATED WITH SINUS LIFTING PROCEDURES

#### 3.1 | Open sinus lifting (lateral window technique)

In spite of the highly predictable subantral bone gain and high reported implant survival rates associated with this intervention, it is not without complications, including intra-surgical and postoperative complications (Table 1).<sup>30</sup>

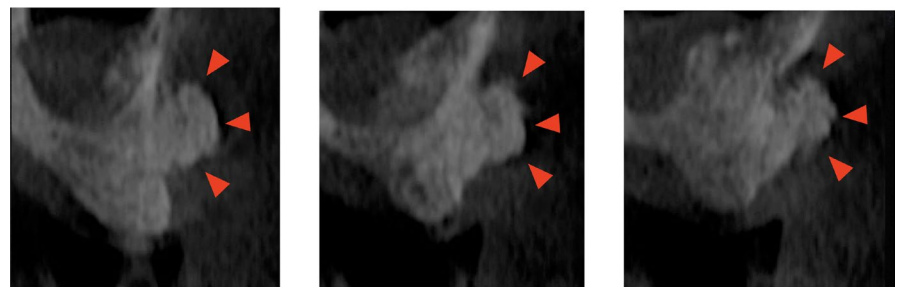
##### 3.1.1 | Schneiderian membrane perforation

The most frequent intrasurgical complication of open sinus lifting is the perforation of the Schneiderian membrane during its dissection and reflection from the sinus bone walls. The reported

incidence varies widely, ranging from 6% to 42%;<sup>30-36</sup> however, most publications have reported rates between 20% and 25%<sup>37-44</sup> (Table 2). Sinus membrane perforations can be classified according to different criteria, such as perforation position and size.<sup>45,46</sup> Their occurrence has been related to the presence of specific anatomical characteristics (minimum alveolar height, narrow sinus cavity, and presence of bony septa within the sinus), to the thickness of the Schneiderian membrane, and lastly to the surgical technique (surgeon's expertise, surgical design, and the instruments employed).

The thickness of the membrane is reported to be the most common feature associated with the occurrence of membrane perforation.<sup>40</sup> Healthy sinus mucosa has a mean thickness of 1 mm, although there is a wide range of variability among individuals.<sup>47</sup> Furthermore, the presence of pathology within the sinus and the use of certain medications may alter the thickness of the Schneiderian membrane. Computed tomography can be a useful tool to assess the thickness of the mucosal lining preoperatively; however, adequate visibility of this anatomic structure cannot be achieved in all cases, and the risk of perforation is dependent upon the thickness and health status of the membrane.<sup>48</sup>

Gingival phenotype has also been studied as a predictor of Schneiderian membrane thickness. In a case series with 20 patients with healthy sinuses that were scheduled to undergo otorhinolaryngologic interventions for ethmoid-nasal interventions, tissue biopsies of the sinus membrane were taken by endoscopy. Gingival thickness was evaluated in the buccal aspect of the anterior maxillary teeth, with the aid of a thin endodontic reamer inserted through the gingiva up to the bone, 1 mm apical to the sulcus. Gingival phenotype was considered thin when gingival thickness was less than 1 mm, and flat-thick when it was greater than 1 mm. Nine subjects presented thin gingival phenotypes (mean  $0.70 \pm 0.10$  mm), and 11 with thick phenotypes (mean  $1.60 \pm 0.27$  mm). The average thickness of the sinus membrane was  $0.97 \pm 0.36$  mm, with a marked variability among individuals, ranging from  $0.45 \pm 0.07$  mm to  $1.40 \pm 0.14$  mm. There was a positive and highly significant association between both parameters, showing a clear correlation between thicker gingival phenotypes and thicker Schneiderian membrane, and vice versa, indicating that gingival thickness may be used as a predictor of sinus membrane thickness.<sup>49</sup> There are also data reporting a direct association between the incidence of membrane perforations and the gingival thickness of the patients. A retrospective case series including 44 patients and 64 sinus lift procedures with simultaneous



**FIGURE 2** Cross-sectional images where graft material can be observed displaced out of the sinus window. No membrane was used to cover the sinus window for stabilizing the bone graft material (courtesy of Dr Jae-Kook Cha)

TABLE 1 Complications associated to sinus lift procedures

Open sinus lifting (lateral window technique)
Schneiderian membrane perforation
Chronic rhinosinusitis
Hemorrhage
Overfilling (ostium blockage)
Closed sinus lifting (osteotome technique)
Schneiderian membrane perforation
Benign paroxysmal positional vertigo
Implant displacement

implant placement reported the correlation between gingival phenotype, residual ridge height, and membrane thickness. Gingival phenotype was assessed through computed tomography images and categorized as thin (less than 1.5 mm) or thick (greater than 2 mm). Membrane perforation occurred in 17% of the procedures during sinus instrumentation, always in thin Schneiderian membranes (less than 5 mm).<sup>45</sup> A high correlation was observed between gingival phenotype and membrane thickness ( $r = 0.722$ ,  $P = 0.001$ ), and also between gingival phenotype and residual ridge height ( $r = 0.722$ ,  $P = 0.001$ ). Membrane perforations showed a moderate correlation with the thickness of the membrane ( $r = 0.417$ ,  $P = 0.001$ ) and may also be related to other factors not evaluated in this study, such as the surgical technique or the anatomy of the sinus.<sup>31</sup>

The presence of bony septa (Figure 3) is another anatomical factor that has been significantly associated with the incidence of membrane perforations during sinus lifting procedures.<sup>36,38,44</sup> The incidence of bony septa has been reported to range between 16% and 58%.<sup>33,38,50</sup> The reflection of the membrane in proximity to these anatomical structures can be technically difficult due to the sharp edges of the septa.<sup>51</sup> In order to avoid these areas, it is recommended to study the anatomy of the sinus and the trajectory of the septa carefully in a computed tomography scan. The design of the buccal osteotomy should then be individualized in order to avoid the septal areas, and it is even recommended to perform two or more windows avoiding the septa.<sup>51</sup>

Similarly, as part of the anatomical landmarks related to membrane perforations, a residual alveolar bone height of less than 3.5 mm has been associated with increased risk for sinus membrane perforations.<sup>31,36</sup>

The occurrence of membrane perforations during surgery not only compromises the viability of the bone augmentation procedure<sup>32,52</sup> but also increases the surgical time and incidence of postoperative complications.<sup>33</sup> These perforations have also been related to a lower implant survival rate.<sup>39,42</sup>

Several approaches have been proposed to manage antral wall perforations, depending on their size and extent. When the perforation is small and is located in an area where the membrane folds together, there is no need for specific management, since the simple reflection of the membrane will obliterate the perforation.<sup>46,51</sup> However, owing to the negative pressure of the sinus cavity, small perforations tend to increase in size. In such cases, they may be

sealed with a fibrin adhesive<sup>34,42,43,51</sup> or with a suture if the perforation is accessible.<sup>42,43,53</sup> For larger perforations, the use of resorbable collagen membranes covering the perforation is common practice (Figure 4).<sup>33,34,37,41,43</sup> Several techniques have been described, and most of them consist of placing the resorbable membrane inside the sinus, covering the perforated area and extending around the bone margins of the osteotomy, where the membrane can be fixed and stabilized with tacks to the cortical buccal bone.<sup>54</sup> Other authors recommend placing a sheet of cortical bone inside the sinus, covering the perforated membrane area prior to insertion of the particulated graft material.<sup>39</sup> In certain clinical situations, when large perforations are present or when the Schneiderian membrane is completely open, it is suggested to abort the surgical procedure, and a reentry procedure may be attempted after a healing period of no less than 6-8 weeks.<sup>40,42,55</sup>

### 3.1.2 | Chronic rhinosinusitis

Rhinosinusitis or sinusitis is an inflammatory process of the mucosa surrounding the nose and paranasal sinuses, frequently a viral, fungal, or bacterial infection, secondary to an allergic episode. According to its evolution, it can be classified as acute when lasting less than 12 weeks, with complete resolution of the symptoms, or chronic with evolution of more than 12 weeks and incomplete resolution of symptoms.<sup>56</sup>

Chronic rhinosinusitis following a sinus lift procedure is a complication commonly reported in the literature as a consequence of bone graft and/or implant infection. It can arise as a result of contamination of the maxillary sinus with bacteria from the oral cavity during surgery, due to ostium blockage caused by graft overfilling or mucosal swelling after surgery, or due to a reduction in air flow secondary to the lesser sinus volume, impaired mucosal activity in the maxillary sinus due to mucosal lacerations, implant protrusion into the sinus, or large membrane perforations during sinus lift procedures.<sup>36</sup> Small perforations do not seem to be associated with postoperative chronic rhinosinusitis in healthy patients.<sup>37,57,58</sup> According to a recent retrospective case series on chronic rhinosinusitis following sinus lifting,<sup>59</sup> the most frequent signs and symptoms observed were muco-purulence (89%), facial pain or pressure (78%), nasal congestion (56%), foul smell (45%), cough (18%), purulent drainage around the implants (18%), ocular pruritus (9%), and postnasal drip (9%). The onset of chronic rhinosinusitis tends to appear within 3 months after the sinus procedure, but it may present up to 1 year following the surgical intervention.<sup>58,59</sup>

The reported incidence of chronic rhinosinusitis after sinus lifting is low, ranging from 4.2% to 8.4%.<sup>36,57,60</sup> However its management can be complex and may necessitate removal of the graft material and the implants.<sup>61</sup> Medical management may involve prescription of systemic antibiotics in single or repeated courses until the infection is controlled, use of nasal douching with saline solutions, nasal steroid sprays, and oral antihistamine medication. When patients present with acute maxillary sinusitis and purulent orofacial

TABLE 2 Prevalence of membrane perforations in open sinus lift procedures

Author (year)	Study type	Follow-up	No. of patients	No. of sinus lifted	No. of implants	Staged/simultaneous	Membrane perforation (%)	Description of other complications reported
Irinakis et al 2017 <sup>38</sup>	RCS	1-37 months	67	79	107	Staged (n = 48 SL)/ simult. (n = 31 SL)	22.80	5.0% graft infection
Schwarz et al 2015 <sup>36</sup>	PCS	Not reported	300	407	Not reported	Not reported	8.6	8.4% sinusitis; 1.2% wound dehiscence
Gurler & Dellibasi 2015 <sup>44</sup>	PCS	Not reported	57	57	Not reported	Not reported	24.5	Not reported
Moreno Vazquez et al 2014 <sup>37</sup>	RCS	39-90 months (mean 57 months)	127	202	364	Staged (n = 247 I)/simult. (n = 117 I)	25.7	4.5% wound infections; 3.0% sinusitis; 2.0% exposure of the bone graft; 1.0% loss of the bone graft; 1.0% bleeding
Nolan et al 2014 <sup>32</sup>	RCS	Minimum 12 months	208	359	Not reported	Not reported	41.8	11.3% sinusitis (perforated membranes); 1.4% sinusitis (intact membranes); 6.7% loss of the bone graft
Cha et al 2014 <sup>34</sup>	PCS	36-98 months	161	217	462	Simult. (n = 462 I)	16.13	Not reported
Yilmaz & Tözüm 2012 <sup>31</sup>	RCS	24 months	44	64	176	Simult. (n = 176 I)	17.00	Not reported
Rickert et al 2013 <sup>35</sup>	RCT	12 months	36	72	193	Staged (n = 193 I)	5.76	Not reported
Becker et al 2008 <sup>40</sup>	PCS	Mean 162 days	201	201	425	Staged/simult.	20.40	Not reported
Hernández-Alfaro et al 2008 <sup>39</sup>	PCS	Not reported	338	474	1166	Simult. (n = 1166 I)	25.15	Not reported
Barone et al 2006 <sup>41</sup>	PCS	Not reported	70	124	287	Staged (n = 287 I)	25.00	5.6% sinusitis
Ewers 2005 <sup>43</sup>	RCS	Up to 136 months	118	209	614	Staged (n = 614 I)	20.6	12% local infection
Schwartz-Arad et al 2004 <sup>33</sup>	RCS	24-84.8 months	70	81	212	Staged/simult.	4.4	Not reported
Khoury 1999 <sup>42</sup>	CS	24-72 months	216	216	467	Simult. (n = 467 I)	23.6	Not reported

Abbreviations: I, implants; PCS, prospective case series; RCS, retrospective case series; RCT, randomized clinical trial; simult., simultaneous; SL, sinus lifting.

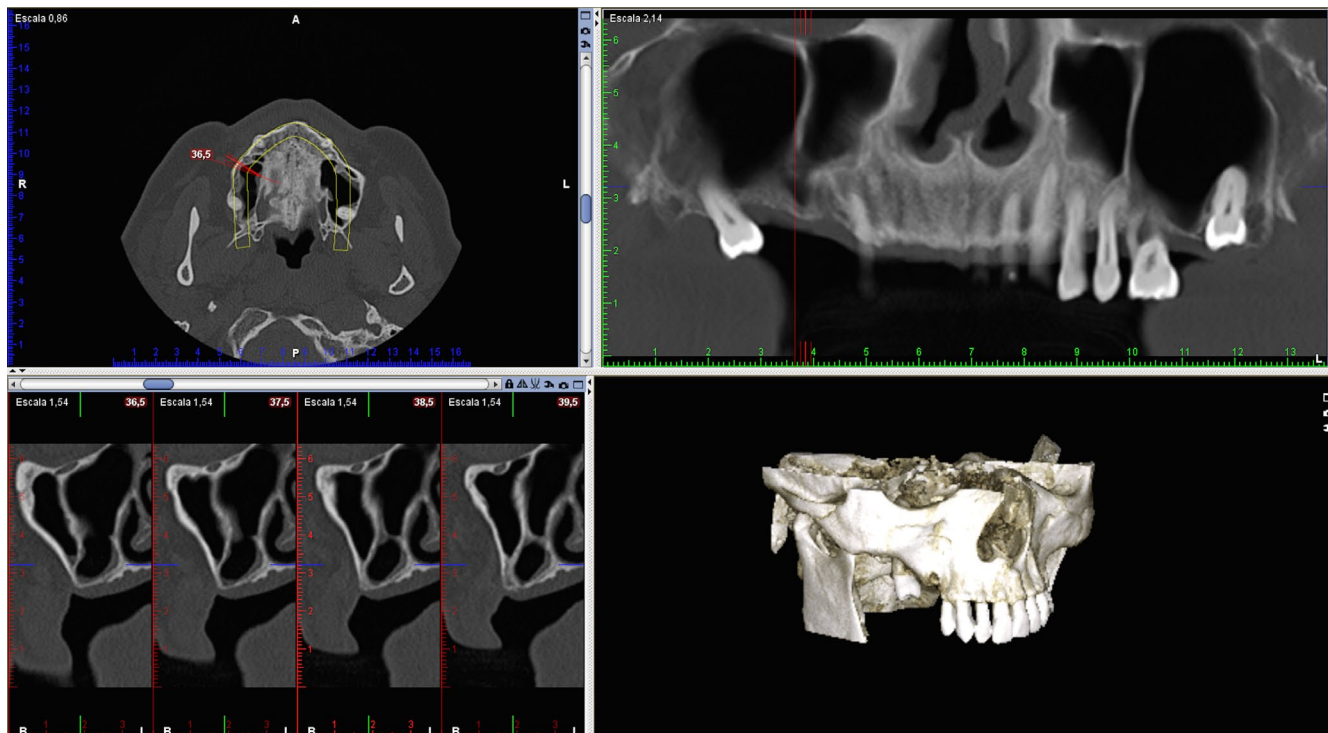


FIGURE 3 Computed tomography image of a patient with multiple bone septa in the right maxillary sinus

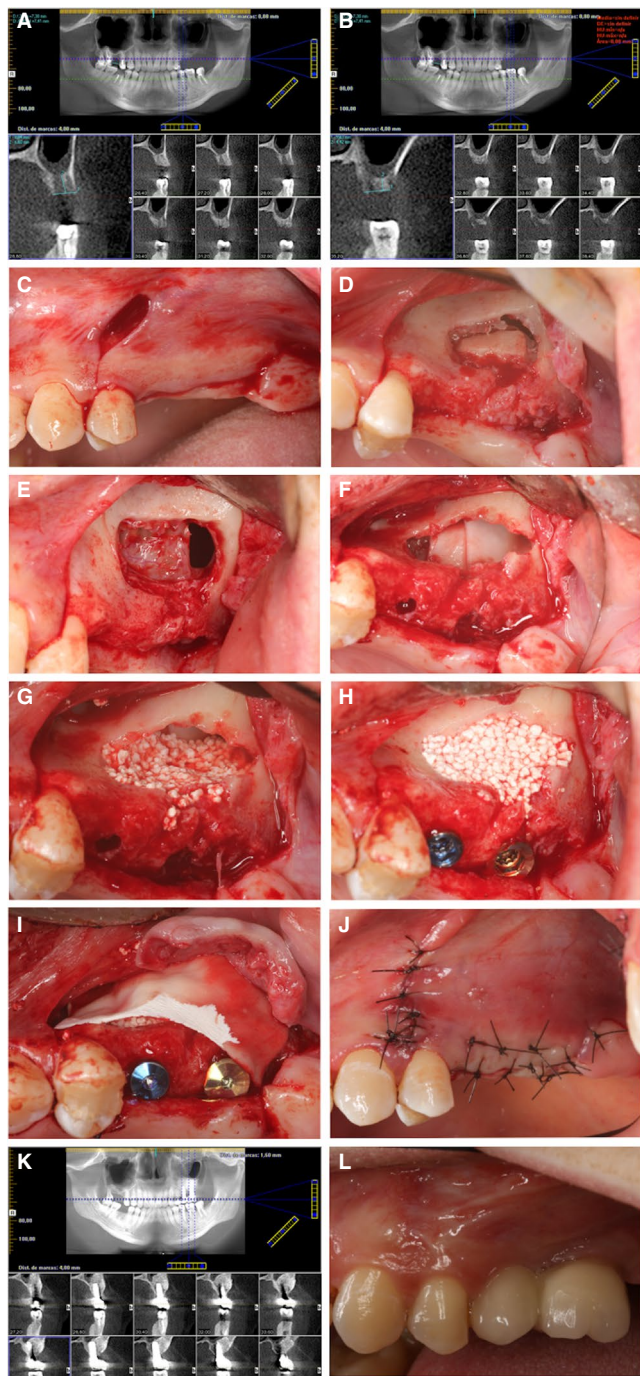
or nasal discharge, sinus irrigation with antibiotic, anti-inflammatory, and antiseptic medication is recommended.<sup>37,58,59</sup> However, these therapies have not proven to be predictable in outcomes. Reentry surgery may be needed if the pathology persists after nonsurgical treatment. Reentry surgery involves a conventional Cadwell-Luc osteotomy through the oral cavity or via endoscopy through the nasal or oral cavities, involving sinus irrigation and, on many occasions, the removal of the contaminated graft and/or the implants (Figures 5 and 6).

### 3.1.3 | Hemorrhage

The blood supply of the maxillary sinus is provided by the maxillary artery, which provides several branches that perfuse the sinus cavity and its surrounding tissues and structures, such as the infraorbital artery, the anterior superior palatine artery, and the posterior superior alveolar artery. It is common to find several anastomoses between the posterior superior alveolar artery and the infraorbital artery inside the lateral bony wall of the sinus.<sup>62,63</sup> These vessels irrigate the Schneiderian membrane, the epiperiosteal buccal tissues, and the maxillary teeth. There is a wide variability among individuals in terms of vessel anatomy and size, as well as their distribution and location in the maxillary sinus. According to a study using human biopsies and computed tomography scans, 10.5% of the population present with sinus vessels of a diameter greater than 0.5 mm in the lower two-thirds of the anterolateral sinus wall. The mean thickness of these arteries is 1.2 mm, ranging between 0.5 to 2.5 mm.<sup>63-65</sup>

When these vessels are found, they are usually bilateral (in 71.4% of the cases). According to position, they can be located superficially (underneath the periosteal tissues), intraosseously or intramembranously, the intraosseous location being the most frequently observed (71.4%). There is a potential risk of bleeding during sinus lifting procedures if any of these arteries are damaged either during the window osteotomy or during the reflection of the Schneiderian membrane. Some authors estimate that this risk of hemorrhage rises up to 57% when the sinus artery diameter is greater than 0.5 mm.<sup>63</sup> In order to avoid bleeding complications during surgery it is recommended to analyze a computed tomography scan carefully prior to any open sinus lifting procedure in order to detect the presence or absence of sinus vessels with a diameter greater than 0.5 mm and to keep in mind that, if detected in one sinus, there is a high probability of a similar vessel on the contralateral side. Once detected, the next precaution to be taken is with regard to its location. If it is present superficially, under the buccal soft tissues, it can be carefully detached from the bone and reflected with the buccal flap without damaging it. However, when it is found intraosseously, the recommendation is to avoid its course by modifying the size and position of the buccal wall osteotomy, since there is a high risk of perforating the vessel with the osteotomy. Lastly, if found inside the sinus attached to the Schneiderian membrane, the clinician can either carefully detach and reflect the artery together with the sinus membrane (Figure 7) or adapt the buccal window to a different area where the artery is not present.

When the sinus artery is accidentally damaged during surgery, hemostatic measurements have to be applied immediately



**FIGURE 4** Membrane perforation management during open sinus lift with simultaneous implant placement (courtesy of Dr Eduardo Montero). A, B, Computed tomography image of bone availability and maxillary sinus of the target area. C, Flap design. D, Membrane perforation during buccal window osteotomy. E, View of membrane perforation after buccal plate removal. F, Placement of two resorbable collagen membranes in the inner area of the sinus, covering the membrane perforation. Notice that the implant bed had been previously prepared in the residual bone crest. G, Hydroxyapatite graft placement. H, Implant placement. I, Covering of the buccal osteotomy with a resorbable collagen membrane. J, Flap closure. K, Computed tomography image of the 1-year follow-up after implant loading. L, Prostheses loading

to control the bleeding. If the vessel course is accessible, it can be clamped with an instrument and sutured on its distal end. However, when the vessel is damaged in close proximity to the window borders, the artery might retract and not be accessible for clamping. In these situations, the use of hemostatic agents, such as aminocaproic acid or bone wax, can be applied to the bone until hemostasis is achieved.

### 3.1.4 | Overfilling (ostium blockage)

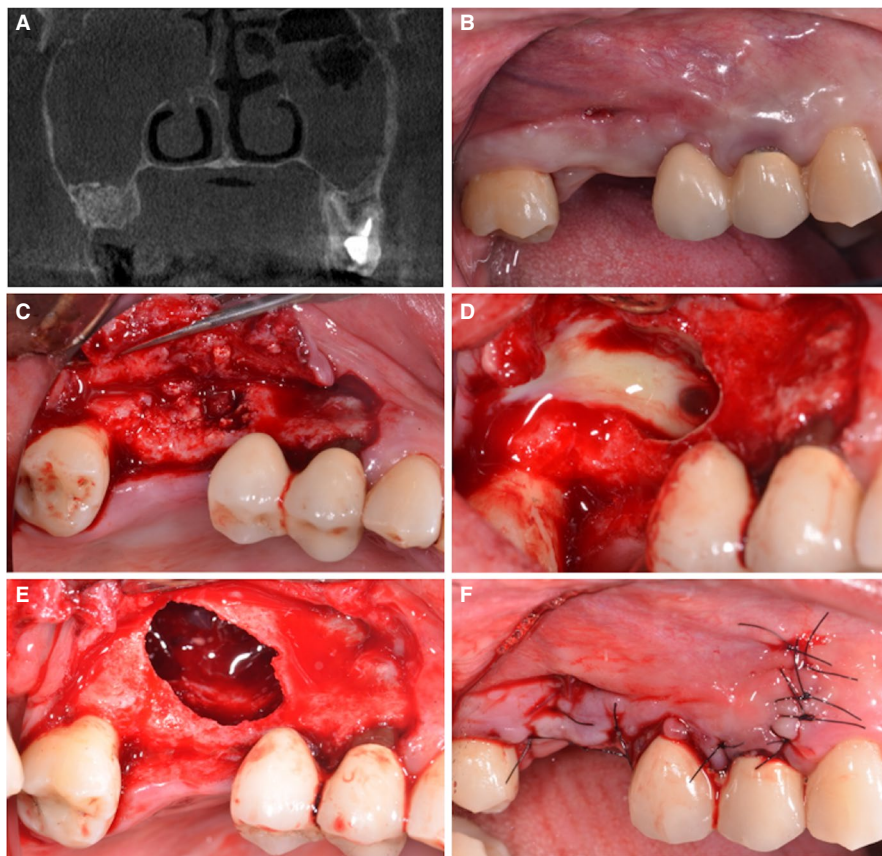
The sinus ostium communicates the maxillary sinus with the nasal cavity and is located in the inner wall of the sinus in an apical position. Its function is to maintain adequate drainage of the mucosal secretions of the sinus, as well as to allow for adequate ventilation. Owing to its high cranial position, its iatrogenic blockage by overfilling with bone grafts during sinus lifting is a rare complication.<sup>51</sup> This blockage should be avoided, since it can impair the normal physiology of the sinus and provoke the appearance of further complications, such as chronic rhinosinusitis.<sup>57,60</sup> It is recommended to evaluate the position and patency of the ostium prior to surgery via a computed tomography scan in order to detect any positional abnormalities.

### 3.2 | Closed sinus lifting (osteotome technique)

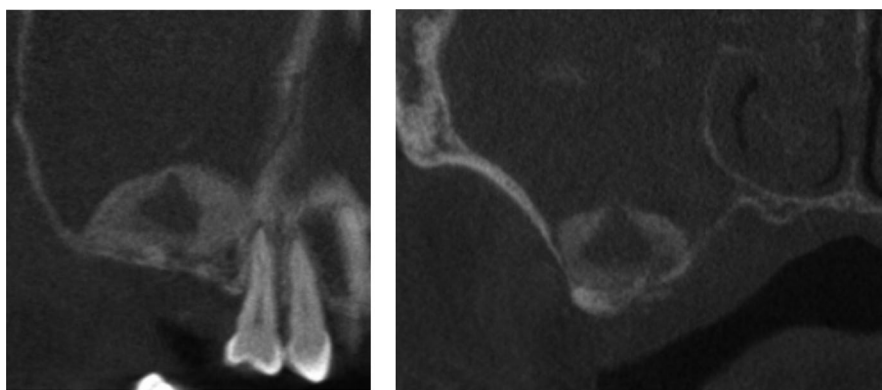
Closed sinus lifting is a faster and less invasive surgical intervention; therefore, the risk of complications should be reduced relative to the open approach.<sup>66</sup> However, it is only indicated in the presence of minimal residual ridge height to achieve the adequate primary stability of the implant. There is no evidence-based threshold for the amount of residual ridge height required for the indication of either open or closed sinus lifting; however, as a general recommendation, it is commonly suggested in the literature to perform the osteotome technique in cases with a minimum 4-5 mm of residual bone height.<sup>36</sup> Despite its advantages, closed sinus lifting is a technically demanding procedure and is not exempt from complications, since the clinician is blinded to what happens inside the sinus during its manipulation and can only test membrane integrity by indirect methods, such as the Valsalva maneuver (Table 1).

#### 3.2.1 | Schneiderian membrane perforation

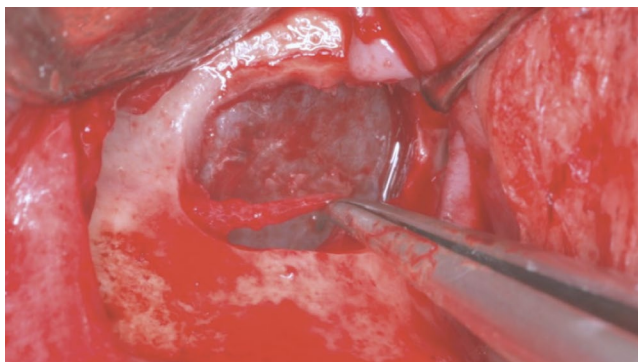
The most frequent complication when performing closed sinus lifting is the tearing of the sinus membrane during malleting with the osteotome. Its reported rate ranges between 0% and 17% (Table 3).<sup>24,67-69</sup> Such membrane perforations are usually associated with either anatomical or surgical technique factors. It has been reported that the thinner the membrane is, the higher the risk of tears during elevation.<sup>69</sup> These perforations are more frequent when the sinus floor is oblique and when the sinus membrane is elevated more than 3 mm<sup>24,70</sup> (Figure 8).



**FIGURE 5** Surgical treatment of a patient with chronic rhinosinusitis after sinus lifting (courtesy of Dr Myroslav Solonko). A, Computed tomography image of the maxillary sinuses of the patient, showing extensive occupancy. B, Intraoral fistula communicating the oral cavity and the right maxillary sinus. C, View of the buccal osteotomy after full-thickness flap raising, with particles of the infected graft embedded in the soft tissues. D, Mucopurulent discharge from the sinus cavity. E, View of the osteotomy and the maxillary sinus cavity after removal of the infected graft and sinus drainage. F, Flap closure



**FIGURE 6** Cross-sectional images in a patient that presented with suppurative and pain after 7 days of external sinus augmentation. A radiolucent image like a “black hole” can be observed at the center of the grafted area. The graft material was removed, the area was rinsed abundantly with saline, and the antibiotic regimen was changed (courtesy of Dr Jae-Kook Cha)



**FIGURE 7** Postero-superior alveolar artery isolated during open sinus lift

Sinus lining integrity can be controlled intrasurgically by endoscopy through an osteotomy in the lateral wall of the sinus; however, this procedure involves the perforation of the lateral wall of the sinus. Recently, it has been proposed to use small-diameter endoscopic devices that can be introduced through the crestal osteotomy and allow checking membrane integrity with no need for a second osteotomy into the sinus at an apical position.<sup>69</sup> Once the perforation has occurred, and in order to restore the sinus floor lining, several approaches can be followed. Some authors recommend using platelet aggregates to seal the communication before inserting the implant,<sup>69</sup> whereas others suggest the placement of a small piece of resorbable membrane through the crestal osteotomy to separate the sinus cavity from the implant, especially when implant placement is performed in conjunction with a bone graft.<sup>71</sup> Another option



TABLE 3 Prevalence of membrane perforations in closed sinus lift procedures (simultaneous implant placement)

Author (year)	Study type	Follow-up (mean)	Num. of patients	Num. of sinus lifted	Num. of implants	Membrane perforations	Description of other complications
Elian & Barakat 2018 <sup>69</sup>	PCS	Transversal design	12	12	Not reported	16.70%	Not reported
Markovic et al 2016 <sup>68</sup>	RCT	24 months	50	100	200	10%	Not reported
Nedir et al 2013 <sup>67</sup>	RCT	12 months	12	19	37	0%	Not reported
Pjetursson et al 2009 <sup>24</sup>	PCS	3.2 years	181	Not reported	252	10.4%	Not reported

Abbreviations: Num., number; PCS, prospective case series; RCT, randomized clinical trial.

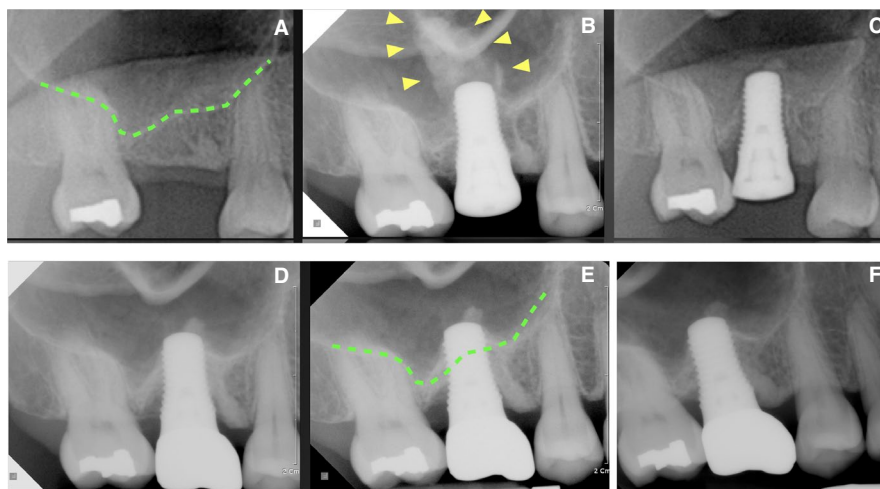


FIGURE 8 Periapical radiographs of a patient that presented a perforation while a crestal elevation with osteotomes was performed (courtesy of Dr Jae-Kook Cha). A, Baseline radiograph with the outline of the sinus depicted with a green dashed line. B, Postoperative radiograph shows the biomaterial protruding into the sinus cavity. C, At the 6 month evaluation there are no signs of pathology and no residual graft particles near the implant. D, Periapical radiograph at 2 years. E, Periapical radiograph at 5 years. F, Periapical radiograph at 12 years

in such a situation is placement of a shorter implant if the residual bone height allows, in order to avoid the protrusion of the implant tip into the sinus through the perforated Schneiderian membrane.<sup>71</sup>

### 3.2.2 | Benign paroxysmal positional vertigo

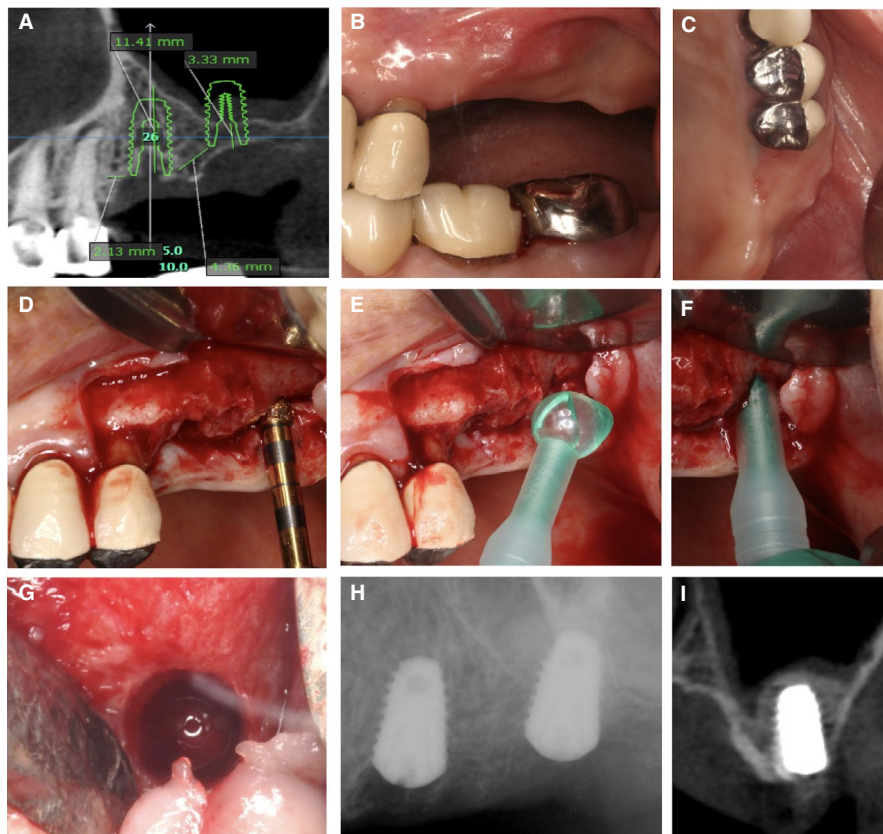
Benign paroxysmal positional vertigo is a highly prevalent otoneurological disorder characterized by brief episodes of vertigo and nausea precipitated by a rapid change in head posture. Its etiology can be idiopathic, posttraumatic, postinfectious, or due to vascular disorders. Its pathogenesis has been attributed to the detachment of otoliths from the utricular macula and their dislocation to the semicircular canals.<sup>72</sup>

A prospective cohort study of 146 patients scheduled to undergo closed sinus lifting found a 5.84% incidence of benign paroxysmal positional vertigo after the procedure.<sup>72</sup> Symptoms appeared 1 or 2 days after the operation and affected the contralateral area to the operated side. All patients were successfully treated with the Epley repositioning maneuver and showed complete recovery 2 days later, with no further recurrences in time. The Epley maneuver, also known as the canalith repositioning procedure or particle repositioning, consists of

a sequence of head movements that help the otoliths to get back to their original position. This maneuver has to be performed by a trained clinician with the patient lying on a table or stretcher.<sup>73,74</sup>

It has been hypothesized that the detachment of the otoliths during closed sinus lifting is induced by the surgical trauma caused by the osteotomes and the surgical hammer while malleting and condensing the bone. The patient's head position, hyperextended and tilted to the contralateral surgical side facilitates the entry of the otoliths in the posterior semicircular canal of the implanted site.<sup>72,75</sup> In order to reduce the incidence of benign paroxysmal positional vertigo it is recommended to minimize the trauma induced with the osteotomes by careful and precise malleting and to change the patient's head position frequently during surgery, favoring its movement and uprighting it when possible.<sup>72,76</sup> A randomized clinical trial comparing the use of conventional malleting osteotomes vs screwable ones, which do not require malleting with a hammer, demonstrated a 3.06% and 0% incidence of benign paroxysmal positional vertigo, respectively, supporting the hypothesis that reducing the percussive and vibratory trauma on the head may reduce the incidence of benign paroxysmal positional vertigo.<sup>75</sup>

Although in many cases benign paroxysmal positional vertigo post-sinus lift is self-limiting with time and has a spontaneous



**FIGURE 9** Balloon technique for internal sinus lift (courtesy of Dr Jae-Kook Cha). A, Cone beam computed tomography scan shows limited residual ridge height. B, Clinical images of the area to be treated. C, Occlusal image that shows the horizontal tissue loss. D, A diamond-coated drill is used to gain access to the sinus cavity. E, The syringe is filled with sterile saline; the balloon can be appreciated. F, The tip of the syringe is introduced and the content flushed to fill the balloon. G, The membrane was intact after the manipulation. H, Periapical image showing the augmentation achieved. I, Cone beam computed tomography scan cross-sectional image showing the bone achieved

recovery, patients should be aware of the possibility of suffering temporal vertigo after the surgery as part of the informed consent process, and because symptoms can be uncomfortable and incapacitating, causing severe stress to the patient.<sup>76</sup>

### 3.2.3 | Implant displacement

The occurrence of implant displacement to the maxillary sinus has also been reported in the literature.<sup>33</sup> It may occur during surgery or months later during prostheses manipulation. Its retrieval is highly recommended, even in the absence of pathology or clinical symptoms, due to the risk of infection, sinusitis, or further displacement of this foreign body to adjacent anatomical structures, such as the nasal cavity, the orbit, the sphenoid and ethmoid sinuses, or the cranial fossa.<sup>77</sup> Three main surgical approaches have been described for the retrieval of the ectopic dental implant: via a transnasal approach, via a transoral approach through the canine fossa, and directly through the implant bed preparation. The first two are generally assisted with the use of endoscopic devices.<sup>77</sup>

To prevent the occurrence of implant migration to the sinus, it is recommended to carefully perform the implant bed in a cone-shaped configuration and to use tapered implants with a reduced diameter in the apical portion, which will prevent the displacement of the whole device into the sinus. Also, special attention has to be placed in order to achieve adequate primary stability of the implant during insertion. For this purpose, it might be useful to underprepare

the bony bed by individualizing the drilling protocol and omitting the use of the latest implant drills or limiting its action to the most coronal portion of the residual alveolar crest.<sup>66</sup>

## 4 | PREVENTION: RISK FACTORS CONTROL AND STRATEGIES TO MINIMIZE COMPLICATIONS

Before considering performing a sinus augmentation procedure and in order to minimize the incidence of intrasurgical and postoperative complications, it is mandatory to perform a thorough medical history, together with a careful clinical and radiographic evaluation. The medical history should focus on any symptoms compatible with sinus pathologies, such as impaired nose breathing, retronasal secretions, headaches, or eyelids' swelling.<sup>52</sup> In those cases, a preoperative consultation with the otorhinolaryngologist before the bone augmentation is recommended for a closer evaluation of the possible sinus pathology.

In a large retrospective case series evaluating the incidence of various complications after 202 sinus lift procedures,<sup>37</sup> smoking was not associated with a higher incidence of complications after open sinus lift, with a total complication rate of 20.4% in smokers vs 19.2% in nonsmokers. However, sinusitis occurred more frequently in smokers than in nonsmokers (four cases vs one case), which is in agreement with another study that reported a significantly greater prevalence of acute sinusitis in smokers (14.2%) than in nonsmokers

(2.2%) in a case series of 124 procedures.<sup>41</sup> Although smoking cannot be considered a total contraindication for sinus lifting, patients should be advised on the increased risk of certain complications, and smoking cessation must be encouraged before surgery.

When choosing the most appropriate technique for maxillary sinus augmentation, several systemic and local aspects have to be considered, including the residual alveolar height, the sinus anatomy (presence/absence of septa, location and course of the posterior superior alveolar artery, etc), the presence or absence of previous sinus pathologies, and the number of teeth to be restored.

Rotary hand instrumentation by means of diamond burs and a handpiece is a commonly used method for the lateral window osteotomy, since it is quicker than other techniques and quite accessible in most clinics.<sup>35</sup> However, this surgical technique has reported the highest incidence of membrane perforations, with rates up to 32%.<sup>78</sup> Piezoelectric devices have been advocated as an improved tool. These devices use ultrasonic waves for bone cutting and reduce the risk of membrane tearing, since the inserts are not able to cut soft tissues. The incidence of membrane perforations with piezoelectric devices reported in the literature ranges from 3.6% to 8%,<sup>35,79,80</sup> and in most cases they occur during hand instrumentation and membrane deflection, instead of during lateral osteotomy.<sup>79,80</sup>

The use of hydraulic controlled pressure to detach the Schneiderian membrane from the bone walls of the sinus has also been advocated to reduce the occurrence of membrane perforations. This technique can be implemented in both open and closed sinus lifting procedures.<sup>81,82</sup> Various protocols have been proposed, but in general terms the procedure consists of gaining access to the Schneiderian membrane either through a crestal or a buccal osteotomy and applying hydraulic pressure by means of direct water flow from a handpiece,<sup>81</sup> or a radiographic contrast medium, saline, or water injected underneath the membrane by means of specifically designed injectors or pumps.<sup>82-84</sup> Once the membrane is loosened from the sinus bone walls, a graft is carefully introduced and condensed through the osteotomy to obtain space gain (Figure 9). When there is sufficient residual bone height to stabilize dental implants, these can be placed in the same procedure, or at a later stage if primary stability cannot be achieved at the moment of sinus lift.<sup>81,83</sup> Hydraulic sinus lifting has reported low perforations rates, ranging from 0% to 11.8%.<sup>82,84-86</sup> However, the evidence supporting the effectiveness and success of this technique is mainly based on case series and, to date, there are no randomized clinical trials comparing the hydraulic sinus lift procedure with conventional open or closed sinus lifting techniques.

More recently, a novel system of high-speed rotatory burs has been developed, which has a trephine with a reamer design that compacts bone while drilling and protects the membrane when performing the bone osteotomy. To date, the evidence supporting its effectiveness is scarce, with only one clinical trial showing favorable results in terms of the incidence of membrane perforations when compared with conventional rotatory instruments (8% vs 32%)<sup>78</sup> and one retrospective case series showing an incidence of perforation of 15%, most of them occurring during osteotomy drilling (12.5%).<sup>87</sup>

## 5 | CONCLUSIONS

Sinus lifting procedures are highly predictable techniques to increase bone availability for implant placement in the posterior maxilla. However, these surgical interventions are frequently associated with an increase in comorbidities and patient discomfort. The most commonly reported complication for both open and closed sinus lifting procedures is the Schneider membrane perforation, with incidence rates around 20%-25% and 15% respectively.

In order to minimize the occurrence of intrasurgical and postoperative complications, it is highly recommended to carefully plan the case and examine the health status of the patient to detect any preexisting pathology or condition that may lead to an increased risk for undesired events. Further research is needed in order to develop and to test safer and less-invasive technologies for the patient that would reduce the incidence of complications associated with sinus lifting procedures.

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## CONFLICTS OF INTEREST

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

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