Sinus membrane elevation and simultaneous insertion of dental implants: a new surgical technique in maxillary sinus floor augmentation

STEFAN LUNDGREN, GIOVANNI CRICCHIO, VINICIUS C. PALMA, LUIZ A. SALATA & LARS SENNERBY

Endosseous implants are frequently used for prosthetic reconstruction in the edentulous patient. Sufficient volume and density of the alveolar bone for implant integration and load bearing are prerequisites for good clinical outcome. Bone resorption following the extraction of posterior maxillary teeth sometimes results in severe loss of bone in vertical and/or horizontal dimensions, which may compromise the use of dental implants. Various grafting procedures have been used to establish an adequate bone volume for the placement of endosseous implants in atrophic posterior maxillae. The most common technique is augmentation of the maxillary sinus floor, a technique introduced by Tatum (28) and modified by Boyne & James (2) and Wood & Moore (34). Access to the maxillary sinus is obtained by drilling a bone window in the lateral sinus wall using a small round bur, while ensuring that the sinus membrane remains intact. The sinus membrane is then carefully elevated, mobilized together with the attached bone window and rotated medially. Maxillary sinus elevation surgery is usually performed in conjunction with a variety of bone grafting material, including autogenous bone from the iliac crest (1, 21), the mandibular chin (16, 19, 22, 34), the mandibular ramus (3) or the calvarium (31), as well as bone substitutes used alone (8, 10) or in combination with autogenous bone (18, 24, 32, 35).

Summers (26) described an alternative surgical technique to increase the available bone volume in the posterior maxilla. Access to the maxillary sinus floor was achieved through the alveolar ridge, using various instruments to form and shape a socket. The sinus membrane was subsequently elevated and a bone graft was placed prior to the immediate insertion of a titanium implant.

Even if new bone can be obtained after placing bone grafts in the maxillary sinus, it might not be a prerequisite for bone formation per se. The mere lifting of the sinus membrane and the establishment of a void space with a blood clot may yield new bone, following the principles of guided tissue regeneration (4). This concept was supported by a study in which bone formation was detected at the apical part of implants protruding into the sinus cavity (5). Spontaneous bone formation at the floor of the maxillary sinus has also been observed 3 months following the removal of an intrasinusal cyst (14).

The present article presents the development and the clinical and histological evaluation of a new clinical technique for maxillary floor augmentation, which does not include bone grafting.

Development of a surgical technique

Bone reformation after sinus membrane elevation is a novel technique for maxillary sinus floor augmentation and the rationale behind it originated from the experience with a patient who was referred for augmentation of the right maxillary sinus and a delayed
placement of implants. During the pre-operative examination, a mucosal intrasinusal cyst was diagnosed (Fig. 1A,B). As the patient had symptoms of nasal congestion, the cyst was removed in a separate session 3 months before sinus floor augmentation surgery. The 3-month time period was chosen to ensure healing of the sinus membrane prior to the bone grafting procedure.

In order to reposition the bone window after the removal of the cyst, an oblique osteotomy was made using a microreciprocating saw (Fig. 1C). The osteotomized window was detached by careful dissection from the sinus membrane and stored in saline. The sinus membrane around the created window was dissected free from the sinus wall before a vertical incision was made in the membrane to reach and remove the cyst (Fig. 1D). After removal of the cyst, the sinus membrane was lifted from the sinus floor to make the mucosa as tension-free as possible before closing with three resorbable sutures (Fig. 1E). The bone window was then repositioned and the oral mucosa sutured with single resorbable sutures (Fig. 1F). Healing of the bone window was completed within 3 months of the time of the bone grafting procedure. During preparation of a new bone window for the sinus floor augmentation, extensive new bone formation was visible in the area where the sinus membrane had been elevated from the floor of the sinus in order to remove the cyst (14).

Encouraged by this observation, a decision was made to study, in greater detail, the bone-forming potential of a sinus membrane elevation technique. A patient referred for maxillary sinus augmentation

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**Fig. 1.** (A) Orthopantomogram of a patient planned for removal of a sinus cyst at 3 months before a sinus floor augmentation procedure in the left maxilla. (B) Tomographic section of a showing a sinus cyst. (C) A replaceable bone window has been cut with a saw. (D) The sinus cyst is visible and has been removed. (E) The lacerated membrane is repaired using resorbable sutures. (F) The bone window is placed in position.
prior to the placement of a single implant was found to have an alveolar bone height of 7 mm in the future implant site (Fig. 2A). A mucoperiosteal flap was raised to expose the lateral wall of the maxillary sinus. Five holes were drilled using a round bur in order to outline the planned window, and an oblique osteotomy was made (Fig. 2B). The bone window was detached from the underlying sinus membrane and stored in saline (Fig. 2C). The sinus membrane was dissected around the margins of the window and extended inferiorly to expose the floor of the sinus in the edentulous area (Fig. 2D,E). Finally, using a drill with a diameter of 2.85 mm (without use of a countersink), a 13 × 3.75 mm machined surface implant (MK III; Nobel Biocare AB, Gothenburg, Sweden) was inserted into the residual bone (Fig. 2F). The implant protruded 6 mm into the prepared cavity in the sinus. Care was taken not to lacerate the elevated sinus membrane with the tip of the implants during the insertion. The bone window was re-attached and the oral mucosa was re-adapted and sutured with single sutures (Fig. 2G).
The same technique was tested in a second patient, who received three implants (Fig. 3A). The three implants, each 13 × 3.75 mm, were placed with a final drill diameter of 2.85 mm (without use of a countersink) (Fig. 3B). The bone window was replaced and the surgical site was closed by sutures (Fig. 3C).

Post-operative radiographs of these two patients showed bone formation around all placed implants (Fig. 4). Figure 4 is from the first patient; Figure 7 is from the second patient.

**Clinical experience**

The satisfactory clinical and radiographic results obtained prompted a study of 10 additional patients who received a total of 19 implants (13). The protocol included sinus membrane elevation and simultaneous placement of implants with an oxidized surface (TiUnite; Nobel Biocare AB) (Fig. 5). The residual alveolar bone height was measured in situ. Initial implant stability was optimized by using an under-preparation technique; drilling through the residual alveolar process using a 2.0 mm twist drill followed by a 3 mm pilot drill, just enough to enable the introduction of the implant in the drill canal, followed drilling using a 2.85 mm twist drill, with no use
of a countersink bur. In patients with low bone density, implants were placed after the initial preparation using the 2 mm drill. Implant stability was measured using resonance frequency analysis (Osstell™; Integration Diagnostics AB, Gothenburg, Sweden). Radiographic bone formation was evident in all 10 patients, and all 19 implants were stable after 12 months of loading (Figs 6, 8, 9, 10).

These results were confirmed in two other publications, which also obtained bone augmentation in the maxillary sinus floor by the mere elevation of the Schneiderian membrane and the simultaneous placement of endosseous implants beneath the membrane without adding a graft material. In six patients with an average of 5 mm residual alveolar bone, Hatano et al. (9) placed 14 implants (TiUnite MK III; Nobel Biocare AB) protruding into the sinus cavity. The cavity produced beneath the sinus membrane was filled with venous blood drawn from a remote site, and the bone window was repositioned. Bone formation was evident in all six patients, and the average height of newly formed bone around the implants was 10 mm. One implant was lost during the initial healing period, but was immediately replaced by another implant, which then experienced a successful healing (9). Thor et al. (29) placed 44 endosseous implants (Astra Tech ST Implants; Astra Tech Company, Mölnndal, Sweden) in 20 patients, who presented with an average of 5 mm residual bone at the floor of the maxillary sinus. One implant failed to integrate. During a follow-up period averaging 28 months, no additional implant failed and new bone formation averaged 7 mm. The authors found that the greater the length of the
implants (i.e. the further the implants protruded into the secluded space between the floor of the sinus and the elevated sinus membrane), the more new bone that was formed (29). They also found that the less residual bone that was present, the more new bone was formed (29).

### Histological findings from sinus membrane elevation

The mechanism of bone formation underneath the elevated sinus membrane is not fully understood. Because autogenous bone has been considered to be the gold standard for bone grafting, the clinical findings of the novel technique presented here need to be supported by histological investigations. Palma et al. (20) compared the histological outcome of sinus membrane elevation and simultaneous placement of implants with and without adjunctive autogenous bone graft. Each of four tufted capuchin primates underwent two surgical procedures. Initial surgery involved bilateral extraction of the maxillary first, second and third premolars and of the first molar. The sinus floor augmentation surgery took place after a dental socket healing of 4 months. A mucoperiosteal flap was raised and a window was prepared in the lateral wall of the sinus. The window was removed and, after carefully elevating the sinus membrane, two different $3.75 \times 8.5$ mm Brånemark (Nobel Biocare AB) implants were placed in each jaw side, namely a MK III implant with a machined...
surface and a TiUnite MK III implant with a titanium surface enlarged by oxidation (Fig. 11). One sinus was left to be filled with a coagulum alone, whereas the contralateral sinus was sacrificed with autogenous bone harvested from the tibia. The bone windows were repositioned and the surgical site was closed with the mucoperisteal flap and sutured. Six months post-surgery, the animals were sacrificed and the maxilla was retrieved en bloc for preparation of ground sections for light microscopy.

The histological examination revealed that the floor of the sinus provided approximately 2.2 mm (SD ± 1.1 mm) of cortical bone for primary stability, while the rest of the implant projected into the sinus cavity, which after healing was filled with new bone (Fig. 12). The sinus membrane appeared morphologically intact in most cases and in contact with the apical surface of the implant (Fig. 13). The membrane-elevated sites showed most new bone at the
periphery, in contact with the membrane and sometimes extending downwards towards the centre of the augmented area (Fig. 14). In grafted sites, bone tissue was seldom seen lining the sinus membrane at the uppermost part of the implant. Different patterns of implant integration could be distinguished for oxidized and machined implants. While the bone contact with the machined surface seemed to be a consequence of bone growth from the periphery onto the implants (Fig. 15), the oxidized surface showed
direct bone formation without evidence of trabeculae projection from the surroundings (Fig. 16). The dynamics of the bone formation process was assessed by using calcein staining and fluoroscopy. For instance, bone labeling after 50 days was detected mainly at the implant interface for oxidized implants (Fig. 17A), but at a distance from the surface of machined implants (Fig. 17B). This was irrespective of the implants being placed in membrane elevated sites only or in bone grafted sites. Morphometric measurements also showed a markedly higher degree of bone–implant contacts for oxidized than for machined implants. The findings thus indicate that implant surface modification increases the potential for bone integration of implants placed with no primary bone contact (Fig. 19A,B).

Maintaining an elevated sinus membrane without the use of implants

A prerequisite for the present technique is that dental implants can be placed to serve as tent poles for the sinus membrane. However, the residual alveolar crest of many patients is too thin or has too low density to allow a firm primary stability of implants. It is well known that bone can be formed in secluded spaces on a bone surface by using various types of barrier membranes or other space-making devices. It is possible that a space-making device can be used also for bone formation in the maxillary sinus. This hypothesis was tested in two patients (Cricchio G, Sennerby L, Lundgren S, unpublished data). A replaceable bone window was prepared at the lateral aspect of the maxillary sinus followed by careful dissection and elevation of the sinus membrane (Fig. 20A–D). A space-making device of about 8 mm, made using a biodegradable polymer, was introduced into the maxillary sinus floor in order to keep up the elevated membrane. Six months later it was evident that new bone, 5–6 mm in height, had been formed at the floor of sinuses in both patients (Fig. 21A–C).
Although the new bone did not allow for placement of 10-mm implants with full bone coverage, the 3–4 mm of new bone made it possible to place implants with sufficient primary stability to perform a second sinus membrane-elevation procedure to gain additional bone (13). The results from these two patients demonstrated that bone can form in a secluded space in the maxillary sinus without the presence of a dental implant. However, the findings were disappointing with regard to the amount of bone formed. It is possible that the space-making polymer material had in some way inhibited the bone-formation process.

Hypotheses on bone formation in sinus sites

The studies presented have revealed the formation of a blood clot around titanium implants placed in the maxillary sinus. Examinations at 6 to 12 months post-implant placement showed shrinkage and ossification of the blood clot and the formation of a new sinus floor. The mechanism of the observed bone formation in the maxillary sinus remains to be determined. Knowledge about bone healing has mainly been gained from studies of healing fractures and bone defects. However, the maxillary sinus is unique as it requires bone to be formed beyond the skeletal contour and not in a bone fracture or defect. Nonetheless, irrespective of the bone-forming site, bone formation and healing require the recruitment, migration and differentiation of osteogenic cells. The lifting of the periosteum may have initiated a resorption process, exposure of the bone marrow and access of stem cells to the sinus cavity, a sequence of events that has been described in animal studies (15, 23). Gruber et al. (6) revealed that the sinus mucosa contains mesenchymal progenitor cells and cells committed to the osteogenic lineage, which may constitute another source of bone-forming cells with sinus membrane elevation.

One factor contributing to the successful outcome of the membrane elevation procedure was probably the use of a replaceable bone window. Technically, this was achieved by using an oscillating saw with a thin blade. The margin of the window was first marked by four to five drill holes. The cutting by the oscillating saw was then performed in an oblique direction, resulting in a flanged bone window capable of being replaced in a stable position. There are several advantages of using a replaceable bone window. First, soft tissue from the overlaying intra-oral mucosa does not gain access to the sinus space. Second, because air cannot pass through the bone window, which reduces the risk of disturbing the sinus membrane and the underlying blood clot, the bone window replacement technique may help to re-establish proper pneumatic conditions (30). Third, it is possible that the surface of the bone window contributes to a prolonged period of healing, passively by serving as a stabilizing surface for the blood clot and actively by promoting bone formation beneath the elevated sinus membrane.
In sum, these observations described here suggest that, in spite of an ongoing bone remodelling, bone deposition is the net outcome of a sinus mucosa elevation without the use of bone grafts, while a resorptive process of bone graft particles predominates in bone-grafted sites. The tissue regeneration field (4, 5, 11–13, 17, 25, 27) has firmly established the importance of the coagulum and its endogenous growth factors for bone formation, and it seems that the osteoinductive properties of a coagulum is limited mainly by lack of a properly maintained space. While several authors (5, 7, 13, 14, 33) have observed bone formation after sinus floor augmentation with no use of bone grafts, Palma et al. (20) were the first to describe the process histologically and to evaluate the integration potential of implants with different surfaces in sinus sites.

Conclusions

The mere elevation of the maxillary sinus membrane and the simultaneous placement of implants results
in bone formation and osseointegration. The amount of bone formation does not seem to differ when performing sinus membrane elevation with or without bone grafts. Histologically, the de novo bone tends to be deposited in contact with the sinus membrane after its elevation, pointing to the osseoinductive potential of the sinus membrane. Surface-modified implants showed a stronger bone response than machined implants in maxillary sites receiving sinus floor augmentation.

References

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