The effectiveness of the osteotome technique for sinus augmentation was evaluated using cone-beam computed tomography (CBCT) analysis. Clinical results of two-stage sinus floor elevation using the osteotome technique performed on 15 patients at the Nakajima Dental Clinic between 2006 and 2013 were evaluated retrospectively. CBCT imaging revealed that the maxillary sinus floor was elevated by an average of 7.28 mm (SD 1.62) immediately following surgery, with a mean bone height of 9.55 mm (SD 1.43). In all cases, the osteotome technique provided sufficient bone height for implant placement. No pre- or postoperative complications (eg, mucosal perforation) were reported. The minimal surgical stress and morbidity further underscore the practicality of this approach for two-stage maxillary sinus floor augmentation.


Conventional implant placement is often difficult when residual bone height. Support for the implant may be inadequate, and there is a risk of perforating the maxillary sinus membrane. In such cases, sinus floor elevation is required to increase the bone height and permit successful implant placement. Transcrestal sinus floor elevation is recommended when residual bone height is > 5mm and the sinus floor is flat, whereas lateral window technique is indicated when the residual bone height is < 5 mm.\textsuperscript{1}

Maxillary sinus floor elevation using a lateral window technique is a well-established and effective surgical procedure with a favorable prognosis.\textsuperscript{2–6} However, it is more invasive than simple implant placement and is associated with a greater incidence of peri- and postoperative complications, such as sinus membrane perforation and sinus infections.\textsuperscript{3,5,6}

A less intrusive method of bone augmentation was recently introduced whereby the sinus floor is accessed through the alveolar ridge crest and osteotomes are employed to assist in performing the sinus floor elevation.\textsuperscript{7–9} Often referred to as the osteotome technique, this technique is more limited than the lateral window technique in terms of the extent of achievable elevation but has gained acceptance.
because of its less invasive nature, low morbidity, and high implant survival rate.10–14

Over the years, sinus augmentation procedures have been modified to minimize patient discomfort and morbidity while maximizing bone gain.15–18 Yet many of these procedures are only indicated when there is adequate residual bone height to support simultaneous implant placement; extensive bone augmentation is required when existing bone height is insufficient.9 The osteotome technique has rarely been applied in cases of inadequate bone height. Fortunately, recent advances have made it possible to employ this approach to elevate the maxillary sinus floor to a level that permits future implant placement.19–21

A major drawback to the osteotome technique is the lack of visibility for the practitioner performing the surgery. Cone beam computed tomography (CBCT) offers a way to view the future implant site pre- and postoperatively and provides valuable bone volume and morphology data.

The present retrospective study was undertaken to determine the amount of postoperative maxillary sinus floor elevation that can be achieved using the osteotome approach; assess the incidence of complications, such as membrane perforation; and evaluate the degree of bone remodeling occurring during the 6-month healing period prior to implant placement.

Materials and methods

Subjects

The clinical results of edentulous patients who underwent two-stage sinus floor elevation using the osteotome technique at the Nakajima Dental Clinic between October 2006 and May 2013 were retrospectively analyzed. Only patients who met the enrollment criteria, as described below, were included in the study.

Inclusion criteria

Patients who received maxillary sinus floor elevation satisfied the following selection criteria: partial or complete edentulism, aged 18 years or older, and in good health or with any preexisting medical conditions (eg, high blood pressure, diabetes, asthma) under control. All patients provided written consent prior to receiving any surgical treatment.

Exclusion criteria

Patients with any of the following conditions were excluded from the study: immunological, blood, or metabolic bone disease; uncontrolled diabetes; poor oral hygiene; oral health disease, including untreated periodontitis; mental health disorders; radiotherapy of the head or neck; drug or alcohol addiction; or history of maxillary sinus inflammation.

Bone substitute material

The bone substitute material used consisted of beta-tricalcium phosphate (β-TCP) (Cerasorb 500–1,000 μm, Riemser Arzneimittel) or hydroxyapatite (HA) (Neobone 500–1,000 μm, CoorsTek), blended with 30% to 50% autogenous bone, which was collected from either the palatine torus or retromolar region.

Two-stage osteotome sinus floor elevation technique

For any given patient, the same dental practitioner performed the maxillary sinus floor elevation and subsequent implant insertion and final restoration. Patients were followed regularly, with checkup interval durations ranging from 3 to 12 months as determined by their level of oral health. Professional tooth cleaning and, if necessary, periodontal treatment were provided according to the clinic’s maintenance program.

Surgical procedure

Two hours before the sinus floor elevation surgery, patients received 500 mg of the antibiotic azithromycin (Zithromac, Pfizer Japan). A local anesthetic, 2% lidocaine (Xylocaine, DENTSPLY-Sankin) with 1:80,000 epi- nephrine, was administered immediately prior to the surgery.

A modified version of the Summers’ method9 for maxillary sinus floor elevation through the alveolar crest was performed (Fig 1).
First, a 1.8-mm round bur was used to mark the future implant site in the alveolar crest. Initial cuts into the ridge were made with thicker-diameter round burs (2.3 and 3.1 mm). The osteotomy was continued with either a 2.8-mm pilot drill or a 3.5-mm twist drill. To reduce the risk of damaging the maxillary sinus mucosa, a 2.8- or 3.2-mm S-reamer was employed to complete the drilling to the sinus floor (sinus crestal approach kits, Forest-one).

A stopper was installed in the osteotome such that a depth of 1 to 2 mm was maintained within the maxillary sinus. Bone substitute material was packed into the prepared hole, and the maxillary sinus floor was elevated by gently tapping with a 2.8- or 3.5-mm angled osteotome (Straumann). The Valsalva maneuver (nose-blowing test) was performed to check for perforation of the maxillary sinus mucosa. Further substitute material was then inserted into the maxillary sinus and spread laterally and vertically using a depth gauge. A total of 0.5 to 1.1 mL of bone substitute was used for each future implant site.

The Valsalva maneuver was repeated following grafting material compaction, and the wound was closed using 4-0 sutures. Patients were administered azithromycin (500 mg daily) for 2 days. Patients were administered azithromycin (500 mg daily) for 2 days. Either Straumann solid screw implants with SLA surface or Camlog screw implants were inserted with a torque of 5 to 20 Ncm.

**Morphological evaluation using CBCT**

To assess bone height and morphology, CBCT was performed before and after the sinus floor elevation as well as prior to implant placement. The images were obtained with the 3DX multi-image micro-CT (Morita) set at 40 × H40 mm, 80 μm voxel size. The center was set in the center of the residual bone at the site of the future implant. This location was recorded; all subsequent images and measurements were taken from the same position and under the same conditions. Radiation exposure was minimal, at 0.03 mSv, due to the short filming range.

Measurements of residual bone height, increase in bone height, and total bone height were determined by CBCT (Fig 2). Residual bone height, measured from the center of the future implant site, was defined as the height from the alveolar crest to the maxillary sinus floor. Increase in bone height was measured from the sinus floor to the border of the new bone. Total bone height was...
defined as the distance from the alveolar crest to the bone augmentation margin. Each measurement was made three times by the same researcher, who was blinded to the type of grafting material, and the average value was used.

**Implant success criteria**

Radiologic and clinical findings, along with the following success criteria proposed by Buser et al., were used to assess implant success:

- Absence of persistent subjective complaints, such as pain, foreign-body sensation, and dysesthesia
- Absence of peri-implant infection
- Absence of mobility
- Absence of continuous radiolucency around the implant

**Statistical analysis**

Statistical analysis of the data was performed using SPSS Statistics 22.0 software (IBM). Kaplan-Meier analysis was used to determine the implant survival and success rates. The correlation between achieved elevation and the buccal-palatal dimensions of the sinus were analyzed using Pearson product-moment correlation coefficient.

**Results**

A total of 15 partially endentulous patients (4 men and 11 women; aged 52 to 72 years, mean age of 60.4 years, SD 6.3) who underwent two-stage sinus floor elevation using the osteotome technique between October 2006 and May 2013 met the inclusion criteria and were enrolled in this study (Table 1). The residual bone height of these patients, measured from the alveolar crest to the maxillary sinus floor, exceeded 1 mm but was less than 5 mm, as determined by CBCT analysis.

Autologous bone grafts were primarily harvested from the mandibular ramus (retromolar area). However, where the palatal tori was well developed, as was the case for patients 3 and 10, the autografts were obtained from this bony protrusion. The bone fragments were ground into 1- to 2-mm fragments and combined with either β-TCP or HA to form a grafting material composite.

For cases 1 through 8 (excluding case 6, site 25) and for case 13, insufficient bone height (< 8 mm) was achieved following the initial sinus floor elevation. In these cases, a second osteotome-directed sinus lift was performed after the 6-month healing period with simultaneous implant placement. In the remaining cases, only implant insertion at was performed at 6 months, as the minimum required bone height had been achieved.

As shown in Table 1, the average residual bone height for future development sites in 15 patients was 2.27 mm (SD 0.85 mm), with a range from 1.00 to 3.44 mm. The average width of the area 5 mm above the maxillary sinus floor was 12.53 mm (SD 2.67 mm), ranging from 8.02 to 16.76 mm. The mean postoperative maxillary sinus floor elevation obtained was 7.28 mm (SD 1.62 mm; range 5.25–11.07 mm), while the average total bone height from the alveolar crest to the augmentation site margin was 9.55 mm (SD 1.43 mm; range 7.50–13.3 mm).

At the time of implant placement, the average total bone height was 7.92 mm (SD 1.64 mm), which represented a mean decrease of 1.62 mm (SD 0.89 mm) from heights achieved immediately following the sinus lift. Therefore, the average net amount of elevation achieved was 5.65 mm (SD 1.93 mm). A greater amount of bone augmentation was observed when HA, rather than β-TCP, was employed as the grafting material (Table 2). The average total bone height after the healing period was 8.88 mm (SD 1.48) in the HA group and only 6.91 mm (SD 1.13) in the β-TCP group.
Table 1  Summary of patient data following two-stage maxillary sinus floor elevation using the osteotome technique

<table>
<thead>
<tr>
<th>Patient ID (age [y], sex)</th>
<th>Site (FDI)</th>
<th>Residual bone height (mm)</th>
<th>Grafting material</th>
<th>Maxillary sinus width (mm)</th>
<th>Postoperative bone height (mm)</th>
<th>Bone height prior to implant placement (mm)</th>
<th>Bone height gain (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (58, F)</td>
<td>16</td>
<td>3.26</td>
<td>β-TCP</td>
<td>12</td>
<td>8.63</td>
<td>6.26</td>
<td>3.00</td>
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<td>2 (58, F)</td>
<td>17</td>
<td>3.10</td>
<td>β-TCP</td>
<td>12.72</td>
<td>9.01</td>
<td>5.26</td>
<td>2.16</td>
</tr>
<tr>
<td>3 (55, F)</td>
<td>15, 16</td>
<td>2.52</td>
<td>β-TCP</td>
<td>10.89</td>
<td>9.07</td>
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<td>4.98</td>
</tr>
<tr>
<td>4 (52, M)</td>
<td>16</td>
<td>2.13</td>
<td>β-TCP</td>
<td>13.76</td>
<td>7.50</td>
<td>5.88</td>
<td>3.75</td>
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<td>5 (72, F)</td>
<td>16, 17</td>
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<td>12.41</td>
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<td>6 (67, M)</td>
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<td>7 (61, F)</td>
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<tr>
<td>8 (62, F)</td>
<td>26, 27</td>
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<td>HA</td>
<td>14.15</td>
<td>8.51</td>
<td>7.52</td>
<td>6.08</td>
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<tr>
<td>9 (58, F)</td>
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<td>HA</td>
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<td>8.39</td>
<td>6.13</td>
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<td>10 (58, M)</td>
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<td>HA</td>
<td>12.23</td>
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<td>9.18</td>
<td>7.30</td>
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<tr>
<td>11 (54, F)</td>
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<td>9.87</td>
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<tr>
<td>12 (57, F)</td>
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<td>HA</td>
<td>10.05</td>
<td>9.42</td>
<td>8.88</td>
<td>6.25</td>
</tr>
<tr>
<td>13 (72, M)</td>
<td>16</td>
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<td>HA</td>
<td>15.13</td>
<td>9.57</td>
<td>7.86</td>
<td>6.86</td>
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<tr>
<td>14 (55, F)</td>
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<td>6.86</td>
</tr>
<tr>
<td>15 (67, F)</td>
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<td>1.81</td>
<td>HA</td>
<td>12.27</td>
<td>10.45</td>
<td>10.11</td>
<td>8.30</td>
</tr>
<tr>
<td>Average</td>
<td>N/A</td>
<td>2.27</td>
<td>N/A</td>
<td>12.53</td>
<td>9.55</td>
<td>7.92</td>
<td>5.65</td>
</tr>
</tbody>
</table>

β-TCP = beta-tricalcium phosphate; HA = hydroxyapatite.

Table 2  Comparison of maxillary sinus floor elevation achieved with two different bone substitute materials

<table>
<thead>
<tr>
<th>Bone substitute material employed</th>
<th>Residual bone height (mm)</th>
<th>Gain in bone height during surgery (mm)</th>
<th>Postoperative bone height (mm)</th>
<th>Bone height at implant placement (mm)</th>
<th>Net bone height gain (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>β-TCP (n = 7)</td>
<td>2.72 (SD 0.89)</td>
<td>6.08 (SD 0.68)</td>
<td>8.81 (SD 0.86)</td>
<td>6.91 (SD 1.13)</td>
<td>5.65 (SD 1.57)</td>
</tr>
<tr>
<td>HA (n = 8)</td>
<td>1.82 (SD 0.54)</td>
<td>8.32 (SD 1.33)</td>
<td>10.06 (SD 1.47)</td>
<td>8.88 (SD 1.48)</td>
<td>7.06 (SD 1.32)</td>
</tr>
<tr>
<td>Combined values (n = 15)</td>
<td>2.27 (SD 0.85)</td>
<td>7.28 (SD 1.62)</td>
<td>9.55 (SD 1.43)</td>
<td>7.92 (SD 1.64)</td>
<td>5.65 (SD 1.93)</td>
</tr>
</tbody>
</table>

β-TCP = beta-tricalcium phosphate; HA = hydroxyapatite.

CT scans were taken immediately following bone augmentation as well as prior to implant placement following the 6-month healing period (Fig 3). In the latter images, it was difficult to discriminate between pristine and augmented bone due to the blurring of their borders caused by bone remodeling during the healing period. Moreover, the elevated regions had become less pronounced and a new maxillary sinus floor line was observed (Figs 4 and 5).

No perforation of the maxillary sinus mucosa was seen in any of the patients, as determined by the Valsalva maneuver and the absence of nose bleeding during and after the surgery. This assessment was corroborated by CBCT imaging,
Fig 3 Pre- and postoperative CT scans of sinus floor elevation sites in 15 patients. CT scans were performed (a) prior to implant placement (sagittal view) and (b and c) immediately following bone augmentation in patients.

Fig 4 Changes in lateral CT scans obtained (a) prior to, (b) immediately following, and (c) 6 months after sinus floor elevation of an area missing two teeth (Patient 6), where β-TCP bone substitute was used as the grafting material.

Fig 5 Changes in lateral CT scans obtained (a) prior to, (b) immediately following, and (c) 6 months after sinus floor elevation of an area missing two teeth, where HA was used as the bone graft material (Patient 9).

which showed an absence of perforation-induced graft leakage (Fig 6). Furthermore, no other peri- or postoperative complications were reported.

In total, 20 Straumann solid screw implants with SLA surface and 2 Camlog screw implants were inserted with a torque of 5 to 20 Ncm (Table 3). The Kaplan-Meier method indicated 7-year cumulative rates of 100% for both implant survival and success. No statistically significant correlation existed between maxillary sinus width and the amount of elevation achieved in the maxillary sinus, nor between maxillary sinus width and degree of decrement after 6 months.
Discussion

The present retrospective study evaluated a total of 22 implants placed in 15 patients between 2006 and 2013, following bone augmentation through a modified version of the osteotome technique. This procedure was remarkably well tolerated by patients, with no reported peri- or postoperative complications. Adequate sinus floor elevation was achieved to permit implant placement in all patients, and implant survival and success rates of 100% were observed.

The concept of future site development for implants has failed to gain widespread popularity since its introduction. Few studies have examined two-stage sinus floor elevation using the osteotome technique when the residual bone height is < 5 mm, as the outcome is considered less predictable. In this study, the average residual bone height was 2.27 mm (SD 0.85 mm). Implant site development using the osteotome technique resulted in an average total bone height of 7.92 mm (SD 1.64 mm), with an average of 5.65 mm (SD 1.93 mm) of new bone formation, which was sufficient for standard-sized implants. In some cases, additional sinus floor elevation was required at the time of implant insertion. It is worth mentioning that as the principal author gained further experience with this technique with subsequent patients, the average bone height has increased to 8.88 mm (SD 1.48 mm), making it possible to insert implants without further socket lift.

These findings are comparable with those reported by Kang, who employed a similar approach to augment bone at 20 posterior maxillary implant sites. The mean pre-operative bone height at these sites was 3.05 mm (SD 0.96 mm). After a healing period of 6 months, the author reported an average amount of new bone of 6.9 mm (SD 1.79 mm) and mean total bone height of 9.93 mm (SD 1.48 mm).

The main complication associated with sinus augmentation using osteotomes is perforation of the sinus membrane, which in turn can result in graft leakage into the maxillary sinus. Although incorporating endoscopic management may reduce the perforation risk, its use as part of routine sinus grafting is hindered by many factors, including higher costs, anatomical restrictions, increased surgical time and patient stress, and the need to secure the services of an endoscopist. A feasible alternative to check for perforation is to employ CBCT technology, which offers sharp axial and three-dimensional images that can be examined for the presence or absence of graft leakage.

The incidence of sinus membrane perforation using the transalveolar approach is generally low, as illustrated in one study where simultaneous sinus lift and implant insertion resulted in a 3.8% perforation rate. The lateral window technique, in contrast, is typically associated with higher perforation rates (eg, membrane perforation rates of 10% and 19.5% have been reported).

### Table 3 Implant types employed

<table>
<thead>
<tr>
<th>Implant type</th>
<th>N</th>
<th>Patient IDs</th>
</tr>
</thead>
<tbody>
<tr>
<td>ST Standard RN (4.1 × 8.0 mm)</td>
<td>4</td>
<td>1, 5-17, 8</td>
</tr>
<tr>
<td>ST Standard RN (4.1 × 10 mm)</td>
<td>6</td>
<td>3-15, 5-16, 6-25, 11, 15</td>
</tr>
<tr>
<td>ST Standard WN (4.8 × 8.0 mm)</td>
<td>5</td>
<td>2, 9-16, 12, 13, 14</td>
</tr>
<tr>
<td>ST Standard WN (4.8 × 10 mm)</td>
<td>5</td>
<td>3-16, 4, 6-26, 9-17, 10</td>
</tr>
<tr>
<td>Cam Screw (5.0 × 11 mm)</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>22</strong></td>
<td></td>
</tr>
</tbody>
</table>

ST = Straumann implant; RN = regular neck (4.8 mm); WN = wide neck (6.5 mm); Cam = Camlog implant.
Pommer et al\textsuperscript{26} conducted an interesting in vitro study examining the mechanical properties of the maxillary sinus mucosa. They observed that during transcrestal sinus floor elevation, enough stress concentrates in the maxillary sinus mucosa that a risk of mucosal membrane perforation exists if excessive pressure is applied. Taking into consideration that in the present study an average maxillary sinus floor elevation of 7.28 mm was achieved with no incidence of membrane perforation, the present authors conjecture that the small amount of graft material and biologic fluid, such as blood, combined and may have helped diffuse local pressure buildup.

The absence of membrane perforation in the present study was determined based on results of the Valsalva maneuver and the lack of peri- and postoperative nose bleeding. However, the reliability of the Valsalva maneuver has been questioned. In one study, this test produced a false negative in a patient who experienced membrane perforation while undergoing maxillary sinus elevation surgery.\textsuperscript{24} CBCT images were taken to confirm the absence of graft leakage.

CBCT imaging of the maxillary sinus also helps overcome a major drawback to the osteotome technique, that is, the lack of visibility when performing the sinus lift. It allows practitioners to appraise residual and acquired bone dimensions, as well as the bone remodeling process. Two to three CBCT scans are required for the sinus floor elevation procedure: pre- and postoperative images, and a scan taken immediately prior to implant placement.\textsuperscript{1}

Although this technology provides more information than radiographs, care must be taken when operating the CBCT scanner to avoid high-level radiation exposure.\textsuperscript{27} In the present study, a short CT imaging range of 40 × H40 mm was used to minimize patients’ exposure to radiation. The effective dose of 0.03 mSv was much lower than that associated with helical CT or head CBCT.\textsuperscript{28} Nevertheless, there is a need to continually improve CBCT equipment and protocols to further reduce radiation exposure.\textsuperscript{29}

Conclusions

The data presented in this retrospective study show that two-stage maxillary sinus elevation using the osteotome technique produces sufficient bone augmentation for successful implant placement. This approach was predictable, minimally invasive, well tolerated, and associated with high implant survival and success rates. These results warrant further research on the usefulness of the osteotome approach for future site development.

Acknowledgments

The authors express their deepest gratitude to Professor Arai Yoshinori, who provided invaluable CBCT support, and declare that they have no conflicts of interest related to this study.

References


