# Bone Regeneration Using a Hollow Hydroxyapatite Space-Maintaining Device for Maxillary Sinus Floor Augmentation – A Clinical Pilot Study

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## ABSTRACT

*Background:* The mere lifting of the maxillary sinus membrane by implants protruding into the sinus cavity allows the establishment of a void space for blood clot and new bone formation.

*Purpose:* To evaluate bone formation by using a spherical, hollow, and perforated hydroxyapatite space-maintaining device (HSMD) in a two-stage sinus lift procedure where residual alveolar bone height was ≤2 mm.

*Material and Methods:* Spherical, hollow, and perforated HSMDs with a diameter of 12 mm were manufactured for this pilot study. Three patients with a residual bone height of 1–2 mm, as verified clinically and radiographically, and in need of a sinus augmentation procedure prior to implant installation were selected for the study. The HSMD and bone formation was evaluated by cone beam computerized tomography (CBCT) 6 months after augmentation procedure. Implants were installed 6 to 9 months after augmentation. The implant sites were prepared by a trephine drill to obtain a specimen of HSMD and bone for histological evaluation. After implant installation, the condition of the sinus membrane adjacent to the HSMD was evaluated endoscopically. After an additional 8 weeks, fixed partial prostheses were fabricated.

*Results:* Bone formation verified by CBCT was found around and inside the device in all three patients after 6 months. Despite the fact that residual bone before augmentation was ≤2 mm, 12-mm-long implants with diameter of 4.8 mm could be inserted with preservation of an intact and healthy sinus membrane verified endoscopically. Bone formation inside HSMDs was noted histologically in two out of three HSMDs. Implants were stable and without any marginal bone loss after 1 year of prosthetic loading.

*Conclusion:* A spherical, hollow, and perforated HSMD used in sinus lift procedures can produce a void space for blood clot and new bone formation and subsequent implant installation.

KEY WORDS: bone formation, endosseous implants, hydroxyapatite, maxillary sinus, partially dentate maxillae, sinus augmentation

## INTRODUCTION

Prosthetic rehabilitation of the severely atrophic maxilla constitutes a therapeutic problem, since bone augmentation is often required to enable placement and to ensure stability of a sufficient number and length of implants. The inadequate bone volume is normally a

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result of ongoing maxillary sinus pneumatization and remodeling of the alveolar crest. Augmentation of the maxillary sinus floor with autogenous bone is a frequently used method. Bone grafts have been harvested from different sites of the skeleton giving a variable postoperative morbidity with bruising, swelling, pain, and functional problems at the donor site.[1–6] Less-invasive surgical methods have also been used for maxillary sinus augmentation in order to reduce morbidity.[7–10] In a recent study, bone grafts were harvested locally at the site of the maxillary sinus augmentation procedure to enable placement, successful healing, and loading of 1 to 3 implants even when the residual bone height was only 3 mm.[11] The implant survival rate after a follow-up of 12 to 60 months was 98.8% in this study.

To reduce morbidity further, allogenic, xenogenic, and alloplastic materials have been used as a substitute for autogenous bone even if there are still no clear-cut guidelines for when to use autogenous bone or bone substitutes in sinus lift procedures.[12]

On the other hand, a number of studies have described maxillary sinus floor augmentation by simply elevating the maxillary sinus membrane by using installed implants to support the elevated membrane without the use of adjunctive grafting materials.[13–21] In these studies, a bone window was prepared in the lateral sinus wall. The sinus membrane was dissected and elevated superiorly to create and maintain a compartment for blood clot formation. Implants were then inserted through the residual bone to protrude into the maxillary sinus in order to support the elevation of the sinus membrane. The surgical protocol concerning replacement of the bone window varied between these studies, but all showed that there is a great potential for healing and bone formation in the maxillary sinus without the use of additional bone grafts or bone substitutes. Bone formation even occurs when sinus floor elevation is performed using a transalveolar osteotome technique without placing any graft material in the maxillary sinus.[8,22–24]

A space-maintaining device used for lifting the sinus mucosa and made of polylactide was recently used by Cricchio and colleagues in an animal model. Sites with simultaneous implant placement showed bone formation along the implant surface, but sites with delayed implant placement showed minor or no bone formation. The authors concluded that the reason for lack of bone formation was displacement of the space-maintaining device when no implant was inserted to stabilize the device during healing.[25]

Being the main component of bone hydroxyapatite has an excellent biocompatibility and can make a physiochemical bond with newly formed bone. This has led to an increased clinical use of hydroxyapatite over the last 30 years.[26–30] Apatite of both natural and synthetic origin is currently used as a bone substitute.

In the present pilot study, the bone augmentation effect of placing a spherical perforated and hollow hydroxyapatite space-maintaining device (HSMD) on the maxillary sinus floor was evaluated in three patients.

## MATERIALS AND METHODS

### Patients

Three healthy patients (two female/one male, age 68 to 70 years) were included in this pilot study. They were nonsmokers with no systemic or local contraindications for oral surgery. The patients had inadequate bone volumes for installation of dental implants due to atrophy after loss of molars and premolars. The residual bone height was ≤2 mm at the intended position of implant placement, and thus often insufficient to attain primary stability for an implant without previous augmentation (Table 1). All patients gave their informed

**TABLE 1 Showing Residual Bone Height, Length of Healing of HSMD, Length and Width of Inserted Implants, Status of Sinus Mucosa at the Time of Implant Installation, and Type of Prosthetic Construction**

| Case | Residual Bone (mm) | HSMD Healing (month) | Implant Size Length *Ø (mm) | Status of Sinus Mucosa | Prosthetic Construction |
|---|---|---|---|---|---|
| 1 | 2 | 6 | 12 × 4.8 | Healthy | Bridge |
| 2 | 1 | 6 | 12 × 4.8 | Healthy | Single crown |
| 3 | 2 | 9 | 12 × 4.8 | Healthy | Single crown |

written consent and could withdraw from the study at any time according to the principles outlined in the Declaration of Helsinki on experimentation involving human subjects.

## Materials

Spherical, perforated, and hollow HSMDs with a diameter of 12 mm were manufactured from a hydroxyapatite powder (Plasma Biotal, Buxton, UK). For the fabrication of the ceramic devices, the raw powder was further processed with an addition of water and dispersant (polycyclic acid) to prepare a ceramic suspension by ball milling. Starch particles were added to the suspension which was stirred for 1 hour in order to obtain a homogeneous suspension before the suspension was poured into a mold with spherical cavities with a diameter of 12 mm. The mold was heated to a temperature around 70°C for 1 hour, which transformed the suspension from a fluid state to a solid state. The cast devices were then removed from the mold, dried, and presintered. Channels with a diameter of 5 mm were machined through the devices along three perpendicular directions. The ceramic devices were sintered to increase the strength of the material, washed in 70% alcohol, dried, and finally autoclaved. The ceramic space-maintaining devices then consisted of a hydroxyapatite part with a large internal volume for blood to coagulate. This internal volume formed by the machined channels corresponded to around 55 vol% of the former sphere. In addition to the internal volume created for blood coagulation, the material also contained a large volume fraction of porosity, which consisted of both submicron-sized pores as well as pores with a size of around 10 to 20 microns.

## Surgical Technique

Under local anesthesia (20-mg/mL lidocaine and 12.5-µg/mL epinephrine, Dentsplay, Skarpnäck, Sweden), a crestal incision was made along the posterior alveolar process. The alveolar crest and lateral aspect of the maxilla were subsequently exposed by raising a buccal mucoperiosteal flap, and a bone window was created on the lateral aspect of the maxillary sinus. In two patients, Piezo surgery equipment was used (Piezosurgery®, tip OT1, Mectron medical technology), and in one patient, a drill with a round burr. The sinus membrane was carefully elevated to avoid perforation. The height of the residual alveolar bone was measured to the nearest millimeter with a calliper (Iwanson instrument, Directa AB, Upplands Väsby, Sweden). The HSMD was inserted under the sinus membrane at the intended implant position and the bone window was replaced. In one patient, the bone window could not be replaced because of insufficient thickness. Wound closure was made with absorbable 4–0 sutures (Vicryl, Johnson & Johnson, Ethicon, Brussels, Belgium). Starting 1 day preoperatively, patients were given phenoxymethyl-penicillin (1 g × 3 for 7 days). Patients also rinsed with a 0.1% chlorhexidine solution for 1 minute twice a day for 14 days, starting 1 day prior to surgery. The HSMD remained in place for 6 to 9 months prior to implant installation. The same antibiotic regimen was used when implants were installed. Following the raising of a buccal mucoperiosteal flap, the integrity of the lateral aspect of the maxillary sinus wall was controlled and a bone window was then created in the lateral sinus wall to allow access to the sinus cavity for endoscopic examination of the sinus membrane. Pictures were taken of the sinus membrane adjacent to the HSMD by using a lateral telescope (Telescope 70°, diameter 2,7 mm, length 11 cm connected to a Telecam SLII with Xenon 300 light and an Aida control, Karl Storz GmbH & Co. KG, Tuttlingen Germany). The implant site was prepared with a trephine drill (inside Ø 3.6 mm, outside Ø 4.2 mm length 37.5 mm, Institut Straumann AG, Basel, Switzerland) in order to obtain a cylindrical core specimen for histological examination. After that, a 12-mm-long implant with a diameter of 4.8 mm was inserted (Implant RC, Bone Level, SLActive, Institut Straumann AG) (Table 1). Wound closure was made with absorbable no. 4–0 sutures (Vicryl, Johnson & Johnson, Ethicon). The patients rinsed with a 0.1% chlorhexidine solution for 1 minute twice a day for 14 days, starting 1 day before surgery.

## Prosthodontics

The implants were allowed to heal for 8 weeks before abutment surgery and prosthetic treatment were performed. None of the patients used temporary partial dentures during the healing of grafts and implants. Metal ceramic fixed crowns were fabricated in two patients and a fixed screw-retained metal ceramic partial denture in one patient.

**TABLE 2 Morphometric Measurements Expressed as a Percentage of Total Specimen Area**

| | Specimen 1 | Specimen 2 | Specimen 3 |
|---|---|---|---|
| Remaining HA | 39.5 | 36.5 | 32.2 |
| Bone tissue | 25.6 | 29.2 | 5.2 |
| New bone | 17.5 | 6.1 | 0 |
| Soft tissue | 34.9 | 34.3 | 62.8 |

## Radiologic Examinations

Before surgery, a preoperative panoramic X-ray (Scanora, Soredex, Helsinki, Finland) and/or CBCT scan (cone beam computerized tomography) (Picasso Trio, E-WOO Technology Co., Seoul, Korea) and intraoral radiographs were used to visualize the residual alveolar bone adjacent to the sinus cavity and to exclude pathology of the edentulous ridge, sinus area, and adjacent teeth. Six months after placement of the HSMD, the area was analyzed with CBCT scan in frontal and sagittal projections. At 1 year follow-up after prosthetic loading, the integrity of the HSMD, implant, and marginal bone level was assessed by panoramic and intraoral radiographs. All radiographs were analyzed by the same specialist in oral radiology.

## Histological Processing

The fixed core specimens were dehydrated in a graded series of ethanol and embedded in plastic resin (Technovit 7200 VCL, Kulzer, Wehrheim, Germany). One

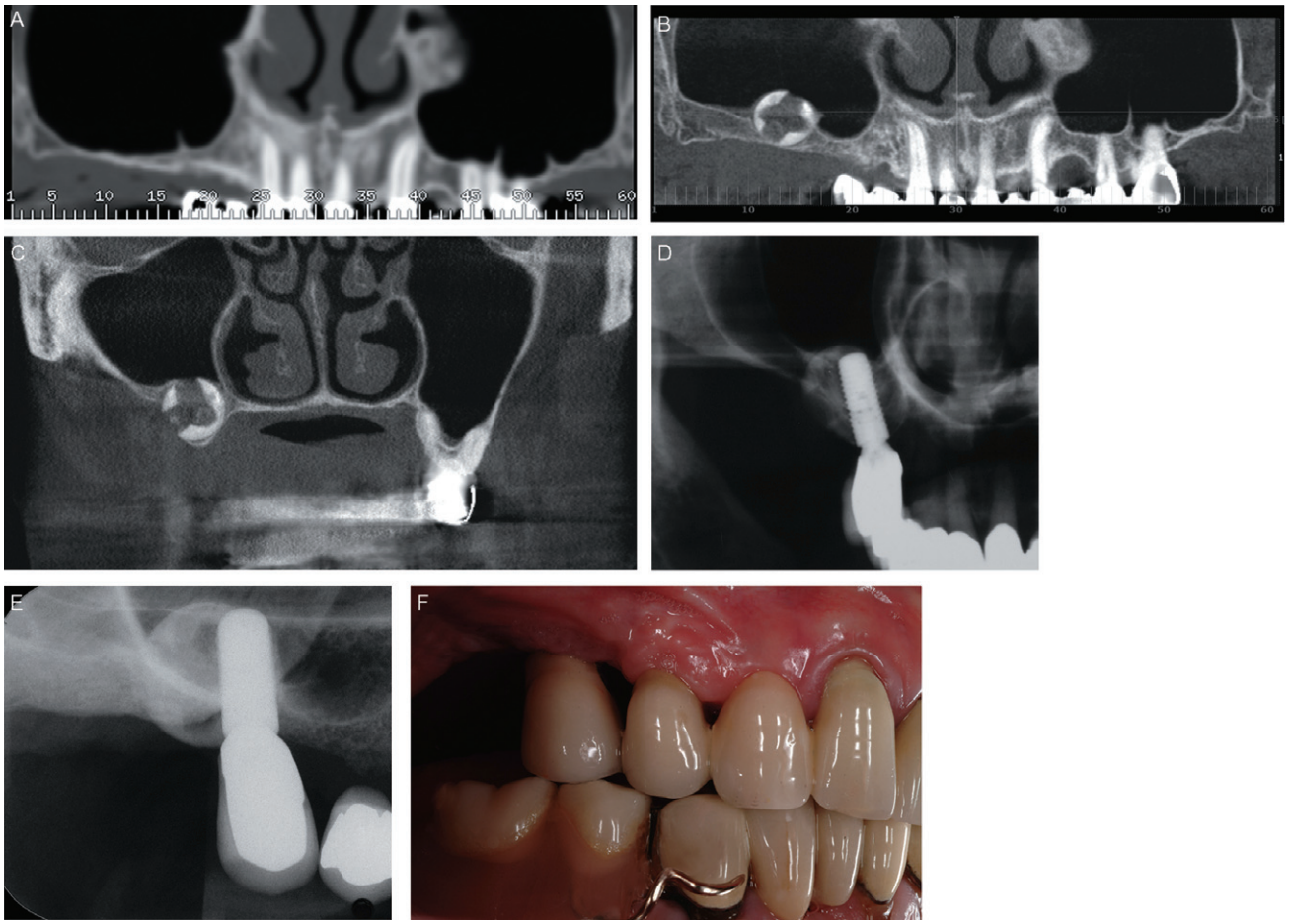


**Figure 1** *A*, (Case 2) CT showing initial residual bone height of 2 mm at the intended position of implant placement 145 × 49 mm (72 × 72 DPI). *B*, (Case 2) CBCT showing new bone formation around and inside hydroxyapatite space-maintaining device (HSMD) after 6 months (lateral view) 361 × 138 mm (72 × 72 DPI). *C*, (Case 2) CBCT showing new bone formation around and inside HSMD after 6 months (frontal view) 293 × 159 mm (72 × 72 DPI). *D*, (Case 2) Detail of panoramic radiograph after prosthetic treatment 226 × 195 mm (300 × 300 DPI). *E*, (Case 2) Intraoral radiograph after 12 months of prosthetic loading. The radiograph is overaxial to make reproduction of HSMD and implant possible. 212 × 157 mm (300 × 300 DPI). *F*, (Case 2) Clinical situation after 12 months of prosthetic loading 812 × 541 mm (72 × 72 DPI).

central section was taken longitudinally through the biopsy by means of Exact cutting and grinding equipment (Exact Apparatebau, Norderstedt, Germany). The sections were ground to a final thickness of about 10 µm and stained with 1% toluidine blue and 1% pyronin-G. Examination, photography, and morphometric measurements were made in a Leitz Orthoplan microscope equipped with a Microvid morphometric system (Leitz, Wetzlar, Germany) connected to a personal computer. The morphometric analysis comprised measurements of remaining hydroxyapatite, bone tissue, new bone, and soft tissue as expressed as a percentage of the total specimen area (Table 2).

## RESULTS

### Radiologic Evaluation

All three patients had a preoperative residual bone height at the intended implant position of 1 to 2 mm (Table 1, Figure 1). After 6 months of healing, the integration of the HSMD was verified by CBCT. New bone formation was also found anterior, posterior, and inferior to the HSMD after 6 months (Figure 2). After 1 year of prosthetic loading, there was no marginal bone loss or any signs of infection around implants.

### Clinical Observations

No patient had any postoperative complications from the HSMD placement procedure or the implant surgery. During implant installation, the integrity of the buccal mucosa and the lateral sinus wall was assessed. All patients had an intact buccal mucosa without any signs of fistula formation or inflammation. In one patient, the HSMD was partially exposed in the buccal sinus wall but was completely filled with and surrounded by bone without any signs of inflammation (Figure 3). This

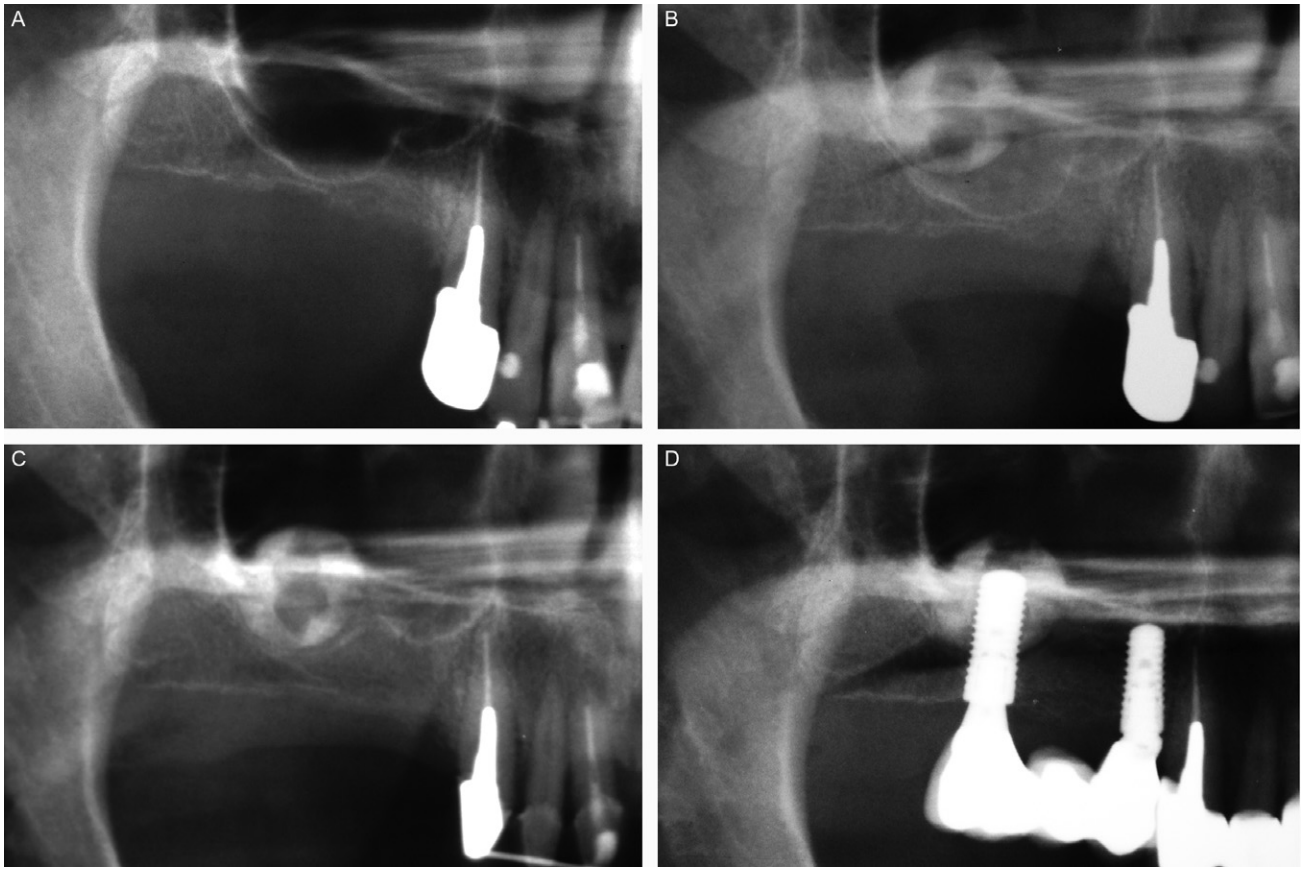


**Figure 2** *A*, (Case 1) Detail of panoramic radiograph showing residual bone before hydroxyapatite space-maintaining device (HSMD) installation 254 × 169 mm (300 × 300 DPI). *B*, (Case 1) Radiograph after HSMD installation 254 × 169 mm (300 × 300 DPI). *C*, (Case 1) 6 months healing showing new bone formation anterior and inferior to the HSMD. Note that the position of the HSMD is the same as in Figure 2B. 254 × 169 mm (300 × 300 DPI). *D*, (Case 1) Radiograph after 12 months of prosthetic loading 254 × 169 mm (300 × 300 DPI).

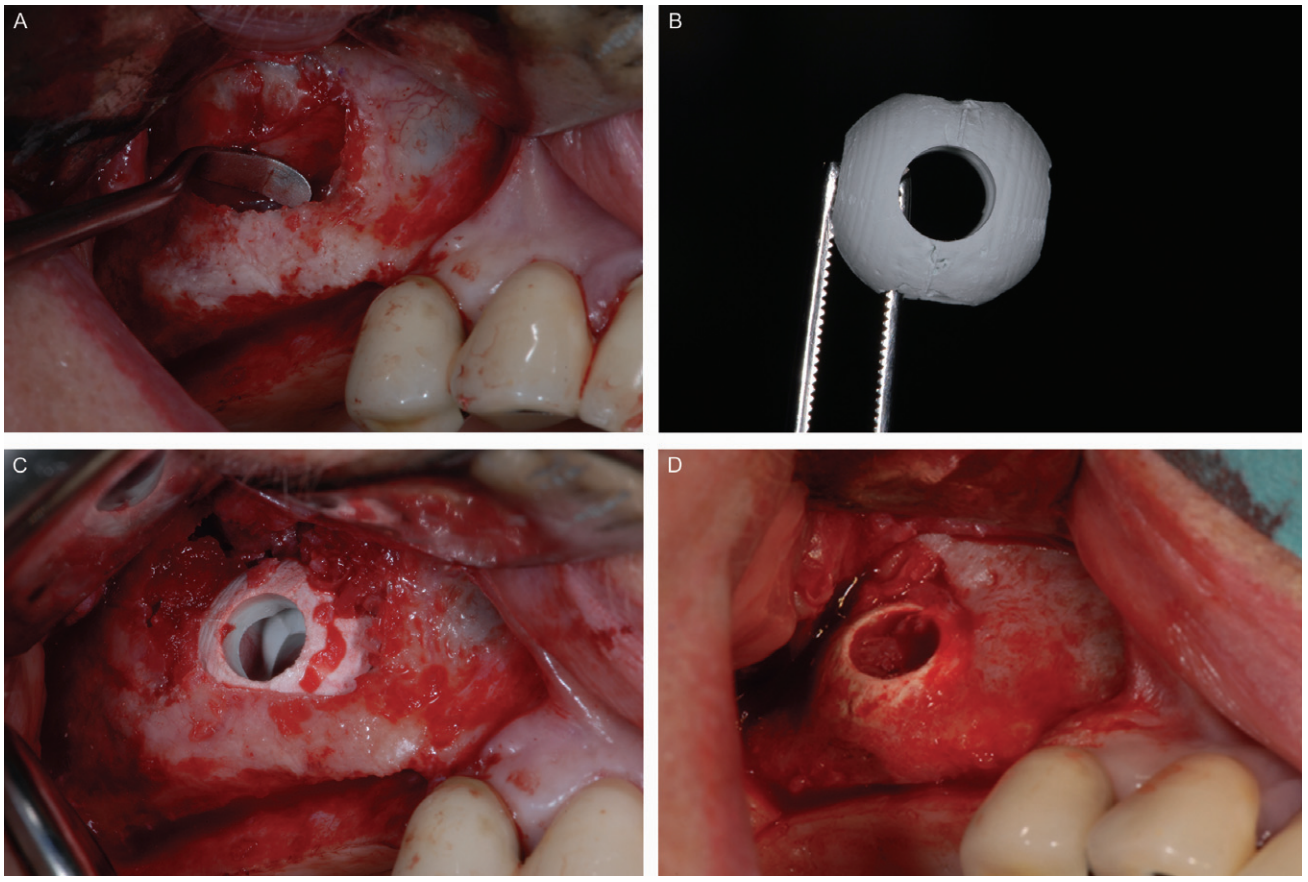


**Figure 3** *A*, (Case 2) Surgical technique to install the hydroxyapatite space-maintaining device (HSMD). The sinus mucosa with paper thin bone wall is carefully elevated and the HSMD is installed. 327 × 219 mm (300 × 300 DPI). *B*, (Case 2) The hollow and perforated HSMD 327 × 219 mm (300 × 300 DPI). *C*, (Case 2) HSMD is installed under the intact sinus mucosa which is visible beyond the device 327 × 219 mm (300 × 300 DPI). *D*, (Case 2) 6 months of healing showing integrated HSMD filled with new bone. 169 × 113 mm (72 × 72 DPI).

finding was due to the fact that this particular HSMD was not completely covered due to an insufficient thickness of the bone window. After 1 year of prosthetic loading, all three implants were stable. Two implants supported single crowns and one implant was included in a three-unit screw-retained bridge (Table 1). This bridge was removed to assess the integration of the implant at the 1-year review.

## Histological Outcomes

All specimens contained parts of the device, bone, and soft tissue to various degrees (Table 2). The HSMD showed a hollow appearance often with stainable biological material inside (Figure 4A). The integrity of the device seemed intact, although displaced hydroxyapatite (HA) particles could occasionally be found in the soft tissue. There were no signs of any adverse reactions toward the device. The soft tissue consisted of a loose connective tissue rich in vessels, sinusoids, and various types of cells, some identified as macrophages and lymphocytes. Bone had been formed beneath and inside the devices and was often in direct contact. In higher magnification of the contact areas, it was obvious that bone had also formed in the pores of the HA (Figure 4B).

## Endoscopic Evaluation

All three patients showed healthy sinuses without any purulent or nonpurulent exudate. The sinus membrane adjacent to the HSMDs had the appearance of normal noninflamed mucosa. The augmented area protruded distinctly into the sinus cavity and similarly was covered completely with sinus mucosa showing no signs of inflammation (Figure 5).

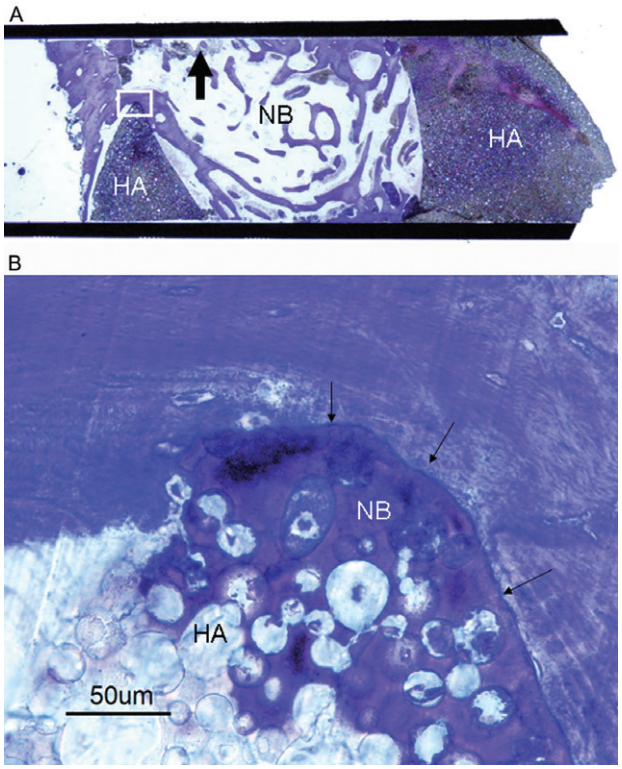


**Figure 4** *A*, (Case 2) Light micrograph showing overview of remnants of the device (HA) and new bone (NB). Arrow points to areas of displaced HA particles from trephining the specimen. Left = orally 200 × 103 mm (72 × 72 DPI). *B*, Close up of rectangle (Figure 4A) showing direct contact between new bone and the device (arrows) as well as bone formation (NB) inside the pores of the device (HA) 200 × 160 mm (72 × 72 DPI).

## DISCUSSION

The healing process of a nongrafted bone defect is dependant on the presence of a blood clot in order to ensure invasion of angiogenic and osteogenic cells into the area. The fibrin network of the clot serves as a scaffold for migrating osteogenic precursor cells which, when they reach the wound area, differentiate into osteoblasts. Invading microvessels also play an important role in providing various agents such as bone-inducing substances to the wound area. Even the Schneiderian membrane has been reported to have a genuine osteogenic potential and most likely contributes in part to bone formation when using various maxillary sinus floor augmentation techniques.[31,32] However, the exact mechanisms behind bone formation in the maxillary sinus are not fully understood. The principle of guided bone regeneration originally described by Dahlin and colleagues have been suggested as a possible factor in the healing process when graft-free sinus lift procedures have been tested using implants protruding into the sinus cavity to support the sinus membrane.[14,33–36] In our study, the hollow HSMD supported the elevated Schneiderian membrane, and blood from the wound area filled the hollow perforated device which facilitated stabilization of a clot. Due to the tenting effect of the device, a blood clot formation can also appear anterior, posterior, medial, and inferior to the device depending on the anatomy of the sinus cavity. By avoiding scaffolding fillers made from biological and/or synthetic materials, with or without additional particulated autogenous bone, we can probably expect shorter healing time for optimal bone formation.[30]

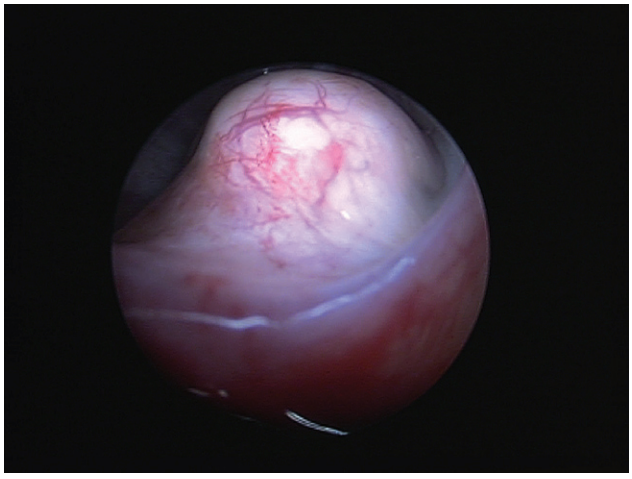

**Figure 5** (Case 2) Endoscopic picture of healthy sinus mucosa adjacent to the hydroxyapatite space-maintaining device at the time of implant installation 270 × 203 mm (72 × 72 DPI).

When scaffolding fillers are used, the volume of the used filler is determined by the maxillary sinus pneumatization, the anatomy, and the number and length of implants planned for insertion. In this respect, grafts are usually oversized compared to what is normally needed when implant integration and functional loading is established even if several studies have reported partial resorption of grafts after sinus augmentation procedures.[37,38] Provided that marginal bone loss can be avoided, equilibrium is probably established between the effects of continuous sinus pneumatization, resorption of the graft, and stimulation of the bone that supports the implant. Functional loading of an implant generates greater loading on the marginal bone than around the apical part of the implant.[39–42]

By using a spherical, hollow, and perforated HSMD, the principles of guided bone regeneration were used in a two-stage sinus lift procedure when residual

bone height was insufficient for implant installation. The regenerated bone volume could be limited to the intended implant position and no additional grafting material was needed. Other shapes of the device were initially discussed, but the spherical device appeared to be clinically easy to handle and needed no further stabilization after installation. The hollow perforated device is easily filled with blood from the wound area and the osteoinductive properties of the surrounding bone and sinus membrane can stimulate new bone formation inside and around the perforated spherical device. The characteristics of the hydroxyapatite material with respect to resorption can be modified to obtain a desirable resorption rate of the device. The tested device showed only a minor tendency to resorb 6 to 9 months after installation.

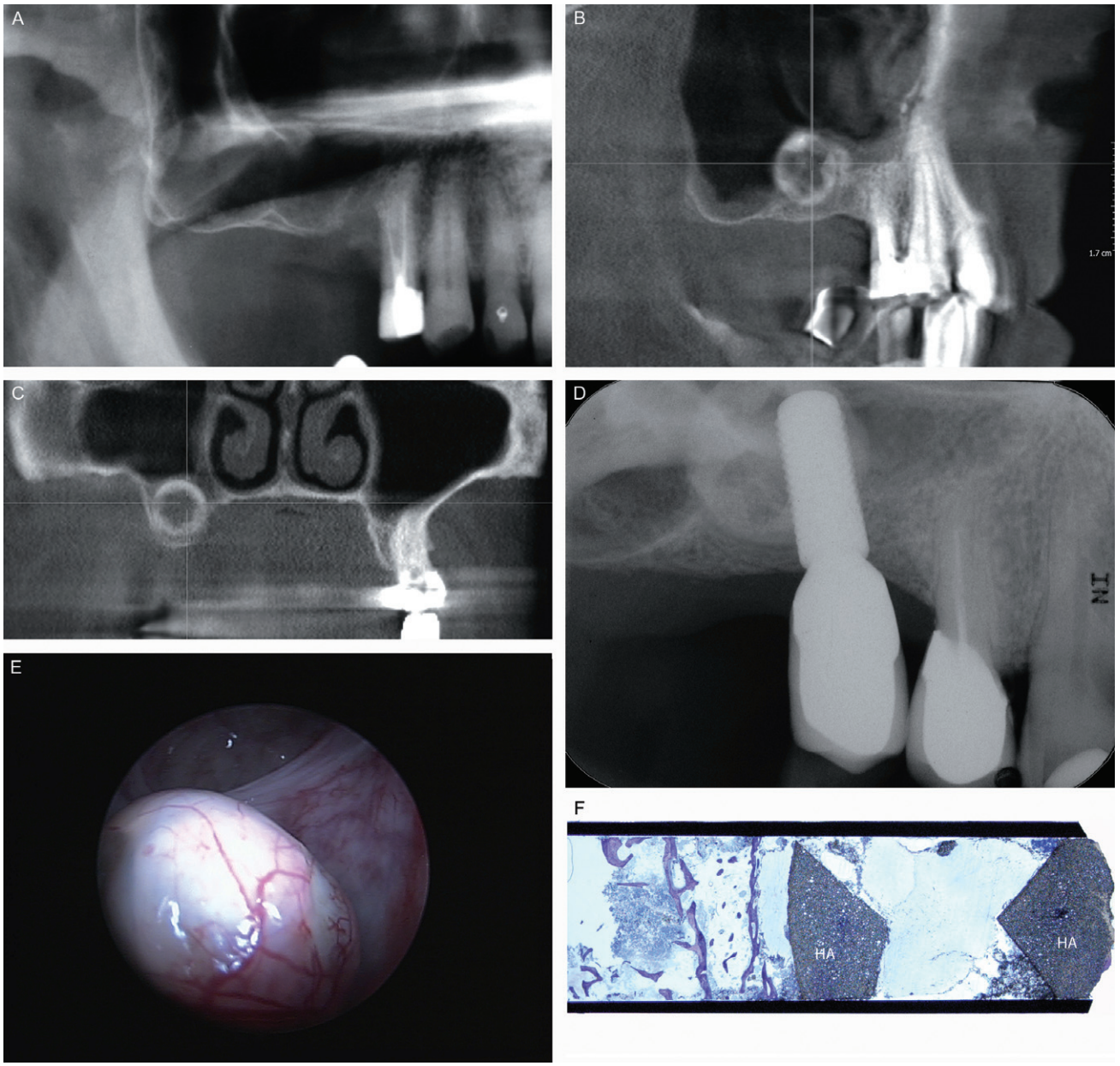


**Figure 6** *A*, (Case 3) Detail of panoramic radiograph showing residual bone before hydroxyapatite space-maintaining device (HSMD) installation 242 × 161 mm (72 × 72 DPI). *B*, (Case 3) CBCT showing new bone formation around HSMD after 6 months (lateral view) 436 × 263 mm (72 × 72 DPI). *C*, (Case 3) CBCT showing HSMD after 6 months (frontal view) 420 × 198 mm (72 × 72 DPI). *D*, (Case 3) Intraoral radiograph after 12 months of prosthetic loading. The radiograph is overaxial to make reproduction of HSMD and implant possible. 221 × 164 mm (300 × 300 DPI). *E*, (Case 3) Endoscopic picture of healthy sinus mucosa adjacent to the HSMD at the time of implant installation 271 × 203 mm (72 × 72 DPI). *F*, (Case 3) Light micrograph showing overview of remnants of the device (HA). No bone formation could be detected between the HA remnants. Left = orally 216 × 173 mm (150 × 150 DPI).

No bone formation could be detected in the specimen from case 3 (Figure 6F). One explanation could be that only a single section was taken from each biopsy for morphometric measurements. Even in this patient, implant and prosthetic treatment were completed and assessed as successful at the 1-year follow-up (Figure 6).

## CONCLUSION

Spherical, hollow, and perforated HSMDs used in sinus lift procedures can successfully create a void space for blood clot and new bone formation and allow subsequent implant installation.

## ACKNOWLEDGMENTS

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