Minimally Invasive Sinus Augmentation Using Ultrasonic Piezoelectric Vibration and Hydraulic Pressure: A Multicenter Retrospective Study

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Purpose: The purpose of this study was to evaluate the success rate of implants and vertical bone gain of edentulous posterior maxilla using ultrasonic piezoelectric vibration and hydraulic pressure, namely the hydrodynamic piezoelectric internal sinus elevation (HPISE) technique through a crestal approach.

Materials and Methods: A total of 250 maxillary sinuses were augmented using HPISE and 353 implants (averaging 11.8 mm in length and 4.5 mm in diameter), with 12 different systems, were placed simultaneously with or without additional bone grafting. Plain radiograms and cone beam computed tomograms were taken in all patients to evaluate sinus augmentation.

Results: Membrane perforation was recorded at 10 of the 353 implant sites. The perforation rate was 2.83%. The total success rate of implantation was 97.2% after an average of 69.3 weeks of loading.

Conclusion: The crestally approached sinus augmentation using ultrasonic piezoelectric vibration and hydraulic pressure is an additional method of maxillary sinus augmentation. (Implant Dent 2012;0:1–7)

Key Words: crestal approach, hydraulic pressure, hydrodynamic piezoelectric internal sinus elevation

In the edentulous posterior maxilla, the presence of the maxillary sinus often limits the available bone height for implant placement. To overcome vertical deficiency of atrophic posterior maxilla, sinus floor elevation using a crestal approach and the lateral window technique have been used.1,2 Even though the lateral window technique has been considered to be a predictable method for sinus augmentation, this technique can cause more postoperative discomfort, such as postoperative swelling and pain, and a longer edentulous healing period than does the crestal approach. The crestal approach is considered to be a less invasive procedure than the lateral approach.3,4 Thus, to overcome the disadvantages of sinus augmentation using the lateral window approach, variable crestal approaches, such as osteotome-mediated sinus floor elevation (OMSFE),1 piezoelectric internal sinus elevation (PISE),5,6 hydraulic sinus condensing (HSC),7 internal sinus manipulation,8 and hydrodynamic piezoelectric internal sinus elevation (HPISE)9,10 and the crestal window technique (CWT),11 have been introduced. Most of these techniques, except HPISE, rely on bone compaction to elevate the sinus membrane, so that the crestal approaches that depend on bone compaction have some limitations, such as possible sinus membrane perforation from bone packing. In addition, vertical augmentation limited by inaccessibility and postoperative vertigo, from the mallet striking the sinus floor, has been reported.12,13 Unlike other crestal-approached sinus augmentation methods, HPISE does not require the osteotome to break the sinus floor and usually does not depend on bone compaction to elevate the sinus membrane. HPISE breaks the sinus floor with ultrasonic vibration and elevates the sinus membrane using hydraulic pressure, without bone compaction. The aim of this study was to evaluate the predictability of the HPISE through clinical success rates and radiographic analysis.

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MATERIALS AND METHODS

Patient Selection

This study consists of 250 sinus elevations (198 unilateral and 26 bilateral sinuses) performed on 224 partially or completely edentulous patients who fulfilled the inclusion criteria. The patients included 114 men and 110 women, with an average age of 52 ± 12 years, varying from 22 to 90 years (Table 1).

The surgery was performed at the Department of Oral and Maxillofacial Surgery, Catholic University Medical Center of Daegu, and at 2 private practices, from January 2008 to May 2010. All patients were informed about the treatment procedure and gave oral and written consent. Before the sinus graft procedure was performed, patients’ medical histories were carefully evaluated and patients with diseases known to affect bone metabolism were excluded. Smokers were not excluded from the study but were informed that smoking could compromise the quality of the sinus elevation and reduce the success rate of implantation. Patients were advised to stop smoking 4 weeks before surgery. Plain radiographs and cone beam computed tomograms (CBCT; Combi; Pointnix, Seoul, Korea) were taken to evaluate preoperative sinus conditions and residual bone heights and, later, to assess postoperative bone gain (Fig. 1).

Surgical and Prosthetic Procedure

The surgical procedure was performed according to the authors’ article published in 2008 and 2010.9,10 Patients were given prophylactic oral antibiotics, Amoxicillin, potassium clavulanate (Augmentin; Ilsung Pharmaceutical Co., Seoul, Korea), 625 mg 3 times a day, beginning the day before surgery and continuing for 7 days. Flomoxef sodium (Flumarin; Ildong Pharmaceutical Co., Korea, 500 mg iv) was injected 1 hour before surgery. All surgical procedures were performed under local anesthesia using 2% lidocaine with 1:100,000 epinephrine. The full thickness of the muco-periosteal flap was elevated to expose the alveolar crest of the implant placement site. Flapless surgery was also performed when the width of the alveolar ridge was adequate, as confirmed by CBCT. As a first step, a 1.6-mm-wide round carbide insert with external irrigation (S016; BukBu Dental Co., Daegu, Korea), connected to the ultrasonic piezoelectric device (Surgerybone; Silfradent srl, Sofia, Italy), was used to break the sinus floor directly from the alveolar crest. The vibrating round insert provided a tactile sensation of the cortex of the sinus floor and the sinus membrane when the sinus floor was broken up directly (Fig. 2). The round insert has depth-indicating lines marked at 2 mm intervals. Thus, it measures the exact residual bone height at each implant placement site. Hydraulic pressure to the sinus membrane from internally irrigated sterile saline was applied until the sinus floor was penetrated with the HPISE tip. Subsequently, the insert was pushed a few millimeters over the sinus floor and then hydraulic pressure was applied again for 10 to 20 seconds to confirm the elevation of the sinus membrane at each implant placement site. Membrane perforation was

Table 1. Baseline characteristics and treated implant sites of patient population

<table>
<thead>
<tr>
<th>No. of Patients</th>
<th>Gender (Male / Female)</th>
<th>Mean Age (y)</th>
<th>No. of Sinuses (Unilateral/Bilateral)</th>
<th>No. of Implants</th>
<th>Mean Residual Bone Height (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>224</td>
<td>114/110</td>
<td>52</td>
<td>250 (198/26)</td>
<td>353</td>
<td>6.14</td>
</tr>
</tbody>
</table>

Fig. 1. Preoperative CBCT. A, Preoperative panoramic view shows low bone height at both edentulous posterior maxilla. B, The cross-sectional view of the site of the right second molar showing approximately 2 mm of bone height. C, The cross-sectional view of the site of the right first molar showing approximately 4 mm of bone height. D, The cross-sectional view of the site of the right second premolar showing approximately 6 mm of bone height. E, The cross-sectional view of the site of the left second premolar showing approximately 6 mm of bone height.
confirmed by the Valsalva maneuver or direct visualization of the sinus membrane. The back flow of saline from the sinus cavity during the application of hydraulic pressure also confirmed the integrity of sinus membrane (Fig. 4). After this procedure, surgeons could observe the up and down movement of the sinus membrane whenever patients took a breath. This was the final osteotomy procedure for accommodating 3.7- to 4.0-mm-wide tapered implants. When wide implants (more than 4 mm) were placed, an intermittent drilling procedure was required to accommodate the implant. When the required sinus elevation was minimal (less than 5 mm), 2 to 6 pieces of autologous fibrin-rich block with concentrated growth factors (CGFs) made by special centrifuge (Medifuge; Silfradent srl) was inserted in the new compartment under the elevated sinus membrane as an alternative to bone grafting in 188 sinuses (Fig. 5). Fibrin-rich blocks with CGF were prepared according to Sacco’s protocol, using the patient’s own venous blood to accelerate new bone formation in the sinus.14

Bone graft material was used when vertical augmentation greater than 6 mm was required. Bone grafting was used in 62 sinuses. The authors’ preferred bone graft materials were gel-conditioned allograft (Orthoblast II; Isotis Orthobiologics, Inc., Irvine, CA) or the mixture of gel-conditioned allograft with Ca-P noncoated anorganic bovine bone (Bio-Cera; Oscotec Co., Chunan, Korea) or mineral allograft (Puros, Zimmer Dental, Carlsbad, CA). The mixture of bone graft, with an amalgam carrier, was delivered into the new compartment under the elevated sinus membrane through the osteotomy site. Gentle bone compaction was attained by using ultrasonic vibration, controlling pressure to sinus membrane to reduce the possibility of membrane perforation. The implant was placed simultaneously in all cases. A total of 353 implants, with 4 different surfaces (99 resorbable blast media–surfaced implants, 129 hydroxyapatite-coated implants, 119 sandblasted large grit acid-etched surface implants, and 6 sintered porous-surfaced implants) were placed.
The incision was closed with interrupted sutures. Patients were instructed not to blow their noses and to cough or sneeze with an open mouth for 2 weeks after surgery. The sutures were removed 10 days postoperatively. After sinus augmentation, plain panoramic radiographs and CBCTs were taken immediately after surgery and, to assess new bone formation around the implants, on the uncovering day. Implants were uncovered after an average 30.55 weeks of healing (Figs. 6 and 7). A porcelain fused to metal crown was cemented after 4 to 8 weeks’ use of a provisional prosthesis and followed up to an average 69.3 weeks of loading (Fig. 8).

Clinical Evaluations

The survival criteria presented by Buser et al\textsuperscript{15} and Cochran et al\textsuperscript{16} were followed at implant uncovering and at the follow-up after an average 30.55 weeks of healing.

1. Absence of clinically detectable implant mobility.
2. Absence of pain or any subjective sensation.
3. Absence of recurrent peri-implant infection.
4. Absence of continuous radiolucency around the implant.

Radiographic Evaluation and Analysis

CBCTs were taken preoperatively, immediately postoperatively, and at implant uncovering, in all cases. One examiner evaluated all radiographic information. Mean residual bone height at the implant placement was 6.14 ± 2.36 mm, varying 0.5 to 11 mm. The vertical bone gain from the original sinus floor to the newly formed sinus floor was measured, along the implant axis, on CBCTs.

RESULTS

Membrane perforation was recorded at 10 of 353 implant sites. The perforation rate was 2.83%. When membrane perforation occurred, patients complained of water flow in their noses because of running saline into nasal cavity. All perforations were made due to round piezoelectric insert’s physical intrusion into the sinus cavity at the stage of perforation of sinus floor. Six perforations were covered with resorbable gelatin sponge (Cutanplast; Mascia Brunelli Spa, Milano, Italy) and then fibrin-rich blocks were inserted before implant placement. Laterally approached sinus elevation was performed to seal another 4 perforation sites. The site of perforation was hardly visible when the membrane was elevated because the size of perforation was very small and invisible when the membrane was folded. Autologous fibrin-rich blocks alone were grafted into all the perforated sinuses. After sinus elevation using HPISE, no patients had significant postoperative complications during the healing period. The success rate of implantation, according to the
criteria of Buser et al.\textsuperscript{15} and Cochran et al.\textsuperscript{16} was 97.2\% after an average of 69.3 weeks of postloading. A total of 11 implants failed. Seven implants failed after the uncovering, and 4 implants failed after the prosthetic loading period. Eight of the 258 implants placed in 188 sinuses using fibrin-rich blocks alone and 3 of the 95 implants in 62 sinuses using bone grafting failed. The failure rates were 3.1\% and 3.16\%, respectively.

After an average of 30.55-week healing period, plain panoramic radiograms and CBCTs showed newly formed bone along the implants in all cases. Total vertical bone gain was 5.49 ± 2.51 mm, varying 0.5 to 10 mm (Table 2).

**DISCUSSION**

OMSFE is the first crestal approach for sinus augmentation. However, OMSFE has limitations, such as limited vertical augmentation due to visual inaccessibility and possible postoperative vertigo from hammering the sinus floor.\textsuperscript{12,13} Breaking the sinus floor using OMSFE in the steep anterior wall of the sinus cavity and septum area may be difficult because of dense bone. The PISE and HSC techniques are innovative crestal methods for which a surgical mallet is not required to break the sinus floor directly.\textsuperscript{6,7} These techniques are free from possible postoperative vertigo, but bone compaction is required to elevate the sinus membrane because hydraulic pressure from external irrigation is not enough in most cases. The CWT may overcome the blind nature of conventional crestal approaches,\textsuperscript{11} but its application is limited because this technique is indicated only when wide diameter implants (5 mm or more) are required.

The HPISE technique uses ultrasonic piezoelectric microvibration to break the sinus floor directly, just as PISE does, but hydraulic pressure from internal irrigation is used to elevate the sinus membrane. Thus, this technique does not rely on bone compaction to elevate the sinus membrane. However, bone graft material was used when vertical augmentation greater than 6 mm was required. Unlike a rotary cutting device, the ultrasonic piezoelectric device provides highly controlled osteotomy because of the selective bone cut effect, inducing minimal trauma to soft and hard tissues.\textsuperscript{17,18} Ultrasonic piezoelectric microvibrations only cut hard tissue, such as the sinus floor. This allows a very low rate of sinus membrane perforation when applying the crestal approach and the lateral window technique compared with conventional techniques using a surgical mallet or osteotomes.\textsuperscript{6,17,19} In addition, ultrasonic vibration provides a tactile sensation when the sinus cortex is penetrated. The size of perforation of the sinus membrane from water pressure or piezoelectric round carbide tip was very small. So, when laterally approached sinus elevation was used to seal the perforated site in 4 cases, the perforated sites usually were difficult to identify.

Sinus augmentation from HPISE is different than the localized dome-shaped membrane elevation from OMSFE. Hydraulic pressure from internal irrigation allowed gentle and even elevation of the sinus membrane. In most cases, even elevation of the sinus membrane from the medial and lateral walls of the sinus cavity, above the implant apices, was revealed by CBCT scans. This finding corresponds to the results from the lateral window technique. Bone compaction is not a prerequisite for sinus elevation in the HPISE technique, unlike conventional crestal approaches, because the sinus membrane is elevated before implant placement. Average vertical bone gain was 5.5 mm after an average 30.55-week healing period.

Several studies demonstrated new bone formation in the new compartment under the elevated sinus membrane without bone grafting in animal and human.\textsuperscript{20–24} In addition, bone reformation in the maxillary sinus, using patient’s venous blood alone, gelatin sponge alone, and fibrin-rich block alone

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**Table 2. Summary of clinical and radiographic findings**

<table>
<thead>
<tr>
<th>Patients Findings</th>
<th>Mean Healing Time (wk)</th>
<th>Mean Vertical Bone Gain (mm)</th>
<th>Mean Loading Period (wk)</th>
<th>Perforation Rate (%)</th>
<th>Success Rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30.55</td>
<td>5.49</td>
<td>69.3</td>
<td>2.83</td>
<td>97.2</td>
</tr>
</tbody>
</table>

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**Fig. 8.** Clinical and radiographic views show stable sinus augmentation 7 months after loading.
as alternative bone graft, has been reported in clinical studies. Platelet aggregates have been widely used to accelerate new bone formation associated with guided bone regeneration and sinus grafting for many years. Fibrin-rich gel/blocks are known to slowly release CGFs, such as transforming growth factor-β1, platelet-derived growth factor, and vascular endothelial growth factor, and accelerate new bone formation when mixed with or without bone grafting in the maxillary sinus. In addition, fibrin-rich blocks with CGFs, as a sole material, induced rapid new bone formation in the new compartment under the elevated sinus membrane. In this study, 2 to 6 pieces of fibrin-rich blocks with CGFs alone were inserted in 188 sinuses after membrane elevation. All cases showed new bone formation along the implant, even when the implant failed. Rapid new bone formation, in all of the sinuses, was apparent in CBCT. The key for new bone formation may be the creation of space in the new compartment under the elevated sinus membrane rather than the type of bone grafting for sinus augmentation using crestally and laterally approached sinus procedures.

According to systemic review of Del Fabbro et al on implant survival rates using the crestal approach, the average implant success rate was 91.49%. Emmerich et al analyzed 44 articles about sinus floor elevation using osteotomes and reported 95.7% and 96.0% success rates after 24 and 36 months, respectively. Laterally approached sinus augmentation showed 61.7% to 100% implant success rates. It was similar to the 97.2% implant success rate from the authors’ study using the HPISE technique.

### DISCUSSION

Professor Dong-Seok Sohn is an inventor of the HPISE technique. The other authors claim to have no financial interest in any company or any of the products mentioned in this article.

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### REFERENCES


