

Combination of a Hydraulic Device and Nanohydroxylapatite Paste for Minimally Invasive Transcrestal Sinus Floor Elevation: Procedure and 4-Year Results

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Purpose: The objectives of this retrospective study were to describe a transcrestal sinus floor elevation technique combining the use of a hydraulic device and a nanohydroxylapatite paste and to report on 4-year clinical and radiographic outcomes. **Materials and Methods:** The sinus floor elevation procedure used a specially designed drill (SinusJet) to start sinus membrane unsticking and a nanohydroxylapatite paste (Ostim) for further sinus membrane elevation and bone augmentation. It was performed as a one-step procedure with immediate implant placement or a two-step procedure with delayed implant placement 9 months later. Implant survival rate, sinus membrane perforation, postoperative complications, and the level of intraoperative and postoperative patient comfort using a visual analog scale were analyzed retrospectively. A nonparametric Wilcoxon matched-pairs test and parametric paired *t* test were used to identify significant differences. **Results:** One hundred thirty-six sinus floor elevations were performed in 110 patients at two dental clinics in Belgium with a mean follow-up period of 48 months. In the one-step procedure, the mean 6-month elevation was 8.5 ± 2.7 mm; 194 implants were placed. In the two-step procedure, the mean 9-month elevation was 9.5 ± 2.4 mm; 8 implants were placed. The osteotomy, sinus membrane elevation, and bone grafting typically took less than 3 minutes. Sinus membrane perforation was observed in 2.9% (n = 4/136). The 4-year implant survival rate was 97% (n = 196/202), with six early implant losses. 96.4% of patients reported either no or minimal discomfort. **Conclusion:** This minimally invasive transcrestal sinus floor elevation procedure that combines a hydraulic device and nanohydroxylapatite paste appears to be safe and predictable. However, further randomized controlled studies are needed to validate the results of this retrospective observational study. *Int J Oral Maxillofac Implants* 2021;36:587–597. doi: 10.11607/jomi.6092

Keywords: atrophic posterior maxilla, bone augmentation, dental implant, hydraulic device, nanocrystalline hydroxyapatite, sinus floor elevation, transcrestal procedure

Dental implant placement in the posterior maxilla is greatly hindered by progressive bone resorption and sinus pneumatization that often follows tooth loss. Sinus floor elevation is one of a number of bone augmentation procedures to support dental implant placement when there is reduced vertical bone volume. The sinus membrane is elevated from

the maxillary sinus floor, and a bone graft or bone substitute is placed into the created space. From the clinical point of view, two techniques are used: the lateral and transalveolar approaches. The lateral window technique was first reported by Boyne and James¹ in 1980 and modified several times.^{2–4} The extension of surgery can lead to important postoperative patient discomfort with side effects such as pain, hematoma, and swelling. In order to reduce complications and to scope with minimally invasive techniques, new surgical procedures including transalveolar approaches have been developed.⁵

The first translaveolar procedure was described in 1986 by Tatum⁶ as the osteotome sinus floor elevation procedure, and then modified by Summers^{7,8} as the bone-added osteotome sinus floor elevation procedure. Both procedures involved gentle tapping of the osteotome to fracture the sinus floor. The sinus membrane can then be elevated using several pressure methods, and bone grafting can be performed using various spreading and condensing instruments.

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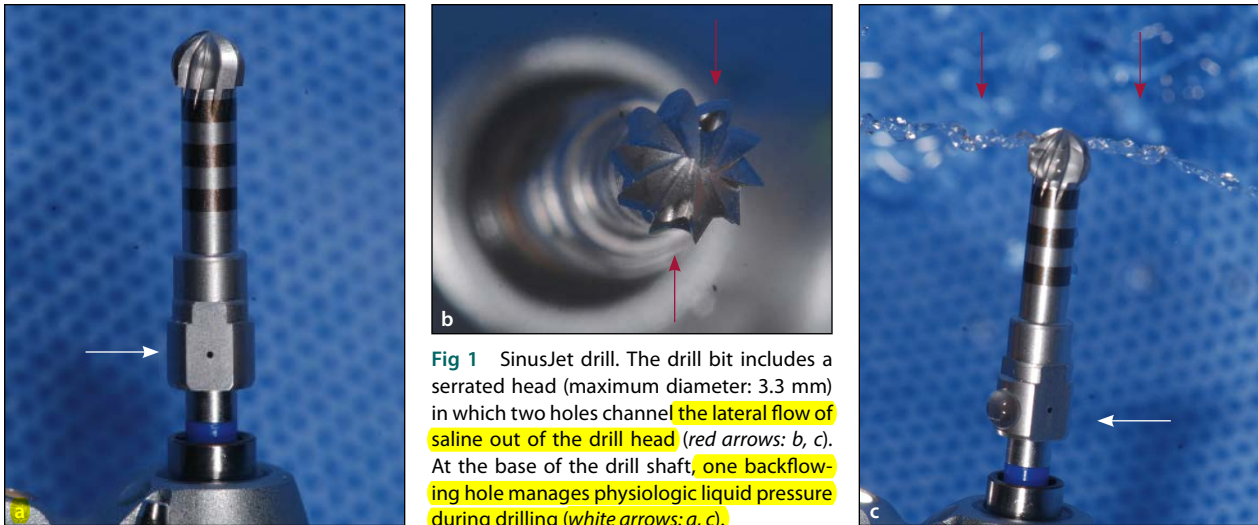


Fig 1 SinusJet drill. The drill bit includes a serrated head (maximum diameter: 3.3 mm) in which two holes channel the lateral flow of saline out of the drill head (red arrows: b, c). At the base of the drill shaft, one backflowing hole manages physiologic liquid pressure during drilling (white arrows: a, c).



However, the osteotome procedure has several disadvantages, including limited sinus membrane elevation and bone augmentation. It is difficult to control the osteotome tapping force to achieve effective membrane elevation without perforating the sinus membrane.⁹ The use of osteotome is uncomfortable for the patient and can induce complications such as osteotome sinus floor elevation–related benign paroxysmal positional vertigo.^{10–13}

Since 2003, several transalveolar sinus membrane elevation procedures that avoid the use of an osteotome or a mallet have been described, including the balloon procedure,^{14–16} the piezotome procedure,^{17,18} the reamer procedure,¹⁹ and the gel pressure technique.²⁰ However, all those procedures require the use of multiple drills and/or instruments.

An alternative transcresal procedure for sinus floor elevation has been recently developed, not only to avoid the use of an osteotome or a mallet, but also to reduce the number of drills and/or instruments. Instead, the procedure uses a specialized drill that creates hydraulic pressure through the release of saline in the osteotomy (Fig 1 and 2b to 2e), and a bioabsorbable nanocrystalline hydroxyapatite aqueous paste as augmentation material (Figs 2f to 2h and 2m). The hydraulic pressure in the osteotomy was used to begin the unsticking of the sinus membrane from the sinus floor (Fig 2e). Nanocrystalline hydroxyapatite paste was used for further sinus membrane unsticking, for sinus membrane elevation, and as augmentation material (Figs 2f and 2m). Nanocrystalline hydroxyapatite paste was used instead of hydroxyapatite granules because of its suitability for injection by syringe into the 3.3-mm-diameter osteotomy (Figs 2f, 2g, 2l, and 2m). Moreover, clinical,^{20–24} radiographic,^{20–24} histologic,^{21–24} and his-

tomorphometric^{21–23} results show that nanocrystalline hydroxyapatite paste is suitable for both lateral^{21,22} and transcresal^{20,23,24} sinus floor elevation. The objectives of this retrospective observational study were to describe this procedure and to report 4-year clinical and radiographic outcomes.

MATERIALS AND METHODS

Study Design and Population

Figure 3 presents the flow diagram of the study. The retrospective observational study was conducted at two sites in Belgium. The inclusion criteria were as follows: atrophic posterior maxilla with insufficient sub-antral bone height, adequate alveolar ridge width, and adequate vertical and horizontal interarch relationships (Group 1 indication based on categorization by Katsuyama and Jensen²⁵). The exclusion criteria were as follows: smoking (> 10 cigarettes daily), pregnancy, a general systemic disease that could compromise bone grafting success (eg, diabetes), and the extraction of a molar or premolar within the previous 3 months (to avoid the risk of sinus membrane perforation). Figure 2 presents the flow diagram of the study.

Presurgical Assessment

Intention-to-treat was determined by a preoperative assessment. This assessment consisted of a DentaScan (GE Healthcare) or a CBCT of the maxilla to analyze: (1) the sinus ostium to confirm its permeability (Fig 4a); (2) the shape of the sinus floor (horizontal—Fig 4a or oblique—Fig 4b); (3) the mean height of the residual alveolar crest, calculated from several measurements, especially in the case of an oblique sinus floor (Fig 4b);



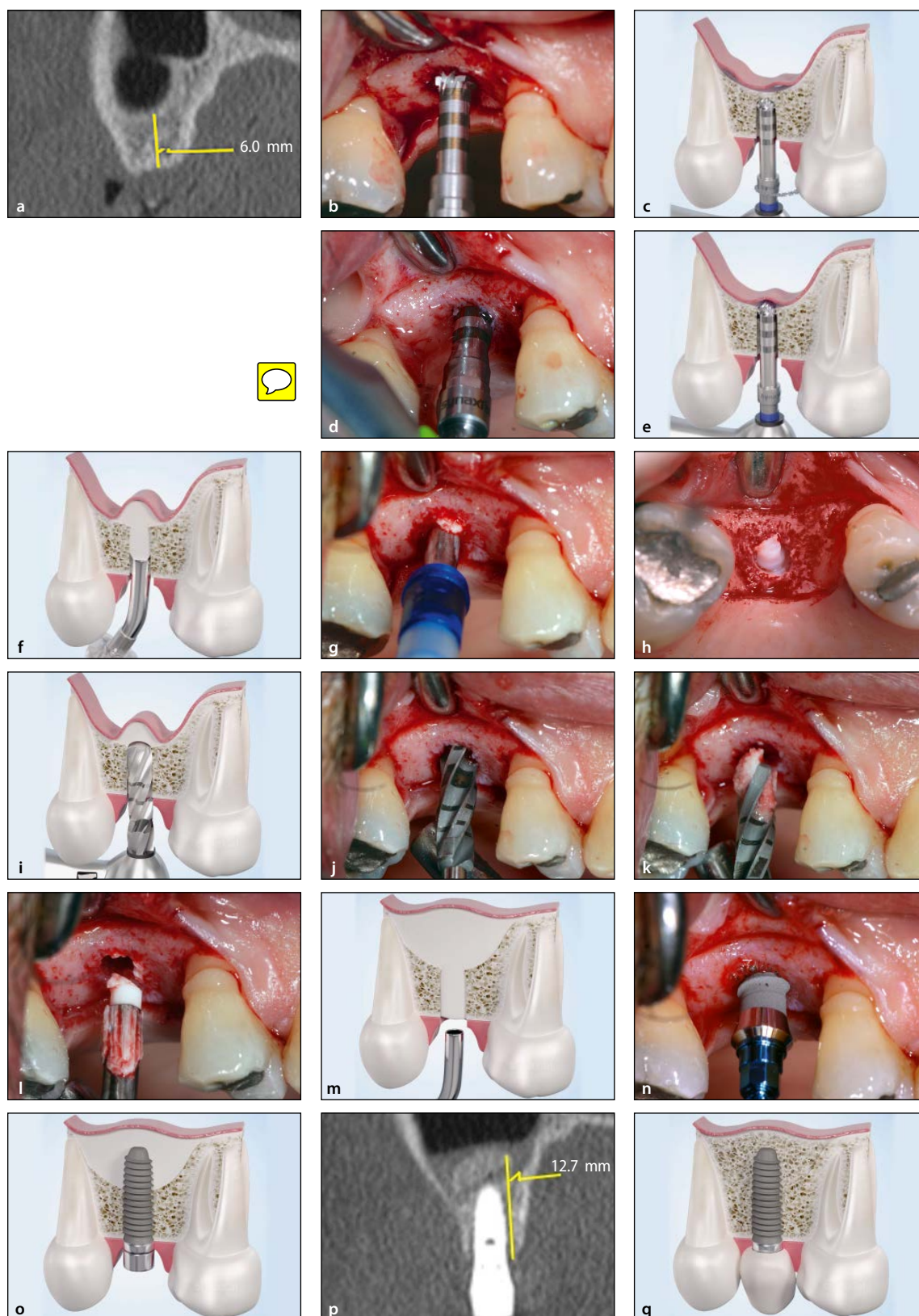


Fig 2 One-step procedure with immediate implant placement. (a) 6-mm residual crest height. (b to e) Osteotomy with SinusJet drill—beginning of hydraulic unsticking and elevation of the sinus membrane. (f to h) Injection of the nanocrystalline hydroxyapatite paste (0.5 to 1 cc) by syringe through the osteotomy for further sinus membrane elevation and bone grafting. (i to k) Implant bed preparation using the final drill of the implant system. Nanocrystalline hydroxyapatite graft protects the sinus membrane from perforation by this drill. (l, m) Second injection of nanocrystalline hydroxyapatite paste by syringe (0.5 to 1 cc). (n, o) Implant placement. (p, q) New bone formation can be observed 6 months later.



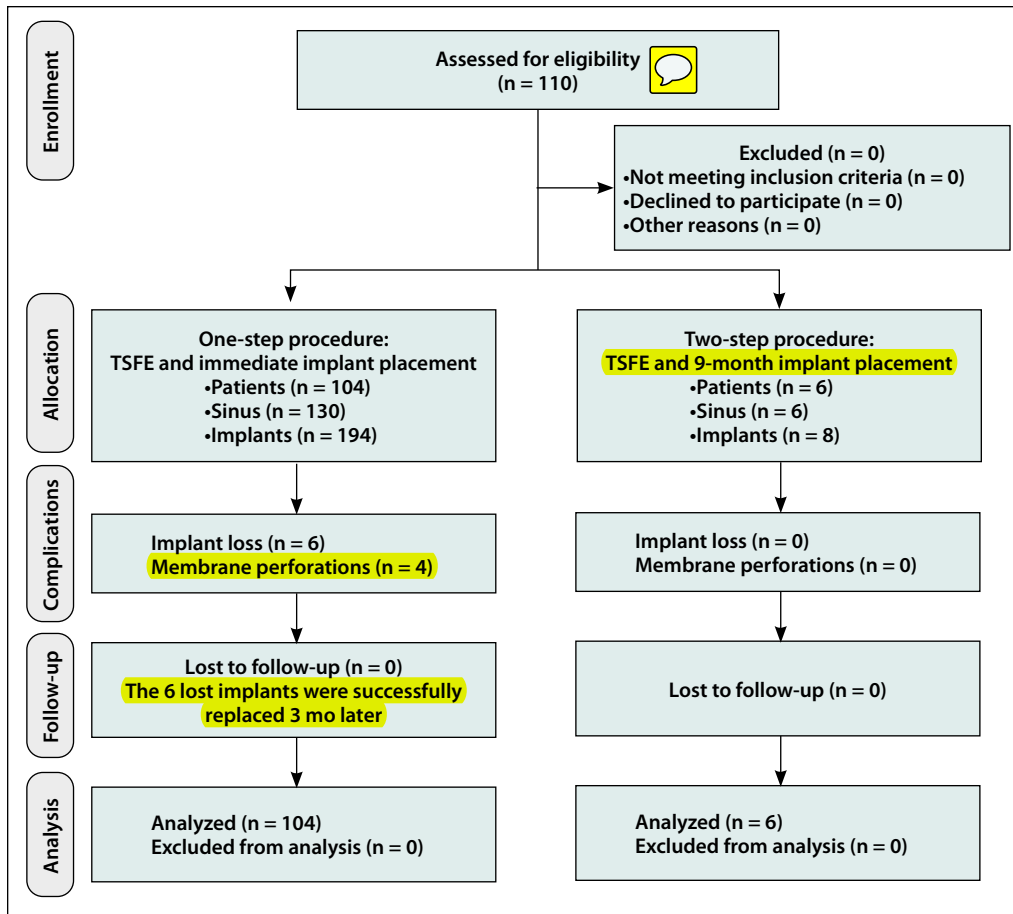


Fig 3 Flow diagram.

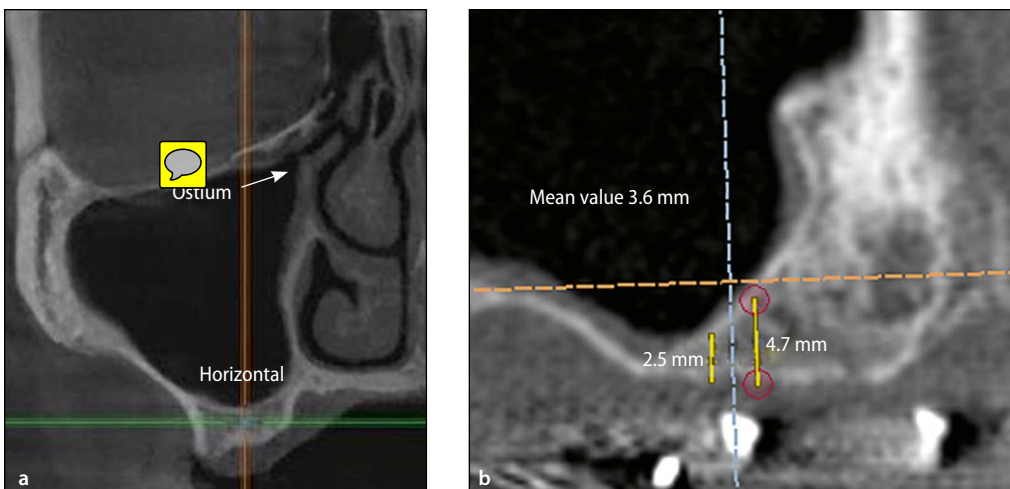


Fig 4 Inclusion criteria. CBCT or DentaScan assessment of (a) sinus ostium and the absence of obstruction, and (a, b) the orientation of the sinus floor, (a) horizontal or (b) oblique.

(4) the sinus membrane thickness (Figs 4a and 5a); and (5) the presence of sinus (Underwood) septa (Figs 6b and 6c).



Surgical Procedure

Surgery was performed without antibiotic prophylaxis. Preoperative mouth rinsing (1 minute) with 1% povidone iodine solution was performed.

A full-thickness crestal incision was made under local anesthesia using lidocaine 2% with adrenaline. The crestal incision was positioned on the palatal side. Small mesial or distal release incisions were done if needed. A full-thickness mucoperiosteal buccal flap was raised.

In the case of hard cortical bone, a precision drill was used to mark the implant position and to perforate the cortical bone.

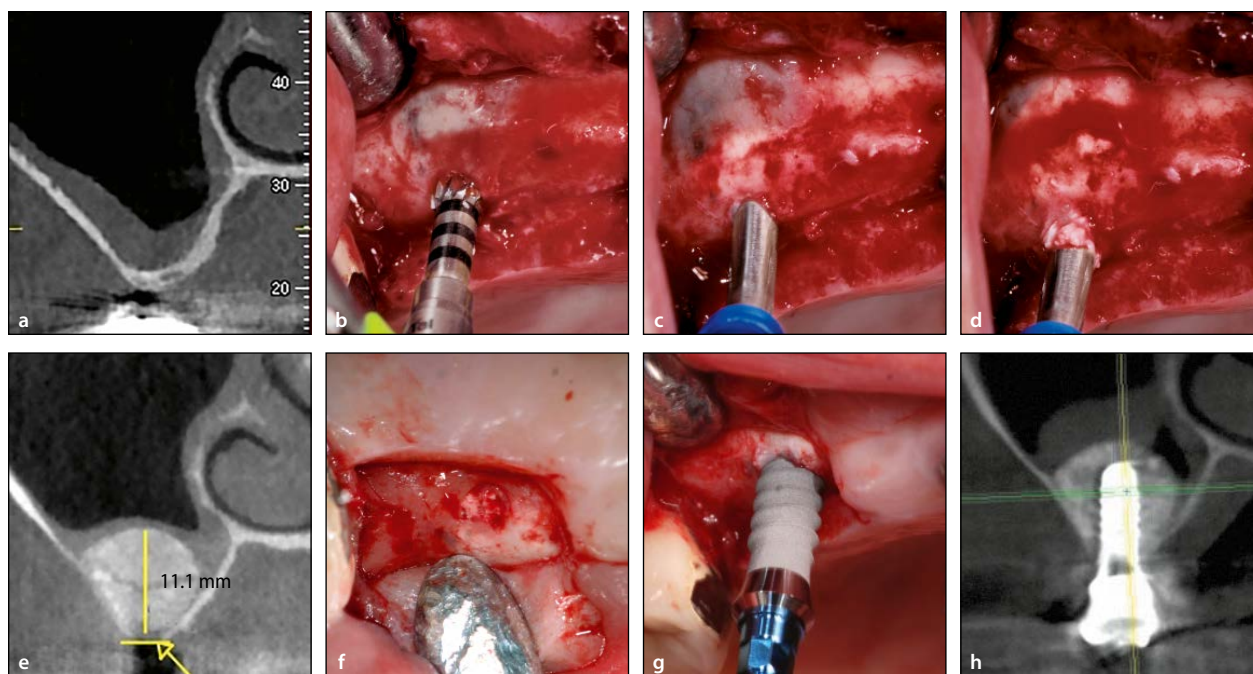


Fig 5 Two-step procedure with delayed implant placement 9 months after graft. (a) The residual crest height was 1.5 mm. (b) Osteotomy with SinusJet drill. The gray color of sinus membrane can be observed through the thin buccal cortical bone. (c, d) Injection of the nanocrystalline hydroxyapatite paste by syringe for bone grafting (1.5 to 2 cc). Further elevation of sinus membrane can be observed thanks to the thin buccal cortical bone and the white color of injected nanocrystalline hydroxyapatite. (e) New bone formation 9 months later with a height of 11.1 mm. (f, g) 6-month implant placement (length = 10 mm). (h) Control CBCT 2 years after implant placement.

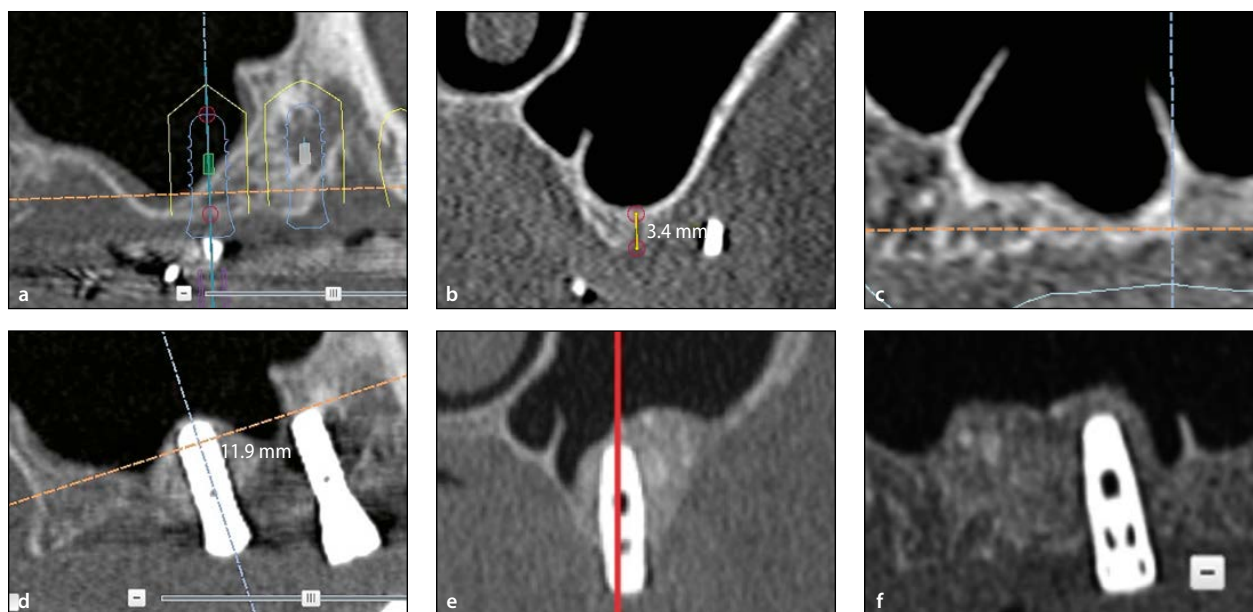


Fig 6 6-month results. Successful procedure despite the presence of two risk factors for sinus membrane perforation: (a and d) A thin sinus membrane and oblique sinus floor; and (b, c, e, f) a thin sinus membrane and Underwood septa.

The osteotomy (Figs 2b to 2e) was performed with a single-patient-use drill (Fig 1: diameter of 3.3 mm; SinusJet, Synaxial) at a maximum speed of 300 to 500 rpm and with an inner-drill sterile-saline irrigation system set at 60 mL/min. Every 3 to 5 seconds during the procedure, the drill was withdrawn from the

osteotomy to check the free flow of saline at the drill head and absence of any obstructions to the saline irrigation holes (Figs 1b and 1c).

Physiologic liquid comes out from the head of the drill by two lateral holes and flows through maxillary bone during drilling. As the sinus membrane is a natural

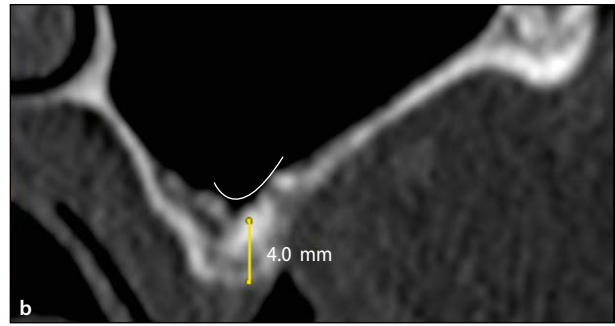
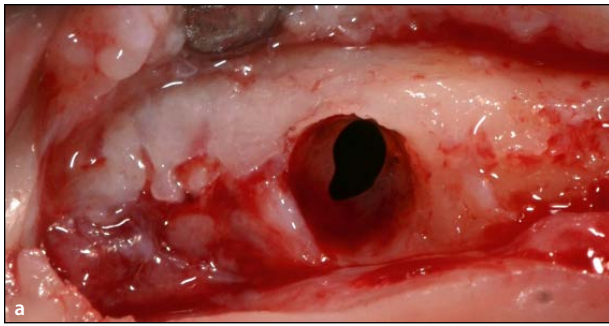


Fig 7 (a) Sinus membrane perforation observed by direct intraoral visualization through the osteotomy in a very difficult-to-treat case. (b) Thin membrane, oblique sinus floor with a “V” shape.

waterproof barrier, physiologic liquid is trapped between the sinus floor and sinus membrane; the pressure of physiologic liquid begins to unstick the sinus membrane before the drill pierces the sinus floor (Figs 2c and 2e).

This surgical protocol is called “controlled hydraulic pressurized direct intralift.” The term “hydraulic” underlines that physiologic liquid begins to unstick the sinus membrane. The term “controlled pressurized” underlines the importance of the backflowing security system (Figs 1a and 1c: white arrows) in the management of physiologic pressure during sinus membrane unstick-ing. When the drill end is in contact with bone, physiologic liquid pressure increases at the working point, especially with hard bone and high residual bone. The backflowing security system prevents intrabony pressure current peaks, allowing an increasing reflow with increasing pressure at the drilling head and a decreasing reflow with decreasing pressure. The “backflowing hole” located in half-position on the shank of the drill must be checked during drilling.

The idea of this hydraulic technique comes from the observation of a facial emphysema mishap induced by use of compressed air during endodontic treatment or maxillary surgery.^{26–30} This illustrates the ability of compressed air to cross crestal bone, creating tissular emphysema with possible dramatic consequences. The principle of this hydraulic technique starts from the idea that crestal bone is not only permeable to air but also to fluids.

Sinus membrane integrity was assessed intraoperatively by direct intraoral visualization through the osteotomy (Fig 7a). The Valsalva test was used to get further information. The practitioner gently pinched patient nostrils while the patient breathed normally through his nose. Air leakage or bubbles emanating from the osteotomy mean a membrane perforation. Preoperative guidance, practice, and training of the Valsalva test were done to avoid accidental damage to the sinus membrane during the test; an excessive blowing force could tear the membrane.

In the case of damage to the sinus membrane, the osteotomy was filled with a collagen sponge, and the

mucoperiosteal flap was sutured, with the intention that the procedure would be postponed 3 months later. In the case of no damage of the sinus membrane, 0.5 to 1 mL 35% nanocrystalline hydroxyapatite in aqueous paste (Ostim, Heraeus Kulzer) was injected through the osteotomy by syringe, to a volume consistent with filling the osteotomy to the existing crestal bone height (Figs 2f to 2h). The biomaterial contributes to further sinus membrane unstick-ing and elevation (Fig 2f). Excess paste exited the osteotomy at the point of entry of the syringe (Fig 2g).

Implant placement was performed immediately after bone augmentation (one-step procedure; Fig 2n) or 9 months later (two-step procedure; Fig 5g) depending on the possibility of obtaining implant primary stability or not. Hence, in the two-step procedure, the mucoperiosteal flap was sutured after bone augmentation.

Various implant systems were used in this retrospective study: Xive Friadent, Anthogyr Axiom, Straumann, and Nobel Biocare. In the one-step procedure, the implant bed was prepared using the final drill of the implant system (Figs 2i to 2k). Another 0.5 mL of biomaterial was injected through the osteotomy by syringe (Figs 2l and 2m) before implant placement.

The implant was inserted (Figs 2n and 2o). Primary implant stability of at least 15 Ncm was always required. Barrier membrane was not used. A transgingival healing screw was placed. Interrupted Vicryl Fast Resorption 5.0 sutures were used for wound closure around the healing screw according to the nonsubmerged procedure and with special care to maintain a maximum of keratinized mucosa on the buccal side.

Postoperative care included standard oral hygiene and 1% polyvidone iodine mouthwash twice a day for 2 weeks. Surgery was performed without antibiotic prophylaxis. Patients took 1-g doses of paracetamol. These doses were restricted to just after surgery, 4 hours later, and before bed on the day of the surgery.

To confirm appropriate graft containment (one-step and two-step procedures) and implant placement into the graft (one-step procedure), a panoramic radiograph was performed immediately after the surgery.

Monitoring During and After Surgery

During surgery, the following parameters were recorded by the surgeon: the time required to perform the osteotomy and the injection of nanocrystalline hydroxyapatite paste; and complications, including (1) sinus membrane perforation, (2) excessive bleeding, (3) migration of bone graft within the sinus, and (4) poor primary stability of the implant.

After surgery, the following complications were recorded by the surgeon: bleeding, swelling, hematoma, infection, wound dehiscence, bone graft loss, implant loss (implant survival rate), and maxillary sinusitis.

Patient discomfort was monitored using a visual analog scale just after surgery, to evaluate the perioperative comfort, and 2 weeks later to evaluate the postoperative comfort. Each patient was asked to evaluate his/her pain and discomfort in accordance with a graded scale from 0 to 10: 0 indicated "total acceptance or no inconvenience" and 10 indicated "total refusal or worst possible pain."

Bone augmentation at the implant site was assessed by panoramic radiograph immediately after implant placement, and by DentaScan or CBCT 6 months (one-step procedure) or 9 months (two-step procedure) after the surgery (Fig 6). At the same time points, graft-material loss, implant loss (implant survival rate), peri-implantitis, and health of peri-implant soft tissues were assessed.

Prosthetic Procedure

Prosthetic loading was performed 6 months after implant placement (Figs 2p and 2q) with screw-retained single crowns or fixed partial dentures and a torque value of 35 Ncm. All patients received a night guard. Follow-up included the search for technical complications, including ceramic chipping, prosthetic unscrewing, and framework fracture.

Statistical Analysis

The statistical analysis was performed with GraphPad Instat 3 software for Windows. Differences between groups were considered significant if the *P* value was < .05. Mean and SD were calculated. A nonparametric Wilcoxon matched-pairs test was used to compare bone dimensions between baseline and 6 months in the one-step procedure group. A parametric paired *t* test was used to compare differences in bone dimensions between baseline and 9 months in the two-step procedure group.

RESULTS

Study Conduct

In this retrospective study, patients were treated between January 2012 and September 2015. One hundred ten patients were included in the intention-to-treat cohort and underwent surgery. The observational phase

ended in May 2018, with a mean follow-up period of 48 ± 9 months. None of the treated patients was lost to follow-up.

One hundred four patients were treated with the one-step procedure, and six patients were treated with the two-step procedure (Fig 3). Two hundred two implants were placed. The majority (66%, $n = 133/202$) of the implants were placed in molar areas (Table 1).

Surgery Outcomes

In the one-step procedure, 130 sinus floor elevations were followed by the placement of 194 implants. The mean height of the residual alveolar process was 4.5 ± 1.6 mm (Table 2). The procedure allowed a significant sinus membrane elevation, with a mean increase in bone height of 8.5 ± 2.7 mm ($P < .0001$). After 6 months, a homogenous elevation of the sinus membrane was observed. The regenerated bone was observed at distal and mesial aspects of the implant site (Figs 6c and 6f).

In the two-step procedure, six sinus floor elevations were performed. Nine months later, eight implants were placed. Additional bone grafting was needed for one implant. In this group, the mean bone height of the residual alveolar process before surgery was 1.2 ± 0.5 mm (Table 2). A mean increase in bone height of 9.5 ± 2.4 mm ($P < .0001$) was obtained.

For the 136 procedures, osteotomy, sinus membrane elevation, and bone grafting took less than 3 minutes, with a mean time of 100 ± 31 seconds for osteotomy, and a mean time of 50 ± 8 seconds for membrane elevation and bone grafting.

An immediate postoperative panoramic radiograph confirmed appropriate graft containment in all 136 procedures.

Risk factors of sinus membrane perforation were observed in more than half of the 136 procedures (Table 3), with 68% ($n = 92/136$) of thin sinus membrane (Figs 6b and 6c), 49% ($n = 67/136$) of oblique sinus floor (Fig 6a), 28% ($n = 38/136$) of Underwood's septa (Figs 6b and 6c), and 28% ($n = 38/136$) of a combination of Underwood's septa and thin sinus membrane (Figs 6b and 6c).

Sinus membrane perforation was observed in 2.9% ($n = 4/136$). One perforation occurred during the Valsalva test, potentially due to excessive pressure exerted by the patient. The three other perforations were observed in difficult-to-treat cases, with irregular and oblique shape of the sinus floor, and a thin sinus membrane (Fig 7). In the four perforation cases, bone grafting and simultaneous implant placement were successfully performed 3 months later.

No other perioperative complication was observed.

Postsurgery Outcomes

No immediate postoperative complication, infection, bone graft loss, nor peri-implantitis was reported.

Table 1 Distribution of the 202 Implants and 6 Failed Implants

	Implant number, n (%)	Implant position ^a									
		17	16	15	14	13	23	24	25	26	27
All implants	202 (100%)	16	46	22	12	1	0	10	24	51	20
Failed implants	6 (3%)	0	4	0	0	0	0	0	0	1	1

194 and 8 implants were placed in the one-step procedure and two-step procedure, respectively.

All 6 failed implants occurred in the one-step procedure.

^aFDI tooth-numbering system.

Table 2 Surgical Outcomes with the Sinus Elevation

	One-step procedure	Two-step procedure
Sinus number (n)	130	6
Mean height of the residual alveolar process	4.5 ± 1.6 mm	1.2 ± 0.5 mm
Mean bone height after TSFE	13.0 ± 2.4 mm*	10.8 ± 2.3 mm*
Mean bone gain	8.5 ± 2.7 mm*	9.5 ± 2.4 mm*
Mean implant length	10.6 ± 0.9 mm	10 mm

*Two-tailed *P* value < .0001.

In the one-step procedure, six implants failed, even though primary stability was obtained after surgery (Table 1, Fig 3). Five implants failed within 2 months after surgery, and one failed 1 year after surgery, potentially due to excessive mechanical loading.

The overall 4-year survival rate was 97% (n = 196/202; Table 1).

All prosthetic restorations were either screw-retained fixed partial dentures or single crowns. Prosthetic complications were reported for a minority of the 202 implants, with 9% (n = 18) of ceramic chipping, 1% (n = 2) of fixed partial denture unscrewing, and 0.5% (n = 1) of crown unscrewing. No framework fracture was reported.

Patient-Reported Outcomes

During the surgical procedure and over a period of 2 weeks after surgery, 96% (n = 106/110) of patients reported either no discomfort or minimal inconvenience (visual analog scale [VAS] grade = 0 or 1). VAS grade 3 or 4 discomfort was reported by 3% (n = 3/110) of patients. VAS grade 7 discomfort was reported in only one patient (1% on patient level) for one implant (0.5% on implant level). Although almost all patients took 1-g doses of paracetamol, these doses were restricted to just after surgery, 4 hours later, and before bed on the day of the surgery.

No patient reported vertigo or disorientation after surgery. No patient reported jaw myalgia or pain around the temporomandibular joint.

Table 3 Frequency of Risk Factors for Sinus Membrane Perforation

Risk factor	% (n)
Thin sinus membrane	68% (92/136)
Oblique sinus floor	49% (67/136)
Underwood's septa	28% (38/136)
Combination of thin sinus membrane and Underwood's septum	28% (38/136)

mean follow-up period of 4 years. The procedure was different from other transcrestal procedures in that it used a specialized drill that creates hydraulic pressure in the osteotomy to induce unsticking of the sinus membrane from the sinus floor, and then nanocrystalline hydroxyapatite paste for further sinus membrane unsticking and elevation and as augmentation material. The procedure was effective. Surgical complications were infrequent: Sinus membrane perforation was observed in 2.9% (n = 4/136); the 4-year implant survival rate was 97% (n = 196/202), with only six early implant losses. Ninety-six percent of patients reported either no discomfort or minimal inconvenience.

In the one-step and two-step procedures, the mean sinus membrane elevation was 8.5 ± 2.7 mm and 9.5 ± 2.4 mm, respectively, where the mean residual bone heights were 4.5 ± 1.6 mm and 1.2 ± 0.5 mm, respectively. These elevations were similar to another study²⁰ in which nanocrystalline hydroxyapatite paste was used during a transcrestal procedure: the mean elevation was 11.2 ± 2.7 mm in 32 sinus elevations, where the mean residual bone height was 4.7 ± 1.8 mm.

The present sinus elevation procedure was relatively fast, potentially aided by its simplicity, as it avoided the

DISCUSSION

This retrospective study evaluated a surgical procedure for transcrestal sinus elevation in 110 patients with a

use of multiple drills and/or instruments. The mean duration of osteotomy, sinus floor elevation, and bone grafting was less than 3 minutes. By contrast, assessing duration of surgery with or without sinus floor elevation, Thoma et al^{31,32} reported a mean surgical time of 53 minutes in the group of short implants without sinus floor elevation compared to 75 minutes in the group with longer implants and a lateral window sinus floor elevation technique, suggesting that 22 minutes were used for osteotomy, sinus membrane elevation, and bone grafting.^{31,32}

A sinus membrane perforation may compromise the bone graft³³⁻³⁹ and implant survival.^{33,35,40} Although risk factors for sinus membrane perforation were present in the majority of sinus floor elevations (68%, $n = 92/136$), this complication occurred in only 2.9% ($n = 4/136$). Moreover, no sinus membrane perforation was observed in the six patients who were allocated to the two-step procedure, where the height of the residual alveolar process was particularly low (mean: 1.2 ± 0.5 mm). The perforation rate was similar to that observed in transalveolar procedures, with a mean perforation rate of 3.8% reported in the systematic review of Tan et al,⁴¹ ranging from 0% to 21.4% (61/1,621 implants; 8 studies). The perforation rate was lower than that observed with lateral procedures using a drill/rotary instrument,⁴² where a mean perforation rate of 24% is reported, ranging from 4.8% to 44.4% ($n = 661/2,741$; 26 studies). This suggests that sinus membrane perforations with the lateral procedure could perhaps be reduced by using the same type of drill as used in the present study. The use of piezotome⁴² also induces a mean lower perforation rate of 8.1%, ranging from 3.6% to 30.8% ($n = 44/542$; 10 studies).

All transalveolar procedures have the same major disadvantage: The surgeon has reduced visibility. The surgeon's experience is a key factor for successful treatment. Transalveolar techniques are operator-sensitive and therefore require a learning curve to achieve their maximum potential and avoid complications. They should be achieved by experienced surgeons with adequate training, careful preoperative 3D planning of the intervention, and the right selection of each case.

The reduced surgeon visibility makes sinus membrane perforation detection more difficult than that with lateral window procedures.⁴³ An endoscopic study showed⁴³ that membrane perforations were not detected by the operator during the crestal procedure but that experienced clinicians were able to more predictably recognize the presence of the sinus membrane perforations. Training is a key factor for the transcrestal approach. The Valsalva test was used in addition to direct intraoral visualization to get further information. This resulted in one patient having a sinus membrane perforation, due to excessive pressure being exerted,

and illustrated the need for presurgical training of the patient and appropriate supervision during the test. Bad patient compliance or collaboration could be considered as a relative contraindication for the crestal approach. The Valsalva test has also been shown to give false negative results.⁴⁴ The safest way to diagnose sinus membrane perforation is to use an endoscope.⁴³⁻⁴⁵ This gives a "bird's eye view" of the sinus membrane. The routine use of an endoscope placed either transnasally through the ostium or transorally through a small puncture in the canine fossa is questionable for a routine transcrestal procedure. An endoscope was not used in the present study.

The choice of the nanocrystalline hydroxyapatite paste for the bone graft rather than hydroxyapatite granules may have contributed to the low rate of sinus membrane perforation. In an endoscopic study on fresh human cadavers⁴³ in which hydroxyapatite granules were used for bone grafting, the majority of sinus membrane perforations occurred during bone grafting (12%) and implant placement (24%), and not during the osteotomy and membrane elevation (4%). The large size and the irregular and sharp geometry of the bone graft particles can induce uncontrolled late membrane perforations occurring during biomaterial grafting or implant insertion, although the membrane was not damaged during the osteotomy.⁴³ The incidence of membrane perforation varies from 10% to 33%, depending on the height⁴⁴ of the elevation. The critical height of membrane elevation with hydroxyapatite granules seems to be approximately 5.0 mm.⁴³⁻⁴⁸ Perforations increased when the level of the maxillary sinus membrane elevation was > 6 mm. Membrane elevation > 10 mm with the crestal approach appeared to be beyond the resistance capacity of the sinus membrane. All those studies⁴³⁻⁴⁸ used granules as grafting material. The choice of nanocrystalline hydroxyapatite paste probably contributed to obtaining a membrane elevation up to 9.5 mm in the two-step procedure without sinus membrane perforation. The same choice of nanocrystalline hydroxyapatite paste was made by Pommer et al²⁰ and probably contributed to the mean membrane elevation of 11.2 ± 2.7 mm (32 sinus elevations).

Only 3% ($n = 6/202$) of implants failed over a mean follow-up of 4 years, giving an implant survival rate of 97%. All six implant failures occurred within 1 year and were not associated with infection of the maxillary sinus, supporting the rationale of not including systemic antibiotic prophylaxis in the sinus elevation procedure. The survival rate was similar to that obtained in the systematic review by Tan et al⁴¹: The 3-year implant survival rate in transalveolar procedures was 92.8%, ranging from 87.4% to 96% ($n = 4,285/4,388$). In a more recent systematic review of the transalveolar osteotome procedure, Corbella et al⁴⁹ reported 3-year implant survival

rates ranging from 95.4% to 100% in eight studies including 1,208 implants, and were similar to those with the lateral procedures evaluated in the same review. Similar to the present study, the majority of implant failures with the transalveolar osteotome procedure occurred within the first year after surgery and were not associated with an infection.⁴⁹ Moreover, the rate of postoperative graft infection with the trancrestal approach is generally low and has been estimated at 0.8%.⁴¹ Antibiotic prophylaxis in healthy patients does not appear to improve clinical outcomes.⁵⁰ One can argue that sinus floor elevation is more than a “simple implant placement” and that bacterial contamination could occur more easily. The present study illustrates that the procedure can be successful without systemic antibiotic prophylaxis.

Nearly all (106/110) patients reported either no discomfort or minimal inconvenience. Only one patient reported severe discomfort (7/10 on visual analog scale) during surgery and in the 1-week period after surgery for one implant site. Short-time surgery and minimum surgical trauma without lifting of large flaps and osteotome hammering probably explain perioperative and postoperative comfort, and a low level of postoperative pain. By contrast, the systematic review by Pjetursson et al⁵¹ reported that more than 23% of patients experienced unpleasant feeling, vertigo, head hyperextension, nausea, and disorientation during the osteotome procedure. Thoma et al^{31,32} also reported a negative impact of the additional sinus floor elevation procedure on quality of life.

Although the use of this procedure would require training, its adoption should be relatively straightforward in cases where the residual crest height is 3 to 5 mm, the sinus floor has a horizontal orientation, and the sinus membrane is relatively thick (1 to 2 mm).

CONCLUSIONS

Within the limits of this retrospective study, this trancrestal sinus floor elevation procedure that combines a hydraulic device and nanocrystalline hydroxyapatite paste appears to be safe and predictable. Further randomized controlled studies are needed to validate the presented promising results.

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