# Evaluation of Maxillary Sinus Membrane Response Following Elevation with the Crestal Osteotome Technique in Human Cadavers

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*Implant placement in the posterior maxilla often requires elevation of the sinus floor, which can be achieved through either the modified Caldwell-Luc or the crestal osteotome technique. The objectives of this study were to evaluate (a) the resistance to perforation of maxillary sinus membranes obtained from formaldehyde-fixed cadavers in vitro, (b) the frequency and extent of membrane perforations occurring after sinus floor elevation in cadavers using the crestal approach, and (c) the amount of membrane elevation (doming) that can be achieved using the crestal approach. Pretreatment of maxillary sinus membrane tissues with commonly used tissue softeners did not have a statistically significant effect on resistance to perforation. Maxillary sinus membranes were elevated 4 to 8 mm in formaldehyde-fixed cadavers using the osteotome technique; implants were placed. Of the 25 sites that received implants, only 6 showed perforations, as assessed by double-blind investigation after dissection of the lateral wall of the nose, allowing direct examination of the sinus cavity. Perforations were categorized as Class I (≤ 2 mm with exposure of the implant into the sinus cavity and loss of doming); Class II perforations (≥ 2 mm) were associated with proximity of the osteotomy site to the medial wall of the sinus or the presence of septae. These results indicated that the crestal osteotome approach compared favorably to the modified Caldwell-Luc technique as it relates to the frequency of maxillary sinus membrane perforations and the degree of achievable membrane elevation.* (Int J Oral Maxillofac Implants 2001;16:833–840)

**Key words:** *crestal osteotome technique, doming, maxillary sinus membrane perforation, tissue softeners.*



Reduced alveolar bone height involving edentulous maxillary posterior segments in proximity to the maxillary sinus presents an obstacle to successful osseointegrated implant outcomes. Insufficient bone height can be attributed to the inferior location of the sinus floor enveloping the roots of the maxillary posterior teeth (ie, normal anatomy), postextraction resorption,[1–5] and/or periodontal disease. In addition, sinus pneumatization and alveolar ridge resorption associated with removable prostheses can contribute to decreased vertical bone height. Sinus pneumatization can occur as a result of an increase in positive pressure in the sinus and/or increased osteoclastic activity of the maxillary sinus membrane and periosteum following tooth loss.[6–9]

Boyne accomplished the first subsinus augmentation by utilizing the Caldwell-Luc technique in conjunction with the placement of autogenous bone graft material for an edentulous patient.[1] This procedure was accomplished to provide adequate bone support for a complete maxillary denture and demonstrated bone formation inferior to the elevated sinus membrane. Many investigators followed Boyne's work utilizing the Caldwell-Luc technique.[8,10–12] The buccal approach subsinus augmentation is likely the most widely used technique to date when an increase in bone height in the maxillary posterior region is required for placement of endosseous implants.

An alternative approach utilized to elevate the sinus floor through a crestal osteotomy is being used with increased frequency. This technique was first described by Tatum in 1977, but was published several years later.[13] In 1994, Summers reported use of the osteotome technique for sinus membrane elevation as

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**Fig 1a** Dissection of both middle and inferior conchae exposing the sinus osteum (a). Dissection of the maxillary sinus membrane (b) just above the lower third of the maxillary sinus. Proximity to the middle wall of the sinus (c) in cases of advanced ridge resorption may compromise membrane elevation.

**Fig 1b** Maxillary sinus membrane dissection demonstrating the epithelial (a) as well as the periosteal aspect (b). Notice the moist sinus (c).

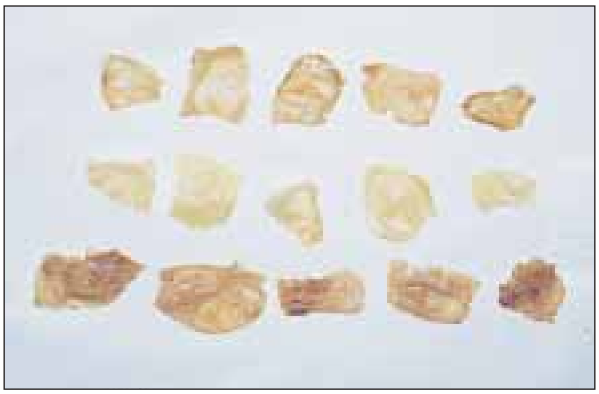

**Fig 1c** Maxillary sinus membrane specimens retrieved from three different cadavers. The lack of membrane thickness uniformity can be appreciated.

a less invasive approach compared to the buccal approach.[14–16] In contrast to Tatum's crestal approach, Summers' technique avoided direct maxillary sinus membrane contact by the osteotome. A combination of autogenous bone retrieved from a bone trap and human bone allograft material was used in this procedure. Localized hydraulic pressure is created, encouraging the membrane to elevate in the shape of a dome with a diameter significantly wider than that of the osteotomy. The bone graft material and subsequently placed implant support the dome. Initial fixation of the implant is derived solely from the residual alveolar ridge; therefore, Summers[14–16] suggested a minimum of 5 mm of preoperative bone height.

Currently, the 2 techniques (buccal and crestal approach) are universally utilized for the purpose of elevating the maxillary sinus membrane. The buccal approach allows direct vision of the elevated sinus membrane, whereas the osteotome approach is a blind procedure; therefore, some controversy exists as to the validity of the latter procedure. However, the osteotome approach is surgically less invasive with decreased probability of operative and/or postoperative complications. Although the crestal osteotomy approach has received wide clinical acceptance, data regarding efficacy and complications are sparse.

In this study, the extent and shape of vertical membrane elevation provided by the osteotome technique was examined. The potential correlation of the extent of elevation and location of the osteotomy site to the frequency and severity of membrane perforations in formalin-fixed cadavers was also evaluated. In addition, an assessment was made of the resistance of the maxillary sinus lining to perforation in vitro. This was accomplished to evaluate the feasibility of using formalin-fixed cadavers in studies where mechanical manipulation of the maxillary sinus membrane is required.

## MATERIALS AND METHODS

Twenty-two formalin-fixed human half heads were obtained from the Department of Anatomy at Tufts University Medical School. The heads had been sectioned in the sagittal plane. There were an equal number of male and female specimens.

### Evaluation of the Resistance to Perforation of the Maxillary Sinus Membrane in Vitro

Sinus membranes were isolated by the dissection of 8 cadavers and trimmed to 64 6×6 mm squares (Figs 1a to 1c). The specimens were glued to a flat surface of a metal device, which had an elevation of 9 mm and a hollow space measuring 4 mm in diameter. The membrane was secured in place with a flat hollow washer (Fig 2a). The 64 samples were divided into 3 groups and treated for 24 hours with one of the following solutions: *(a)* formalin preservative


**Fig 2a** Preparation of a maxillary sinus membrane specimen (a) attached to a metal device to allow alloplast (Biogran, 3i/Implant Innovations, Palm Beach Gardens, FL) placement, so that direct contact of the Instron's metal rod with the tissue is avoided. This condition stimulated a clinical sinus elevation utilizing the osteotome technique.

**Fig 2b** The membranes (a) were challenged by a 3 mm osteotome (3i) attached to the Instron (b) at a descending rate of 10 mm per minute. Maximum load (Ncm) at the time of perforation was recorded.

solution (formaldehyde 48%, phenol 14%, iso-plac 55.2%, propylene glycol mitrol 0.9%) diluted in water, *(b)* 5% glacial acetic acid, or *(c)* glycerol. Biogran (calcium phosphate 300–350 mg, 3i/Implant Innovations, Palm Beach Gardens, FL) was subsequently placed in the elevated side of the device up to 5 mm in height (Fig 2b). The complex was stabilized to an Instron machine table (Instron 4202, Canton, MA) and the midline of the machine was programmed to progress 10 mm per minute. A 3 mm diameter Summers 3i osteotome was connected to the handle of the Instron machine. As the rod progressed, no direct contact with the membrane was present. The maximum load at the time of perforation was recorded (Figs 2b and 2c). This experimental design was utilized as a simulation of the planned in vivo procedure.

### Measurement of the Extent of Membrane Elevation and Perforation Elevation in Cadavers

Sixteen human half heads were utilized: 2 for a pilot trial—both dentate—and 14 for the experimental procedure—4 dentate and 10 edentulous. Specimens were excluded if they *(a)* provided less than 4 mm of residual bone ridge height, *(b)* were very dry, or *(c)* were lacking adequate ridge length for the placement of 2 drill sites at least 7 mm apart. Two clinicians performed osteotome sinus lifts utilizing the Summers technique. A portable X-ray machine was utilized in the anatomy laboratory and occlusal radiographs were taken. Radiographic standardization was accomplished as follows: The X-ray film was positioned with an arrow parallel to the nasal floor so that the entire maxillary sinus could be visualized. The cadavers were placed in a tray so that the position of the teeth could be duplicated at a 90-degree angle to the film. A plastic grid was placed on each occlusal film. The distance between grid lines represented 1 mm.

**Fig 2c** Perforated membrane (a).

Orientation osteotomies were performed at a location anterior to the anterior border of the maxillary sinus. At least 2 drill sites were prepared 7 mm apart, approximately 1 mm inferior to the floor of the maxillary sinus. One drill site served as a control and the other site(s) were used to elevate the sinus membrane. The number of osteotome sinus elevation sites varied, depending upon the posterior ridge length of each specimen. Radiographs were taken with radiopaque indicators in place to determine the proximity of the drill site to the floor of the sinus (Fig 3a). The osteotomy sites were widened to 3 mm in diameter and Biogran alloplastic material (3i, 300 to 350 mg per site) was placed in the osteotomy using an amalgam carrier. Maxillary sinus membrane elevation was accomplished through careful condensation of the alloplastic material with 3 mm diameter osteotomies (3i). At least 2 amalgam carrier loads of Biogran were placed for every millimeter of membrane elevation desired. Elevation of the sinus floor ranged between 4 to 8 mm and osteotomy sites were randomly assigned to 1 of 2 groups (4 to 5 or 6 to 8 mm of elevation), regardless of the original alveolar bone height. Prior to implant placement, additional Biogran material was placed into the osteotomy, thus allowing the implant to push additional material ahead of it into the domed site. Twenty-five implants varying from 10 to 15 mm in length and 3.75 mm in diameter were subsequently placed in the osteotomy sites where maxillary sinus membrane elevation had been accomplished. Radiographs were taken of all specimens preoperatively, post drilling using radiopaque indicators (Figs 3a, 4a, and 5a) and postimplant placement (Figs 3b, 4b, and 5b). (Biogran, an alloplastic graft material, provides radiopacity.) Radiopaque indicators were placed into all of the control sites to mark the level of the sinus floor prior to implant placement (Fig 3a).

Once the implants were placed, 2 investigators who were not involved in the preceding procedures performed a careful dissection of the lateral wall of the nose, which correlates to the mesial wall of the sinus. The middle and inferior conchae were removed. Careful dissection of the maxillary sinus membrane from the bony walls was achieved utilizing a curved blunt curette. The incision of the membrane was carried out at the level of the middle concha so as to provide a safe distance from the elevated portion of the membrane.[5] Visualization of the elevated portions of the maxillary sinus membrane was obtained by placing an intraoral mirror and documentation was achieved by photography (Figs 3c, 4c, and 5c). The presence or absence of a perforation was determined and, when discovered, identified either as a Class I (≤ 2 mm lateral or slight apical perforation; space and dome shape of the elevated membrane maintained) or Class II (≥ 2 mm perforation, loss of space and dome shape; implant exposed to the sinus cavity; Fig 5c).

## RESULTS

Resistance of the maxillary sinus membrane to perforation in vitro, with and without tissue softeners, was evaluated (Table 1). Analysis of variance showed significant differences between the 3 groups; however, the groups responsible for the differences could not be determined. Therefore, Fisher's least significant difference method was used, which showed that the control (formaldehyde) group was not different from either the 5% glacial acetic acid or the glycerol group. However, there was significant difference between the groups treated with 5% glacial acetic acid and glycerol. This finding allowed continuation with the surgical protocol without having to pretreat the sinuses with tissue softeners.

It should be noted that a larger sampling of the 3 treated groups could have shown a significant difference. Location and length of implants placed, level of maxillary sinus membrane elevation achieved, and sites showing perforations are presented in detail in Table 2 and summarized in Table 3. Twenty-five implants were placed in the posterior maxilla of formalin-fixed cadavers utilizing the crestal osteotome maxillary sinus membrane elevation technique. Ten sites were elevated 4 to 5 mm and the remaining 15 sites 6 to 8 mm. A total of 6 membrane perforations were identified (24%); 3 grouped as Class I and 3 as Class II. The majority of the perforations (2 Class I and all 3 Class II) were present in the 6- to 8-mm elevation group. However, the Fisher exact test showed no statistically significant difference between the 2 groups ($P$ = .34 at 95% CI [0.07, 0.42]), probably because of the relative small sample size. It would be reasonable to expect that, clinically, only the 3 Class II perforations would have led to implant failure. Therefore, it is suggested that 22 of 25 sites where osteotome membrane elevations were performed would have the potential to provide clinical success in the placement of implants in vivo. Perforations of the maxillary sinus membrane in this study were associated with proximity to either antral septae or the collateral wall of the nose (Table 2).

## DISCUSSION

The buccal approach and crestal osteotome approach are widely used procedures. They are employed for elevation of the maxillary sinus membrane to enhance alveolar bone ridge height. The average gain of sinus elevation by the crestal approach has been reported in several publications to be 3.5 to 5 mm[15,17–19] as compared to 10 to 12 mm for the buccal approach.[19] The percentage of membrane perforations and their effect on the success of implant procedures has been poorly reported.

Recent studies reported high rates of success for the crestal sinus membrane elevation technique[20–22]; however, these were primarily case reports or limited retrospective studies. To date, no controlled prospective studies have been accomplished that indicate that the maxillary sinus membrane integrity

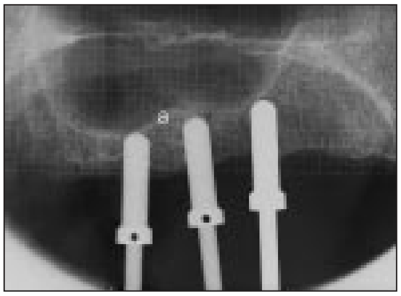


**Fig 3a** Three radiopaque indicators in place within 1 mm of the sinus floor (a).

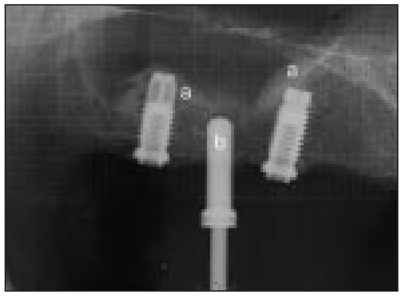


**Fig 3b** Implant placement following osteotome technique provided so as to elevate the maxillary sinus membrane. Notice the radiopaque material surrounding the implants (a) in comparison to the control site (b).


**Fig 3c** Dome shape elevation of the maxillary sinus membrane demonstrated by intrasinus photography achieved by careful dissection of the lateral wall of the nose and placement of an intraoral mirror at the middle third of the sinus. No perforation was present. Notice the moist sinus. Intact dome shape elevations (a) are clearly demonstrated.

**Figs 4a to 4c** Multiple implant placement with the osteotome technique.

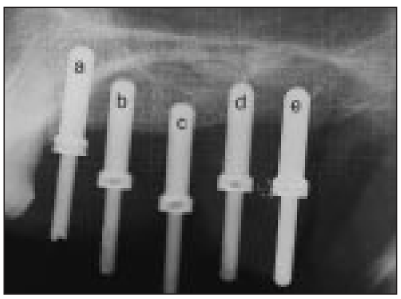


**Fig 4a** Radiographic presentation of orientation drill (a) control site (b) test sites c to e.

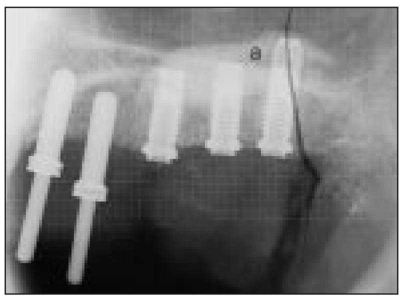


**Fig 4b** The same region following sinus elevation and implant placement. Notice that the radiopaque material around the implants is contained with no indication of perforation (a).

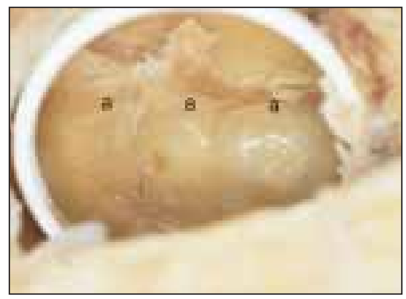


**Fig 4c** Continuous doming of the maxillary sinus membrane (a). This documentation demonstrates that contiguous doming can be successfully achieved by utilizing the crestal osteotome technique.

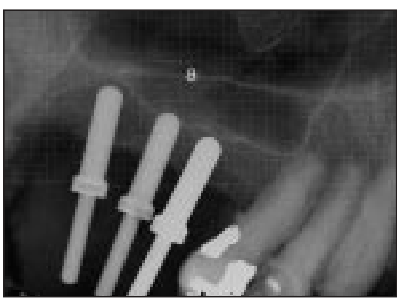


**Fig 5a** Three radiopaque indicators in place—the middle serving as a control. Notice the nasal floor (a).

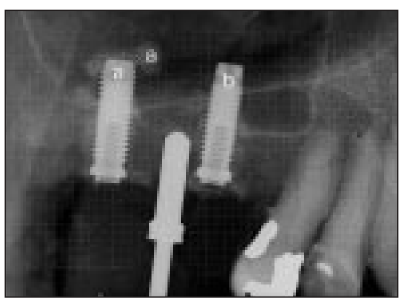


**Fig 5b** Implants in place. Notice the partial loss of containment of the radiopaque material around the distal implant (a) and the lack of radiopaque material around the mesial implant (b).

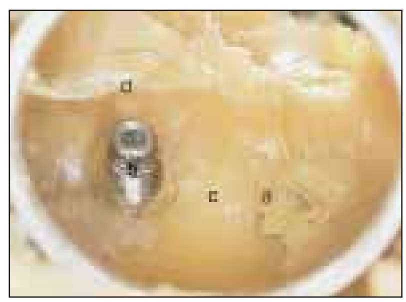


**Fig 5c** Demonstration of a Class I perforation (a) and a Class II perforation (b) adjacent to an incomplete septum (c) located at the floor of the sinus. Proximity to the collateral nasal wall (d) can also be noted. Class I perforation is shown around the distal implant (a). The dome shape elevation is still maintained by the implant. It is possible, in a clinical situation, for the remaining graft and blood clot to serve as a vital scaffold, allowing spontaneous healing of the membrane. The prognosis for such an implant in vivo is considered favorable. Class II perforation is shown around the mesial implant (b). Loss of the dome shape elevation and implant protrusion to the sinus space are noted. The prognosis for such an implant in vivo is considered guarded.

is maintained during the crestal approach procedure. Based on the Sinus Graft Consensus Conference Report in 1996,[23] a residual alveolar ridge height of 4 to 5 mm is necessary to accomplish initial implant stabilization. The primary aims of this study were to: *(1)* validate the doming effect, and *(2)* evaluate the frequency and extent of maxillary sinus membrane perforations resulting from sinus floor elevation using the crestal osteotome technique. Direct membrane visualization was possible after careful dissection of the lateral wall of the nose and perforations were evaluated by two investigators independent of the original surgeons.

Since formaldehyde fixation can decrease flexibility and consistency of cadaver tissues,[24–26] it was considered necessary to first evaluate the resistance to perforation of formalin-fixed maxillary sinus membranes in vitro, with and without tissue softeners. Isolated maxillary sinus membranes were treated with tissue softeners, such as 5% glacial acetic acid and glycerol for 24 hours, and their resistance to perforation was measured using the Instron machine (Table 1). No significant differences were found between the control and glycerol or between the control and 5% glacial acetic acid groups. Although the texture of membranes varied from specimen to specimen, all sinus specimens contained fluid, which caused a moist environment inside the sinus cavities. It is postulated that because of the moist environment and relative thin texture of maxillary sinus membranes, formaldehyde affects the mechanical and physical properties of the sinus soft tissue much less than other cadaver tissues or internal organs as previously reported.[24–26] This finding allowed the performance of surgical procedures in cadavers without the need of pretreatment with tissue softeners.

Twenty-five implants were placed in sites where maxillary sinus membrane elevation of 4–8 mm had been achieved with the osteotome technique (Table 2). Only 6 perforations were recorded, providing a nonperforation frequency of 76%, which compares favorably to the rates previously reported for the buccal approach (Tables 2 and 3). However, the significance of certain precautionary measures taken during the surgical procedure should be emphasized: *(1)* Drilling to within 1 mm of the maxillary sinus membrane allowed the clinician to utilize limited force in displacing the cortical bone with the osteotome so that the membrane could be elevated with the least likely possibility of perforation; *(2)* Graft material was progressively added to encourage membrane doming without perforation; *(3)* Partially filling the osteotomy immediately in advance of placing the implant allowed the implant to push additional bone into the subsinus space providing an additional cushioning and doming effect (Figs 3c and 4c). Furthermore, this

**Table 1 Maximum Load at the Time of Perforation**

| Type of treatment | No. of specimens | Maximum load ($Nt/cm^2$) |
|---|---|---|
| Control (10% Formalin) | 22 | 9.8 ± 5.4 |
| 5% Glacial acetic acid | 22 | 7.5 ± 5.3 |
| Glycerol | 22 | 12.7 ± 7.6 |

Ho: Control = Glacial acetic acid 5% = Glycerol.
N = 64; F(2,61); *P* = .01; Tabulated F value F = 4.98; Obtained F value F = 14.41.

**Table 2 Implant Placement and Perforations**

| No. | Patient ID | Last tooth in the arch* | Residual ridge height (mm) | Implant length (mm)/Elevation (mm)/Perforation† Position 1 | 2 | 3 | 4 | Reason for perforation |
|---|---|---|---|---|---|---|---|---|
| 1 | 3260L | #13 (25) | 6–8 | | 13/5 | CTRL | | |
| 2 | 3266R | #4 (15) | 5–6 | | 13/7/P2 | CTRL | 13/6/P1 | Septum |
| 3 | 3266L | #13 (25) | 4–6 | | CTRL | 10/6/P1 | 13/7 | |
| 4 | 3274R | Edentulous | 5–7 | | CTRL | 15/7 | | |
| 5 | 3274L | Edentulous | 5–7 | | 13/4 | 13/6/P2 | CTRL | Floor of nose |
| 6 | 3264R | Edentulous | 5–7 | | 15/8 | CTRL | 13/6 | |
| 7 | 3264L | Edentulous | 7–9 | | CTRL | 13/4/P1 | 13/6 | Floor of nose |
| 8 | 3276R | Edentulous | 4–6 | | 10/4 | CTRL | 10/6 | |
| 9 | 3276L | Edentulous | 4–5 | | 10/5 | CTRL | 10/6 | |
| 10 | 3220R | Edentulous | 5–9 | | 13/8/P2 | CTRL | 15/5 | Floor of nose |
| 11 | 3220L | Edentulous | 4–6 | | | CTRL | 10/6 | |
| 12 | 3258R | Edentulous | 10 | | 15/5 | 15/4 | CTRL | |
| 13 | 3275R | Edentulous | 4–5 | | | CTRL | 10/4 | |
| 14 | 3176L | #12 (24) | 4–6 | CTRL | 10/6 | 10/5 | 13/6 | |

*Universal tooth numbering system (International system).
†P1: Class I perforation, P2: Class II perforation.

study confirmed that the osteotome technique can be used to elevate the maxillary sinus membrane well beyond the usually reported 4 to 5 mm (Table 2). Finally, it was demonstrated that when several sequential implants are placed, continuous membrane doming can be achieved (Figs 4b and 4c) and that the technique need not be limited to single tooth replacement sites.

Although 6 sites demonstrated perforation of the maxillary sinus membrane, it was discovered that the perforations differed in severity. This finding could have a significant impact on prognosis and clinical outcome. Therefore, a classification scheme of maxillary sinus membrane perforations occurring during sinus floor elevation with the osteotome is presented in an effort to correlate the extent of perforation to prognosis. This classification may prove valuable to clinicians and suggests that incorporating radiographic and clinical tactile findings is of significance in limiting perforations. Class I perforation describes a slight, ≤ 2 mm lateral or apical perforation in which the resulting elevated dome shaped membrane space retains its shape once the implant is placed (Figs 5b/a and 5c/a). These perforations are thought to have a good prognosis. Class II describes a perforation of ≥ 2 mm, resulting in an exposed implant to the sinus cavity as well as loss of space and dome shape (Figs 5b/b, 5c/b).

The clinical course of this type of perforation is difficult to predict since little is known regarding the long-term results of such cases. Boyne evaluated implants that had been under occlusal load for 14 months in Rhesus monkeys.[27] He reported that the implants protruding 2 to 3 mm into the antrum had complete spontaneous regeneration of bone over the entire surface. However, when implants protruded up to 5 mm into the antrum, only partial growth of bone occurred around the implant apex and complete coverage of the implant by osseous repair did not occur. Baumann and Ewers reported spontaneous recovery of slight membrane perforation after placement.[28] This elevation was done through endoscopy in humans in vivo as well as in fresh cadavers. The Boyne and Baumann studies indicate that minor membrane perforations may not play a significant role in clinical outcome. It is speculated that it is possible for minor perforations to be obturated in vivo, as a result of combined bone graft and blood clot stabilization. Furthermore, osseointegration may be enhanced when the osteotome technique is used for 2 additional reasons: *(1)* decreased injury to the membrane vasculature (the middle concha arteries and branches from the internal maxillary, posterior superior alveolar, inferior orbital, ethmoidal, facial, and palatal arteries); and *(2)* utilization of the implant as the final osteotome pushing additional graft material as it is placed, thus allowing the material to advance epically and laterally.

**Table 3 Comparative Analysis of Elevated Sites With and Without Perforation**

| Level of elevation | Sites without perforation | Sites with perforation: Class I | Sites with perforation: Class II |
|---|---|---|---|
| 4–5 mm | 9 | 1 | 0 |
| 6–8 mm | 10 | 2 | 3* |

*The fact that all 3 Class II perforations were associated with the greatest level of membrane elevation is considered coincidental, since all 3 were found to be associated with proximity either to antral septation or the collateral wall of the nose.

Perforations were associated mainly with the presence of antral septae or the collateral wall of the nose (Table 2, Fig 5c). Several other factors may have increased the perforation occurrence in this study. These factors include the possibility of membrane perforation prior to surgery as a result of cadaver membrane texture, the aging affect of formaldehyde on cadaver membranes, the presence of prior sinus infection, and the decreased quality of alveolar bone encountered when working with cadavers. It is important to note that although no perforations occurred involving any of the 14 control drill sites, these sites were not included in statistical analysis. It is suggested that careful presurgical radiographic analysis can further diminish the rate of perforation. Although CT scans were not available for the present study, the authors recommend their use. Scans provide valuable information regarding the location of septae and sharp bony walls in sites where sinus floor elevation is being considered. Careful evaluation of available clinical and radiographic data could reduce the possibility of perforation and potentially increase success rates.

## CONCLUSIONS

This study indicates a lower perforation rate for the osteotome maxillary sinus membrane elevation procedure compared to the rates reported for the buccal approach technique. Although it is not always possible to extrapolate results from cadavers to an in vivo clinical setting (a buccal approach study accomplished with formalin-fixed human cadavers would be necessary for precise comparison), it is postulated that 22 of 25 procedures performed would probably have provided favorable clinical results, since only the 3 Class II category perforations would be considered to have clinical significance. It was demonstrated that sharp walls projecting from the sinus borders can interfere mechanically with successful maxillary sinus membrane elevation.

1. Drilling to within 1 mm of the maxillary sinus membrane allows utilization of limited force to displace the cortical bone with the osteotome. This permits the membrane to be elevated with less likelihood of perforation.
2. The membrane can be domed predictably without perforation by progressively adding graft material utilizing the osteotome technique.
3. Partially filling the osteotomy in advance of implant placement allows the implant to push additional bone into the tented area providing an additional cushion and doming effect.
4. The technique can elevate the sinus membrane well beyond the usually reported 4 to 5 mm.
5. The results of this study appear to validate the use of formalin-fixed human cadaver heads for the simulation of surgical procedures related to the crestal osteotome maxillary sinus membrane elevation procedure.

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