# Calvarial Bone Grafting for Three-Dimensional Reconstruction of Severe Maxillary Defects: A Case Series

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***Purpose:*** *To evaluate the efficacy, associated morbidity, and results of a three-dimensional reconstruction technique for repairing severe defects of the maxilla using a calvarial autogenous bone graft and a soft tissue double-layered surgical approach in preparation for placing dental implants.* ***Materials and Methods:*** *Bone defects of the maxilla consecutively reconstructed with calvarial autologous graft in the authors' institution were retrospectively evaluated. Patients with combined maxilla alveolar ridge defects with a width less than 4 mm and a height less than 7 mm (to the level of the maxillary sinus or the nostril), with at least three teeth involved, were included in the study. Calvarial bone blocks were sagittally sectioned in fine layers and fixed three-dimensionally in a boxlike structure with particulate bone inside. The purpose was to obtain an adequate amount of vertical and horizontal alveolar bone to enable restoration with dental implants at least 3.4 mm in diameter and 11 mm in length.* ***Results:*** *Eleven reconstructive procedures were performed in 10 patients. Bone graft integration was successful in all of them. No major complications were observed in the donor cranial site. A mean bone gain of 5.04 mm (range, 3.4 to 7.8 mm) in height was obtained (standard deviation [SD], 1.69). The implant surgery was performed between the 15th and 19th weeks. A total of 28 implants were placed, and the mean follow-up time was 45 months (range, 23 to 65 months; SD, 12). The mean graft vertical resorption was 0.78 mm (range, 0.50–1.50 mm; SD, 0.00) 41 months after implant fixation.* ***Conclusion:*** *Three-dimensional reconstruction technique using calvarial bone grafts to restore severe segmental or crestal bone defects in the maxilla is an effective and predictable procedure that can increase the horizontal and vertical bone volume in preparation for the successful placement of dental implants.* Int J Oral Maxillofac Implants 2015;30:880–890. doi: 10.11607/jomi.3627

**Key words:** *atrophic maxilla, calvarial bone graft, dental implants, onlay bone grafting, preprosthetic surgery, 3D reconstruction*

Severe alveolar and segmental defects in the maxilla have congenital, infectious, or traumatic causes, including long-standing edentulism, periodontal disease, hyperpneumatization of the maxillary sinus, severe infection complications, and post-traumatic and postsurgical bone defects (tumors and cysts).[1] Multiple techniques and procedures have been developed to solve clinical problems based on the horizontal and vertical components of the maxillary process: maxillary sinus and nasal cavity lifting, guided bone regeneration (GBR) using membrane or titanium mesh, onlay block bone grafting, inlay block bone grafting using maxillary osteotomy, particulate bone grafting from intraoral sites (eg, chin, retromolar area of the mandible), distraction osteogenesis, alveolar ridge expansion, and insertion of zygomatic and pterygoid implants in anatomical buttresses.[2–10]

Multiple intraoral (symphisis and mandibular ramus) and extraoral (iliac crest, calvarium, tibia, and rib) donor sites have been described in autogenous bone graft harvesting.[1] These donor sites provide grafts that differ with regard to various characteristics: embryologic origin (membranous or endochondral ossification), type of bone (cortical or cancellous), bone architecture (thickness, shape, and curvature),

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available volume, resorption rate, and morbidity. The ideal bone graft material must provide adequate volume, integrate well into the recipient site, be close in proximity to the atrophic area, be easily harvestable, and have low morbidity. In addition, it is very important that the graft be stable over time (ie, the resorption rate must be minimal). Thus, the origin of the membranous bone and its structural composition are important: it must have a resistant outer cortex with thin sectioning to facilitate vascular penetration and revascularization of the entire graft, and it must have a predominant inner cancellous layer.[11]

Calvarial bone is a predictable option for reconstructing severe segmental defects of the maxilla when large amounts of bone graft are required.[12] Multiple references in the literature describe the use of particulate or block calvarial bone to reconstruct craniomaxillofacial bone defects of diverse origins.[3,12] Calvarial bone is characterized by its embryologic origin of membranous ossification, which gives this bone a lower and slower resorption rate than the iliac crest (of endochondral origin).[12] When used as a bone graft, it also contains a large number of morphogenetic proteins.[12] Usually the patient will only require a short hospitalization period with minimal postoperative discomfort, and the scar can be hidden by the patient's hair. The reported disadvantages include the need for general anesthesia, the lack of flexibility and malleability of the graft, the resorption overtime (caused by the abundance of cortical bone, which complicates its revascularization and nutrition when it is applied in a block in the recipient site), the insufficient width, and the possible intra- and postoperative complications.[13]

The three-dimensional (3D) reconstruction technique with bone grafts was initially developed by using autologous grafts harvested from the mandibular retromolar area.[11] The goal is to restore the alveolar ridge by developing a superior 3D structural graft with the fundamental mechanical characteristics of an ideal bone graft. For restoration of major defects, bone grafts can be obtained from both intraoral mandibular rami or from distant extraoral donor sites. One suitable donor site is calvarial bone, as it has structural qualities similar to mandibular cortical bone.[3,12] Grafting will occur if the 3D structure is fixed correctly, concurrent with adequate relaxation in the overlying soft tissue. This will minimize the most frequent complication of onlay grafts: wound dehiscence with bone exposure, contamination, and the partial or total loss of the bone graft.

The purpose of this study was to evaluate the results of treatment for severe crestal and segmental defects of the maxilla using the basic principles of 3D reconstruction: harvesting, handling (the bone blocks were sagittally sectioned in fine layers), and fixation (in a boxlike structure with particulate bone inside) using autogenous calvarial bone grafts. A double-layered soft-tissue surgical approach at the recipient site was used to minimize tension and promote grafting as the bone matured.

## MATERIALS AND METHODS

### Patient Selection

Severe bone defects of the maxilla reconstructed with calvarial autologous graft in the Department of Oral and Maxillofacial Surgery of the Principe de Asturias University Hospital (Alcalá de Henares, Madrid, Spain) between February 2009 and July 2012 were retrospectively evaluated. Patients with combined maxilla alveolar ridge defects of any etiology with a width less than 4 mm and a height less than 7 mm (to the level of the maxillary sinus or the nostril), with at least three teeth involved, were included in the study. The exclusion criteria applied before surgery were as follows: smoking habit, poorly controlled diabetes, previous history of repeating sinusitis or maxillary radiotherapy, and deficient oral hygiene.

The purpose of this procedure was to create an alveolar ridge a minimum of 5.5 mm thick and 11 mm high to allow the placement of a dental implant at least 3.4 mm in diameter and 11 mm in length. The height was suitable to restore the vertical dimension, avoiding an excessive discrepancy with the antagonist teeth, and to improve the esthetics, especially of the anterior section.

Before treatment, all patients underwent panoramic radiography and cone-beam computerized tomography (CBCT) to determine the 3D volume of the defect and to estimate the size and shape of the graft (Fig 1).

### Surgical Technique

All patients received prophylactic antibiotics (oral amoxicillin-clavulanic acid 1 g/250 mg every 12 hours starting 1 hour before the intervention and continuing for 7 days). All patients underwent surgery under general anesthesia and nasotracheal intubation. The donor and recipient sites were infiltrated with local anesthetics (articaine hydrochloride with epinephrine 1:100,000).

The surgical procedure at the donor site took place first. One or two corticocancellous bone graft blocks of the diploë of the calvarial bone involving the nondominant parietal bone were removed. MicroSaw disks (0.25 mm thick; FRIOS MicroSaw, Dentsply Implants) were used for bone graft harvesting under copious irrigation with a physiologic saline solution. Bone grafts 4 to 6 cm long (according to the size of the defect) and 2 to 4 mm wide were harvested, leaving intact the internal cortex of the parietal bone throughout

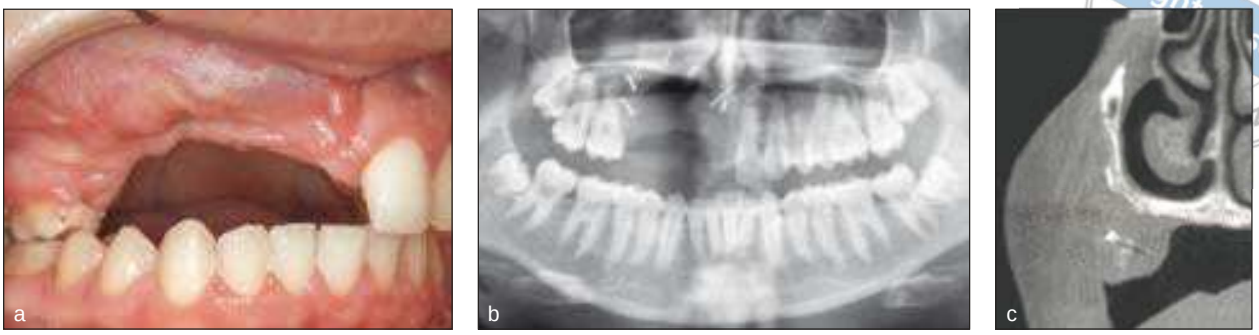


**Fig 1** (*a*) Partial maxillary defect involving five teeth secondary to tumor surgery (giant cell granuloma) and failed primary reconstruction. (*b*, *c*) Panoramic radiograph and cone beam computed tomography scan, respectively. Bone defect and screws are from a previous surgery.

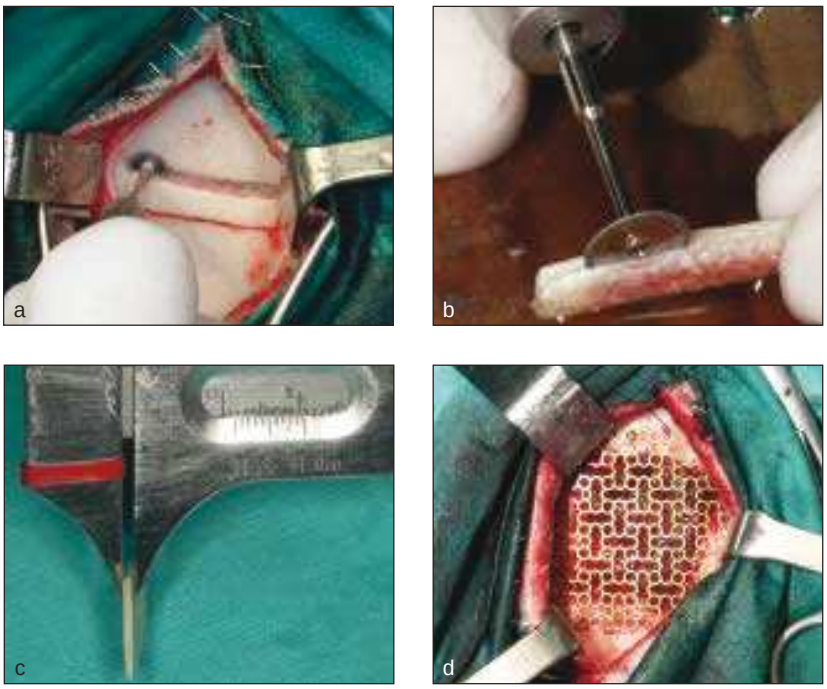


**Fig 2** (*a*) Bone block harvesting from calvarial skull, parietal area. (*b*) Sagittal splitting of bone blocks. (*c*) 1- to 2-mm-wide grafts. (*d*) Titanium mesh at the donor site.

the procedure. The blocks were divided sagittally with MicroSaw discs to harvest two fine monocortical strips between 1 and 2 mm wide. The donor site was covered with titanium mesh or calcium phosphate cement, depending on the case, to protect the skull and avoid collapse. Finally, the pericranium and the scalp were sutured (Fig 2).

Next, the surgical procedure at the recipient site was performed with a wide buccal sulcus incision. The mucosal layer was dissected in a supraperiosteal plane from the most cranial part to the alveolar ridge. A periosteal incision was made over the caudal side of the defect with lateral discharges directed away from the defect. A subperiosteal flap with a superior base exposing the recipient bone was lifted (Fig 3).

One of the cortical strips harvested from the skull was placed in a crestal position and fixed with 1.2-mm osteosynthesis screws (Stryker Leibinger). The rest of the block was particulated in small fragments and, together with cancellous diploë chips, used to fill the space between the defect and the crestal bone graft. The other strip of cortical bone was carved adequately to follow the natural curvature of the maxillary arch, placed in a buccal position over the particulate bone, and fixed with osteosynthesis microscrews and/or miniplates (Fig 4).

Once the bone reconstruction was completed, the periosteal flap was replaced, and the graft covered; the mucosal flap was then replaced, covered, and sutured at the buccal sulcus. Resorbable sutures were used to close the two planes. The mucosal flap was closed using a direct nontensional technique.

Between the third and fifth month after the surgical intervention, panoramic radiography and CBCT were performed to measure the vertical alveolar ridge augmentation and to plan the implant surgery (Fig 5).

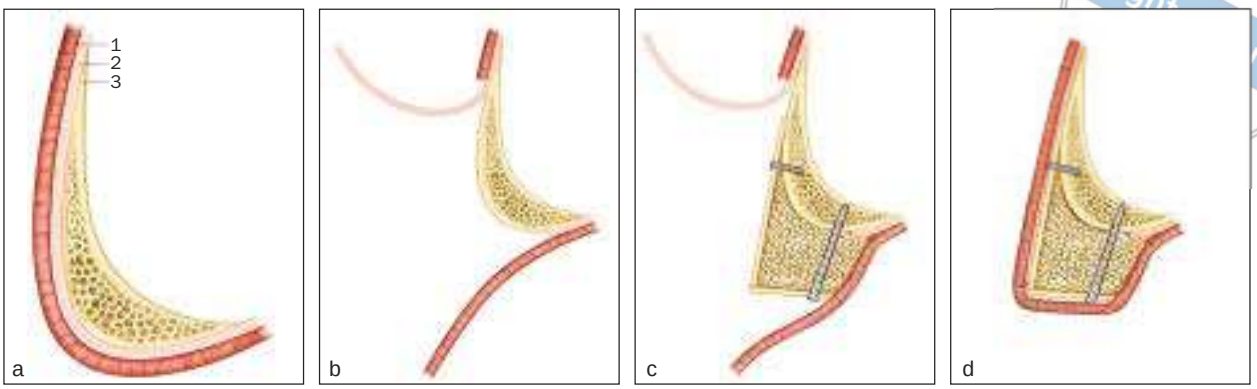
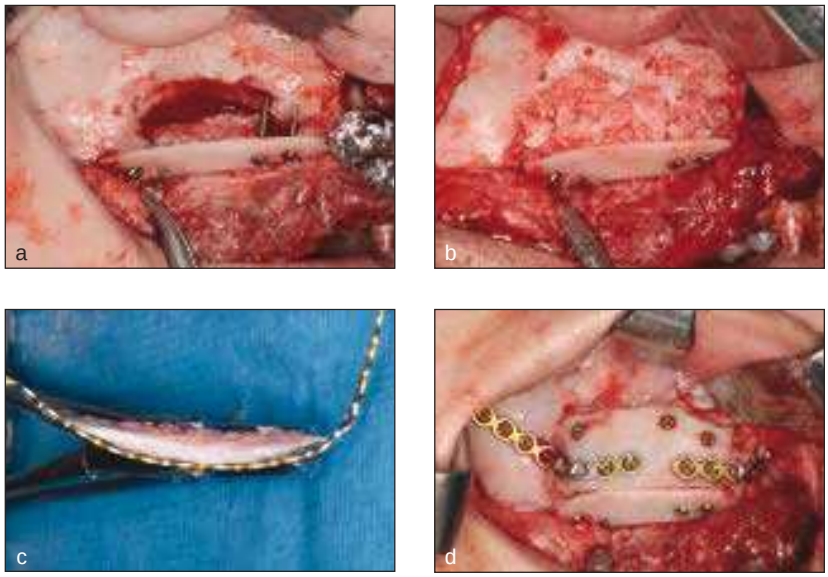



**Fig 3** Schematic illustrations of the vestibular approach to the recipient site using a double-layered soft-tissue surgical flap. (*a*) Initial situation showing (*1*) mucosal layer, (*2*) periosteal layer, and (*3*) bone. (*b*) Mucosal flap is inferiorly reflected in a supraperiosteal plane, periosteal incision on the crestal border, and elevation of a periosteal flap exposing the bone defect. (*c*) 3D reconstruction technique for alveolar bone augmentation is shown. (*d*) Final situation shows soft tissue flaps repositioned and sutured.

**Fig 4** (*a*) Crestal graft fixation. (*b*) Inside filling with particulate bone. (*c*) Vestibular graft shaped to follow the natural curvature of the arcade. (*d*) Vestibular graft fixed with microplates and microscrews.




With the administration of local anesthesia, the osteosynthesis screws and miniplates were removed, and the dental implants were placed (Fig 6).

After an osseointegration period of 4 months, gingival molding devices were placed over the implants, and the prosthetic procedure began (Fig 7). The patients were monitored with clinical and radiologic examinations (Figs 8 and 9).

Bone resorption was assessed in annual panoramic radiographs and a current CBCT scan. The same investigator performed all measurements. Because implants were placed crestally, the initial bone level was considered to be located at the height of the implant shoulder. Vertical bone resorption, mesial and distal to the implants, was calculated on panoramic radiography carried out after 1 year of loading and repeated on an annual basis. The distance from the implant shoulder to the crestal bone level was measured at each point in the study. The magnification was taken into account by comparing the implant length in the radiograph with the measurement recorded in the medical records. At the time of the study, CBCT was performed to measure the buccal and palatal resorption. To assess bone resorption, the arithmetic mean of all measurements was calculated.

## RESULTS

Eleven reconstruction procedures were performed for severe maxillary alveolar ridge defects in 10 patients (eight women and two men) (Table 1). For one woman with bilateral posterior atrophy caused by long-standing partial edentulism, the procedure was performed on both sides in the same intervention. The mean age was 44 years and 2 months (range, 18 to 62 years). The

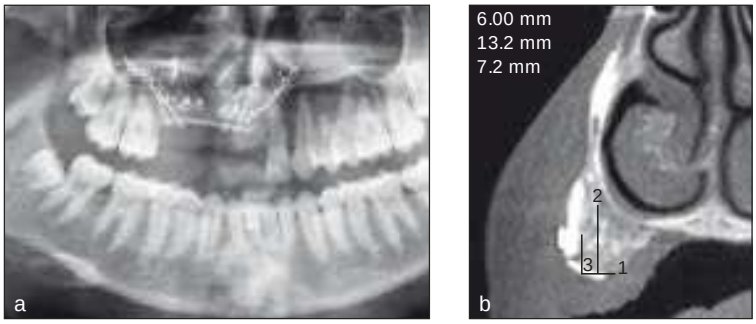



**Fig 5** Radiographic follow-up 16 weeks after augmentation procedure: (*a*) Panoramic radiograph and (*b*) CBCT with measures of (*1*) crestal width, (*2*) length, and (*3*) height gain before implant surgery.

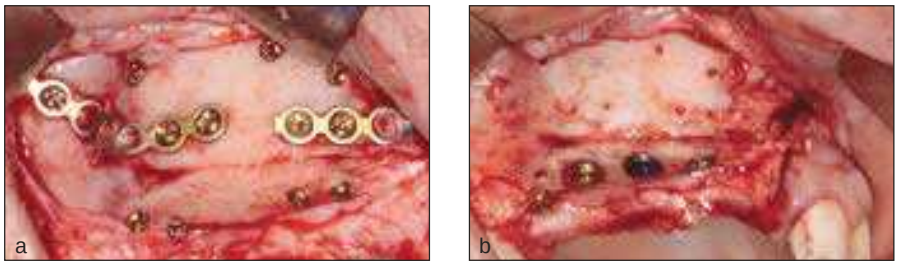



**Fig 6** Implant surgery. (*a*) Minimal graft resorption, and (*b*) osteosynthesis material removal and insertion of dental implants.

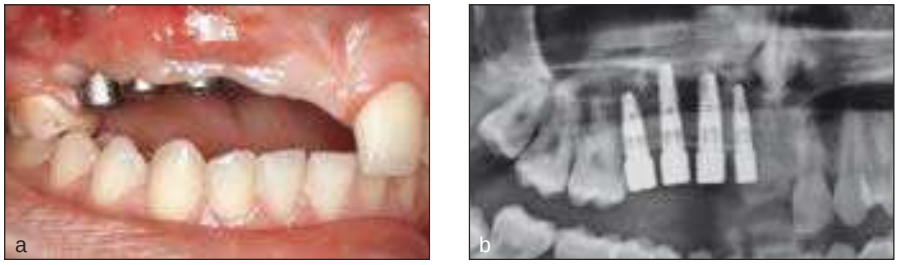



**Fig 7** (*a*) Clinical and (*b*) radiologic appearance with gingival formers in position 4 months after implant placement.

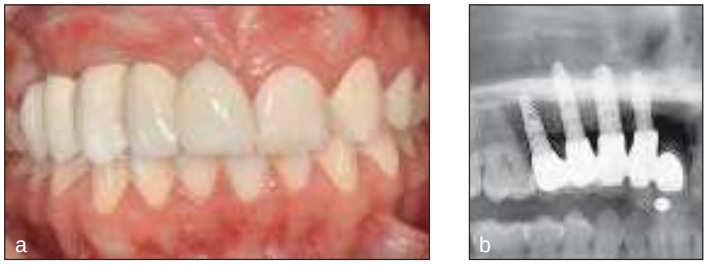



**Fig 8** (*a*) Implant-supported prosthesis. (*b*) Radiographic view after 1 year of functional loading.

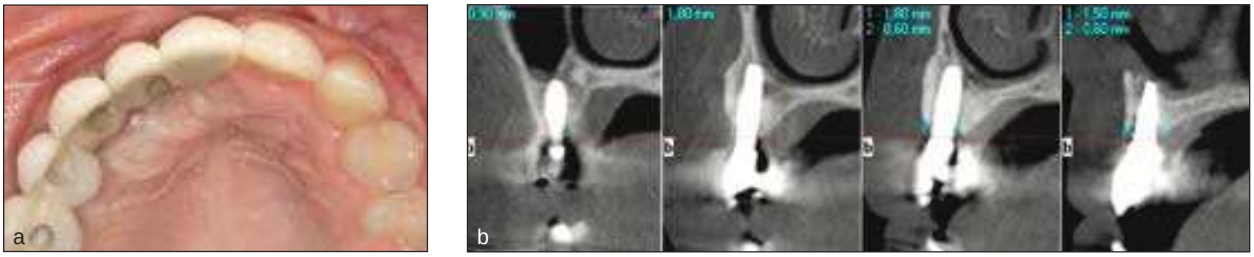



**Fig 9** (*a*) Clinical occlusal view. (*b*) CBCT buccal and palatal resorption measurements around implants after 1 year of functional loading.

etiology of maxillary defects was as follows: four patients experienced bone atrophy after long-standing edentulism; two patients were affected by the sequela of tumor removal (failure of primary reconstruction after the removal of central giant cell granuloma) or the sequela of cyst removal (nasopalatine duct cyst); two patients experienced bone loss after a severe infection (one woman diagnosed with multiple sclerosis

**Table 1 Reconstruction Surgery Data**

| Procedure no. | Sex | Age (y) | Follow-up (mo) | Augmentation site | Involved teeth* | Atrophy etiology | Associated procedure | Donor site closure | Graft fixation | | Complications of augmentation surgery |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Screws | Miniplates | |
| 1 | F | 41 | 65 | LPM | 25–27 | Infection | SL | PPM | 4 | NA | Donor site sinking |
| 2 | F | 29 | 61 | AM | 12–22 | Trauma | | PPM | 4 | NA | Donor site sinking |
| 3 | F | 44 | 60 | AM | 12–22 | GTR failure | PCG | TM | 8 | 2 | Donor site sinking |
| 4 | F | 45 | 45 | AM | 12–22 | Surgical sequela | | TM | 4 | NA | |
| 5† | F | 52 | 44 | RPM | 14–17 | Edentulism | SL | TM | 4 | NA | Donor site sinking |
| 6† | F | 52 | 44 | LPM | 24–27 | Edentulism | SL | TM | 5 | NA | Donor site sinking |
| 7 | M | 41 | 42 | RPM | 15–17 | Infection | SL | PPM | 4 | NA | Crestal graft fracture |
| 8 | F | 62 | 39 | RPM | 14–17 | Edentulism | SL | TM | 6 | NA | |
| 9 | F | 48 | 38 | LPM | 24–27 | Edentulism | SL | TM | 8 | NA | Donor site sinking |
| 10 | M | 54 | 37 | RPM | 14–17 | Edentulism | SL | CPG | 4 | NA | |
| 11 | F | 18 | 23 | RM | 11–15 | Surgical sequela | | TM | 11 | 2 | 8 mm area of alopecia |
| Mean (SD) | | | 45 (12) | | | | | | 5.64 (2) | | |

*FDI tooth-numbering system.
†Bilateral reconstruction in same patient.
LPM = left posterior maxilla; SL = sinus lift; PPM = polypropylene mesh; NA = not applicable; AM = anterior maxilla; GTR = guided tissue regeneration; PCG = pericranial graft; TM = titanium mesh; RPM = right posterior maxilla; CPG = calcium phosphate gel; RM = right maxilla.

**Table 2 Implant Data**

| Procedure no. | Maximum crestal bone vertical gain (mm) | Consolidated period (wk) | No. of Implants | Implant site* | | | | Implant length (mm) | | | | Implant diameter (mm) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| 1 | 7.8 | 18 | 2 | 25 | 27 | NA | NA | 13 | 13 | NA | NA | 3.8 | 3.8 | NA | NA |
| 2 | 4.2 | 17 | 2 | 11 | 22 | NA | NA | 13 | 13 | NA | NA | 3.8 | 3.8 | NA | NA |
| 3 | 4.4 | 15 | 2 | 12 | 22 | NA | NA | 13 | 13 | NA | NA | 3.8 | 3.8 | NA | NA |
| 4 | 3.6 | 19 | 2 | 12 | 22 | NA | NA | 13 | 13 | NA | NA | 3.8 | 3.8 | NA | NA |
| 5† | 3.6 | 16 | 3 | 13 | 15 | 16 | NA | 13 | 13 | 13 | NA | 3.8 | 4.5 | 4.5 | NA |
| 6† | 3.4 | 16 | 3 | 23 | 25 | 26 | NA | 13 | 13 | 13 | NA | 3.8 | 3.8 | 4.5 | NA |
| 7 | 6.4 | 16 | 2 | 15 | 17 | NA | NA | 11 | 11 | NA | NA | 3.8 | 3.8 | NA | NA |
| 8 | 3.6 | 15 | 3 | 14 | 15 | 16 | NA | 11 | 11 | 13 | NA | 3.8 | 3.8 | 3.8 | NA |
| 9 | 4.2 | 15 | 3 | 24 | 25 | 27 | NA | 13 | 13 | 13 | NA | 3.8 | 3.8 | 3.8 | NA |
| 10 | 7.0 | 16 | 2 | 16 | 17 | NA | NA | 13 | 13 | NA | NA | 3.8 | 3.8 | NA | NA |
| 11 | 7.2 | 16 | 4 | 12 | 13 | 14 | 15 | 11 | 13 | 15 | 11 | 3.4 | 4.5 | 3.8 | 3.8 |
| Mean (SD) | 5.04 (1.69) | | | | | | | 12.64 (4.10) | | | | 3.89 (0.78) | | | |
| Total | | | 28 | | | | | | | | | | | | |

*FDI tooth-numbering system.
†Bilateral reconstruction in same patient.
NA = not applicable.

developed osteomyelitis during long-term treatment with corticosteroids and immunosuppressants, and one patient developed extensive alveolitis post-extraction of multiple teeth); one patient experienced facial trauma; and in one patient, regenerative surgery with biomaterials failed. In seven patients, the defect was located in the posterior maxilla between the premolars and the maxillary tuberosity; in three patients, the defect was located in the anterior maxilla and involved the four anterior teeth; and in one case, the defect was intermediate, involving five teeth in the canine area.

The bone grafts were fixed with the 3D procedure using 1.2-mm titanium screws (mean, 5.64 screws). In six cases, four screws were sufficient (two per cortical strip). In two cases, two 1.7-mm miniplates were used to strengthen the fixation. Seven maxillary sinus lifts and one pericranial soft tissue graft were performed as the primary procedure. To protect the cranial vault and to avoid local collapse, the donor site was covered with a malleable dynamic titanium mesh fixed with microscrews in six patients (Stryker Leibinger); three patients received a monofilament polypropylene mesh (Prolite, Atrium Medical); and one patient received an injectable calcium phosphate gel (Hydroset, Stryker Leibinger).

**Table 3 Mesial and Distal Resorption Measurements of Bone Grafts After Functional Loading of Implants (in Millimeters)**

| Procedure no. | Follow-up after implant fixation (mo) | Follow-up after implant loading (mo) | 1st year | | | 2nd year | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | M | D | Mean | M | D | Mean | Δ |
| 1 | 60 | 56 | 1.00 | 0.50 | 0.75 | 1.00 | 1.00 | 1.00 | 0.25 |
| 2 | 57 | 51 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.00 |
| 3 | 57 | 51 | 1.00 | 0.00 | 0.50 | 1.00 | 0.00 | 0.50 | 0.00 |
| 4 | 41 | 34 | 0.00 | 1.00 | 0.50 | 0.50 | 0.50 | 0.50 | 0.00 |
| 5* | 41 | 36 | 1.35 | 1.00 | 1.17 | 1.35 | 1.00 | 1.17 | 0.00 |
| 6* | 40 | 36 | 1.35 | 0.67 | 1.00 | 1.35 | 0.67 | 1.00 | 0.00 |
| 7 | 38 | 32 | 1.00 | 0.00 | 0.50 | 1.00 | 0.50 | 0.75 | 0.25 |
| 8 | 35 | 29 | 1.00 | 0.67 | 0.83 | 1.00 | 0.67 | 0.83 | 0.00 |
| 9 | 34 | 29 | 0.67 | 0.67 | 0.67 | 1.35 | 1.00 | 1.17 | 0.50 |
| 10 | 33 | 28 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.50 | 0.00 |
| 11 | 19 | 14 | 1.50 | 0.50 | 1.00 | | | | |
| Mean (SD) | 41 | 36 | 0.77 (0.00)† | 0.10 (0.00)† | 0.00 (0.00)† | 0.00 (0.00)† | | | |

*Bilateral reconstruction in same patient.
†Mean increase.
M = Mean mesial resorption around implants; D = mean distal resorption around implants; Δ = mean increase of resorption after 1 year of loading.

**Table 4 Overall Mean Vertical Resorption Around Implants at the Time of the Study (in Millimeters)**

| Procedure no. | Current time* | | | | | |
|---|---|---|---|---|---|---|
| | M | D | M-D mean | B | P | B-P mean |
| 1 | 1.00 | 1.00 | 1.00 | 0.60 | .00 | 0.30 |
| 2 | 1.00 | 1.00 | 1.00 | 0.00 | .00 | 0.00 |
| 3 | 1.00 | 0.00 | 0.50 | 0.95 | .00 | 0.48 |
| 4 | 0.50 | 0.50 | 0.50 | 1.35 | .00 | 0.68 |
| 5† | 1.33 | 1.00 | 1.17 | 1.33 | .50 | 0.92 |
| 6† | 1.33 | 0.67 | 1.00 | 1.30 | .63 | 0.97 |
| 7 | 1.00 | 0.50 | 0.75 | 1.35 | .45 | 0.90 |
| 8 | 1.00 | 0.67 | 0.83 | 0.00 | .00 | 0.00 |
| 9 | 1.33 | 1.00 | 1.17 | 1.27 | .00 | 0.63 |
| 10 | 0.50 | 0.50 | 0.50 | 1.00 | .00 | 0.50 |
| 11 | 1.50 | 0.50 | 1.00 | 1.28 | .53 | 0.90 |
| Mean (SD) | | | 0.86 (0.00) | | | 0.60 (0.00) |
| Overall mean (SD) | 0.78 (0.00) | | | | | |

*Mean follow-up after loading: 36 months.
†Bilateral reconstruction in same patient
M = mesial; D = distal; B = buccal; P = palatal.

The average follow-up time after the grafting procedure varied between 23 and 65 months (mean, 45 months). In one case, an early fracture of the crestal lamina of the graft occurred and required the removal of a mesial fragment. Six patients had a mild scalp sinking that was only perceptible on touching. No differences were seen between polypropylene or titanium mesh. In the single case in which injectable calcium phosphate gel was used, this minor complication was not reported. One patient developed visible 8 mm area of alopecia on the anterior section of the scar on the scalp.

The implant placement took place between the 15th and 19th week after the augmentation procedure (mean, 16 weeks and 2 days) (Table 2). The mean gain in bone height after dental implant placement was 5.04 mm (range, 3.4 to 7.8 mm). A total of 28 implants were placed (Xive with original Cell Plus surface, DENTSPLY Implants): 17 were 3.8 mm in diameter and 13 mm in length; four were 4.5 × 13 mm; five were 3.8 × 11 mm; one was 3.8 × 15 mm; and one was 3.4 × 11 mm. The average diameter was 3.89 mm, and the average length was 12.64 mm. All implants were successfully osseointegrated.

Mean follow-up time was 41 months (range, 19 to 60 months) after implant placement (Table 3). The function and stability of these implants were judged to be good. Intraoral clinical examination demonstrated

| 3rd year | | | | 4th year | | | |
|---|---|---|---|---|---|---|---|
| M | D | Mean | Δ | M | D | Mean | Δ |
| 1.00 | 1.00 | 1.00 | 0.00 | 1.00 | 1.00 | 1.00 | 0.00 |
| 1.00 | 1.00 | 1.00 | 0.00 | 1.00 | 1.00 | 1.00 | 0.00 |
| 1.00 | 0.00 | 0.50 | 0.00 | 1.00 | 0.00 | 0.50 | 0.00 |
| 0.50 | 0.50 | 0.50 | 0.00 | | | | |
| 1.35 | 1.00 | 1.17 | 0.00 | | | | |
| 1.35 | 0.6 | 1.00 | 0.00 | | | | |

healthy peri-implant mucosae with no signs of inflammation. Esthetic outcomes were satisfactory. At the time of the study, no major resorptive modification of the calvarial grafts was detected radiologically. The mean mesiodistal bone height resorption measured on panoramic radiography after the first year of implant loading was 0.77 mm (range, 0.50 to 1.17 mm). The resorption increased 0.10 mm in the second year, 0.00 mm in the third and fourth year of loading.

At the time of the study (after a mean loading time of 36 months), the mean mesiodistal resorption was 0.86 mm (range, 0.00 to 1.50 mm) and the mean buccal-palatal resorption was 0.60 mm (range, 0.00 to 1.35 mm) (Table 4). The overall mean vertical resorption was 0.78 mm from 19 months to 5 years after implantation, and ranged from 0.0 to 3 mm.

## DISCUSSION

This study demonstrated that the 3D reconstruction technique with autogenous bone grafts could be one of the most effective procedures used to treat the height and width of severe maxillary defects, because this procedure offers satisfactory medium-term results as well as stability over time.[11] According to Khoury[14] and other authors,[15] autogenous bone grafts are the safest of all procedures, and possess the best mechanical characteristics (mainly because of the cortical bone) and osteogenic characteristics (mainly because of the cancellous bone), as well as nonantigenic capacity. Although this 3D reconstruction technique has been previously described for local alveolar ridge augmentation using autografts from the retromolar area of the mandible,[11] to the authors' knowledge, this study is the first to describe the procedure using calvarial bone grafts for the treatment of severe crestal and segmental defects of the maxilla.

In all 11 reconstructed sites, the height of the maxillary alveolar ridge consistently increased, with mean bone gain of 5.04 mm at the time of implant placement. In the present study, only the amount of bone gained in the vertical direction was calculated. Horizontal width was also clinically achieved and checked using long-term CBCT. After a follow-up period of 2 to 5 years after augmentation surgery, the mean graft height reduction was 0.78 mm. Medium and long-term graft resorption of bone blocks is a problem that has been widely described in the literature.[16–18] Cordaro et al[19] reported a 41.5% loss in bone height in the first 6 months when the chin or mandibular ramus was used as the donor site. Other authors have reported 0 to 20% vertical loss of intraoral autogenous grafts in the first 6 months.[17,20,21] When the bone graft is composed of corticocancellous bone from the iliac crest, resorption occurs more quickly, starting during the remodeling process. Therefore, the implants must be placed soon after the augmentation surgery.[9] Within 6 months, Bell et al[22] observed 23% vertical resorption in the posterior mandible for corticocancellous bone grafts from the iliac crest placed extraorally in patients with severe mandibular atrophy.

In the present study, implants were placed a mean 16.3 weeks after the reconstruction procedure. It is widely acknowledged that dental implants inhibit resorption of both residual and transplanted bone.[23,24] Therefore, even though additional remodeling can be anticipated, many authors hypothesize that implants would aid in stabilizing the graft volume.[25] Radiographic follow-up between 1.5 and 5 years after implantation (mean, 41 months) showed stable marginal bone levels. The mean mesiodistal bone height reduction after the first year of implant loading was 0.77 mm, with minimal or no increase in the years after, which is within the acceptable values suggested by Albrektsson et al.[26] These results are similar to long-term results previously reported for implants placed in regenerated bone, in which the greatest amount of bone resorption occurred within the first year of loading, and the marginal bone levels remained stable thereafter.[27,28] The bone remodeling pattern observed in the present study was consistent with the findings of other studies that reported mean bone resorption of 1 mm after 1 year of functional loading, with a minimal increase during the second year (0.1 mm), around implants placed in regenerated bone using

autogenous bone grafts and titanium meshes.[29] Titanium mesh with autogenous bone alone or mixed with anorganic bovine bone has been used successfully in reconstructive implant surgery.[30–33] These studies indicated that titanium mesh is effective in augmenting the bone volume of the atrophic alveolar ridge.

Intramembranous autogenous block grafting is still considered the main method for extensive reconstruction of the maxilla because it exhibits less bone resorption after healing.[34,35] Compared with the intraoral ramus donor site, calvarium is considered to be a useful donor site that provides a large amount of intramembranous bone to rebuild severe segmental defects. The patients selected in the present study received calvarial grafts because they presented with extensive defects affecting at least three teeth in the maxilla. The results of the present study support the concept that the resorption of calvarial bone after the first year is generally smaller than that of ramus bone, which ranged from 17% to 25% 6 months after surgery.[19,20,36] Other authors evaluated bone volume and density changes of calvarial split bone grafts after alveolar ridge reconstruction. They found a mean volume reduction of 16.2% after 6 months of healing (15 patients) and 19.2% at a 1-year follow-up (five patients).[37,38]

In this study, the bone grafts were harvested from the diploë of the nondominant parietal bone of the calvaria. The MicroSaw discs used to harvest the grafts have a 7-mm radius and provide a 0.25-mm clean cut, which ensures a secure and minimally traumatic technique. The calvarial donor bone has the advantages of excellent structural characteristics and, because of its embryologic origin, minimal resorption. Preparing the harvested calvarial bone graft in fine strips of cortical bone in boxlike forms facilitates vascular penetration and the rapid distribution in the particulate bone.[11] In this manner, graft revascularization can be more predictable than corticocancellous graft blocks.[16–18] This procedure decreases the resorption of the bone graft, which is clinically evident when the implant is placed, and facilitates its insertion.

The immobilization of the harvested bone is another basic requirement for ensuring that neovascularization occurs correctly. The initial stability of the harvested bone is fundamental to achieving absolute immobilization and complete healing without encouraging the formation of fibrous tissue. The boxlike harvested bone placed with the 3D technique provides the structure for adequate mechanical stability, encouraging the incorporation of the bone graft into the recipient site. Fixing the cortical graft strips with two to four microscrews of 1.2 mm diameter was sufficient. In this study, none of the bone grafts showed mobility. Although there was one case of a fracture in a fragment of the crestal layer, it was not attributable to the immobilization technique. From a technical point of view, it is important for the anterior margin of the crestal graft to be supported correctly over the inferior border of the vestibular layer, because accurate fixation is fundamental. If necessary, miniplates may be used to improve fixation.

The dehiscence of the surgical wound over the graft and the resulting early bone graft exposure is an inconvenient complication of the onlay grafting technique for maxillary reconstruction.[19–21] This complication leads to graft contamination and, in most cases, to the partial or total loss of the bone graft. According to other authors, sutures over the harvested bone must be avoided to minimize the probability of a severe complication.[5,12,18,39,40] This precaution is particularly important in cases of vertical augmentation. The double flap surgical approach used in this study provided an excellent field of vision for the recipient site. It offers the advantage of covering the graft in two planes: a periosteal flap over the bone and a tension-free mucosal flap with no crestal incision over the periostium. This technique reduces the incidence of postoperative wound dehiscence. This complication was not reported in the present study.

Maxillary sinus lifting was frequently associated with the 3D reconstruction technique for the posterior maxilla (seven cases in the present study). This technique produces results that are similar to implant osseointegration into nonaugmented bone.[14,41,42] In the present study, the subantral space was filled with calvarial particulate bone in all patients, and the access to the sinus window was closed with a cortical bone graft placed on the buccal aspect. Using both techniques in the posterior region enabled the safe placement of dental implants of adequate length.

Despite successful outcomes described by some authors, the GBR at this site has a high incidence of membrane or mesh exposure associated with the particulate autogenous bone grafts or biomaterials.[7,43–45] The postexposure contamination of the graft inevitably leads to the failure of the procedure.[41] Furthermore, the membrane protects the particulate bone graft from resorption, but once it is removed or reabsorbed, the graft begins to decrease in volume in an unpredictable manner.[46–48] In the present study, membranes were not used because of the structural arrangement of the boxlike monocortical bone strips that hold and stabilize the particulate graft without the need for another barrier.[11]

Traditionally, the main drawbacks of calvarial bone grafts are the complications at the donor site and the need for a second extraoral surgical field as well as general anesthesia. In general, with careful use of the surgical technique, complications at the cranial donor

site are rare, and the procedure is practically pain and inflammation free. Severe complications, such as subdural and epidural hematoma, superior sagittal sinus laceration, or brain damage, have been described.[49,50] Eventually, dural exposure or lacerations with cerebrospinal leaks could occur. Other minor complications include infection at the donor site, hematomas, depression of the bone contour of the skull, sensitivity alterations, scarring on the scalp that becomes visible after hair loss, and localized alopecia. The complications are more common with bicortical bone graft harvesting.[51] Iturriaga and Ruiz[52] found a considerable number of minor and major complications after harvesting cranial bone (57.7%). Scheerlinck et al[53] reported a 19% rate of major complications. However, low complication rates have also been reported: Iizuka et al[54] and Kellman[55] did not observe complications at the donor site in 13 and 20 calvarial bone removal procedures, respectively. In the present study, the incidence of complications at the donor site was relatively low. They included a mild collapse of the cranial vault (only noticeable to the touch) and, in another case, a small nonvisible area of local alopecia that was well tolerated by the patient.

None of the implants failed 19 months to 5 years after implantation, and no implant mobility or pain was revealed on percussion. All patients reported satisfactory function of the implant-supported restorations. The clinical and conventional radiologic follow-up showed excellent stability of the reconstructions. The CBCT scans have added a more accurate and reliable process of resorption measuring to the follow-up.

## CONCLUSIONS

Based on the results of this study, the treatment of severe maxillary defects using autogenous calvarial bone grafts prepared with a 3D technique was a predictable procedure that led to successful osseointegration in all patients. Although the number of cases in this series was limited, there were no major complications at the donor site. The double-layered incision at the recipient site (without opening the crestal mucosa) enabled the nontensional primary closure of the wound and adequate coverage of the bone graft during the maturation process. No radiologic bone resorption of the graft was seen when the implants were inserted. The horizontal and vertical dimensions of the maxilla were restored, and the implants were placed successfully. Calvarial grafts exhibited a minimal resorption on long-term follow-up.

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## REFERENCES


1. Boyne PJ, Herdford AS. An algorithm for reconstruction of alveolar defects before implant placement. Oral Maxillofac Surg Clin North Am 2001;13:533–541.
2. Schwartz-Arad D, Levin L, Sigal L. Surgical success of intraoral autogenous block onlay bone grafting for alveolar ridge augmentation. Implant Dent 2005;14:131–138.
3. Carinci F, Farina A, Zanetti U, et al. Alveolar ridge augmentation: A comparative longitudinal study between calvaria and iliac crest bone grafts. J Oral Implantol 2005;31:39–45.
4. Cordaro L, Torsello F, Accorsi Ribeiro C, Liberatore M, Mirisola di Torresanto V. Inlay-onlay grafting for three-dimensional reconstruction of the posterior atrophic maxilla with mandibular bone. Int J Oral Maxillofac Surg 2010;39:350–357.
5. Simion M, Fontana F, Rasperini G, Maiorana C. Vertical ridge augmentation by expanded-polytetrafluoroethylene membrane and a combination of intraoral autogenous bone graft and deproteinized anorganic bovine bone (Bio Oss). Clin Oral Implants Res 2007;18: 620–629.
6. Jensen OT, Block M. Alveolar modification by distraction osteogenesis. Atlas Oral Maxillofac Surg Clin North Am 2008;16:185–214.
7. Chiapasco M, Consolo U, Bianchi A, Ronchi P. Alveolar distraction osteogenesis for the correction of vertically deficient edentulous ridges: A multicenter prospective study on humans. Int J Oral Maxillofac Implants 2004;19:399–407.
8. Jensen OT. Alveolar segmental "sandwich" osteotomies for posterior edentulous mandibular sites for dental implants. J Oral Maxillofac Surg 2006;64:471–475.
9. Block M, Haggerty C. Interpositional osteotomy for posterior mandible ridge augmentation. J Oral Maxillofac Surg 2009;67(suppl 11):31–39.
10. Brånemark PI, Gröndahl K, Öhrnell L-O, et al. Zygoma fixture in the management of advanced atrophy of the maxilla: Technique and long-term results. Scand J Plast Reconstr Surg Hand Surg 2004;38: 70–85.
11. Khoury F, Khoury C. Mandibular bone block grafts: Instrumentation, harvesting technique and application. Journal de Parodontologie & d'Implantologie Orale 2006;25:15–34.
12. Tessier P. Autogenous bone grafts taken from the calvarium for facial and cranial applications. Clin Plast Surg 1982;9:531–538.
13. Tessier P, Kawamoto H, Matthews D, et al. Autogenous bone grafts and substitutes—tools and techniques: I. A 20,000-case experience in maxillofacial and craniofacial surgery. Plast Reconstr Surg 2005;116(suppl 5):6S–24S.
14. Khoury F. Augmentation of the sinus floor with mandibular bone block and simultaneous implantation: A 6-year clinical investigation. Int J Oral Maxillofac Implants 1999;14:557–564.
15. Rogers GF, Greene AK. Autogenous bone graft: Basic science and clinical implications. J Craniofac Surg 2012;23:323–327.
16. Verhoeven JW, Cune MS, Terlou M, Zoon MA, de Putter C. The combined use of endosteal implants and iliac crest onlay grafts in the severely atrophic mandible: A longitudinal study. Int J Oral Maxillofac Surg 1997;26:351–357.
17. Pikos MA. Mandibular block autografts for alveolar ridge augmentation. Atlas Oral Maxillofac Surg Clin North Am 2005;13:91–107.
18. Pikos MA. Block autografts for localized ridge augmentation: Part II. The posterior mandible. Implant Dent 2000;9:67–75.
19. Cordaro L, Amadé DS, Cordaro M. Clinical results of alveolar ridge augmentation with mandibular block bone grafts in partially edentulous patients prior to implant placement. Clin Oral Implants Res 2002;13:103–111.

20. Proussaefs P, Lozada J, Kleinman A, Rohrer MD. The use of ramus autogenous block grafts for vertical alveolar ridge augmentation and implant placement: A pilot study. Int J Oral Maxillofac Implants 2002;17:238–248.
21. Proussaefs P, Lozada J. The use of intraorally harvested autogenous block grafts for vertical alveolar ridge augmentation: A human study. Int J Periodontics Restorative Dent 2005;25:351–363.
22. Bell RB, Blakey GH, White RP, Hillebrand DG, Molina A. Staged reconstruction of the severely atrophic mandible with autogenous bone graft and endosteal implants. J Oral Maxillofac Surg 2002;60: 1135–1141.
23. Adell R, Lekholm U, Gröndahl K, Brånemark PI, Lindström J, Jacobsson M. Reconstruction of severely resorbed edentulous maxillae using osseointegrated fixtures in immediate autogenous bone grafts. Int J Oral Maxillofac Implants 1990;5:233–246.
24. Becktor JP, Isaksson S, Sennerby L. Survival analysis of endosseous implants in grafted and nongrafted edentulous maxillae. Int J Oral Maxillofac Implants 2004;19:107–115.
25. Hernández-Alfaro F, Sancho-Puchades M, Guijarro-Martínez R. Total reconstruction of the atrophic maxilla with intraoral bone grafts and biomaterials: A prospective clinical study with cone beam computed tomography validation. Int J Oral Maxillofac Implants 2013;28: 241–251.
26. Albrektsson T, Zarb G, Worthington P, Eriksson AR. The long term efficacy of currently used dental implants: A review and proposed criteria of success. Int J Oral Maxillofac Implants 1986;1:11–27.
27. Zitzmann NU, Schärer P, Marinello CP. Long-term results of implants treated with guided bone regeneration: A 5-year prospective study. Int J Oral Maxillofac Implants 2001;16:355–366.
28. Buser D, Ingimarsson S, Dula K, Lussi A, Hirt HP, Belser UC. Long-term stability of osseointegrated implants in augmented bone: A 5-year prospective study in partially edentulous patients. Int J Periodontics Restorative Dent 2002;22:109–117.
29. Corinaldesi G, Pieri F, Sapigni L, Marchetti C. Evaluation of survival and success rates of dental implants placed at the time of or after alveolar ridge augmentation with an autogenous mandibular bone graft and titanium mesh: A 3- to 8-year retrospective study. Int J Oral Maxillofac Implants 2009;24:1119–1128.
30. Von Arx T, Hardt N, Wallkamm B. The TIME technique: A new method for localized alveolar ridge augmentation prior to placement of dental implants. Int J Oral Maxillofac Implants 1996;11:387–394.
31. Lozada JL, Proussaefs PT. Clinical, radiographic, and histologic evaluation of maxillary bone reconstruction by using a titanium mesh and autogenous iliac graft: A case report. J Oral Implantol 2002;28:9–14.
32. Maiorana E, Santoro F, Rabagliati M, Salina S. Evaluation of the use of iliac cancellous bone and anorganic bovine bone in the reconstruction of the atrophic maxilla with titanium mesh: A clinical and histological investigation. Int J Oral Maxillofac Implants 2001;16:427–432.
33. Von Arx T, Kurt B. Implant placement and simultaneous ridge augmentation using autogenous bone and a micro titanium mesh: A prospective clinical study with 20 implants. Clin Oral Implants Res 1999;10:24–33.
34. Monje A, Monje F, Chan HL, et al. Comparison of microstructures between block grafts from the mandibular ramus and calvarium for horizontal bone augmentation of the maxilla: A case series study. Int J Periodontics Restorative Dent 2013;33:e153–161.
35. Monje A, Monje F, Suárez F, et al. Comparison of implant primary stability between maxillary edentulous ridges receiving intramembranous origin block grafts. Med Oral Patol Oral Cir Bucal 2013;18:e449–454.
36. Chiapasco M, Gatti C, Gatti F. Immediate loading of dental implants placed in severely resorbed edentulous mandibles reconstructed with autogenous calvarial grafts. Clin Oral Implants Res 2007;18: 13–20.
37. Acocella A, Bertolai R, Colafranceschi M, Sacco R. Clinical, histological and histo-morphometric evaluation of the healing of mandibular ramus bone block grafts for alveolar ridge augmentation before implant placement. J Craniomaxillofac Surg 2010;38:222–230.
38. Smolka W, Bosshardt DD, Mericske-Stern R, Iizuka T. Reconstruction of the severely atrophic mandible using calvarial split bone grafts for implant-supported oral rehabilitation. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2006;101:35–42.
39. Barone A, Covani U. Maxillary alveolar ridge reconstruction with nonvascularized autogenous block bone: Clinical results. J Oral Maxillofac Surg 2007;65:2039–2046.
40. Rothstein SS, Paris DA, Zacek MP. Use of hydroxylapatite for the augmentation of deficient alveolar ridges. J Oral Maxillofac Surg 1984;42:224–230.
41. Blomqvist JE, Alberius P, Isaksson S. Retrospective analysis of one-stage maxillary sinus augmentation with endosseous implants. Int J Oral Maxillofac Implants 1996;11:512–521.
42. Hürzeler MB, Kirsch A, Ackermann K-L, Quiñones CR. Reconstruction of the severely resorbed maxilla with dental implants in the augmented maxillary sinus: A 5-year clinical investigation. Int J Oral Maxillofac Implants 1996;11:466–475.
43. Simion M, Baldoni M, Rossi P, Zaffe D. A comparative study of the effectiveness of e-PTFE membranes with and without early exposure during the healing period. Int J Periodontics Rest Dent 1994;14: 166–180.
44. Artzi Z, Dayan D, Alpern Y, Nemcovsky CE. Vertical ridge augmentation using xenogenic material supported by a configured titanium mesh: Clinicohistopathologic and histochemical study. Int J Oral Maxillofac Implants 2003;18:440–446.
45. Louis PJ, Gutta R, Said-Al-Naief N, Bartolucci AA. Reconstruction of the maxilla and mandible with particulate bone graft and titanium mesh for implant placement. J Oral Maxillofac Surg 2008;66: 235–245.
46. Rasmusson L, Meredith N, Kahnberg KE, Sennerby L. Effects of barrier membranes on bone resorption and implant stability in onlay bone grafts: An experimental study. Clin Oral Implants Res 1999;10: 267–277.
47. Jensen OT, Greer RO Jr, Johnson L, Kassebaum D. Vertical guided bone graft augmentation in a new canine mandibular model. Int J Oral Maxillofac Implants 1995;10:335–344.
48. Gordh M, Alberius P, Johnell O, Lindberg L, Linde A. Osteopromotive membranes enhance onlay integration and maintenance in the adult rat skull. Int J Oral Maxillofac Surg 1998;27:67–73.
49. González-García R, Naval-Gías L, Muñoz-Guerra MF, Sastre-Pérez J, Rodríguez-Campo FJ, Gil-Díez-Usandizaga JL. Preprosthetic and implantological surgery in patients with severe maxillary atrophy. Med Oral Patol Oral Cir Bucal 2005;10:343–354.
50. Gutta R, Waite PD. Outcomes of calvarial bone grafting for alveolar ridge reconstruction. Int J Oral Maxillofac Implants 2009;24:131–136.
51. Gleizal AM, Beziat JL. Maxillary and mandibular reconstruction using bicortical calvarial bone grafts: A retrospective study of 122 reconstructions in 73 patients. Plast Reconstr Surg 2007;119:542–548.
52. Iturriaga MT, Ruiz CC. Maxillary sinus reconstruction with calvarium bone grafts and endosseous implants. J Oral Maxillofac Surg 2004; 62:344-347.
53. Scheerlinck LM, Muradin MS, van der Bilt A, Meijer GJ, Koole R, Van Cann EM. Donor site complications in bone grafting: Comparison of iliac crest, calvarial, and mandibular ramus bone. Int J Oral Maxillofac Implants 2013;28:222–227.
54. Iizuka T, Smolka W, Hallermann W, Mericske-Stern R. Extensive augmentation of the alveolar ridge using autogenous calvarial split bone grafts for dental rehabilitation. Clin Oral Implants Res 2004;15:607–615.
55. Kellman RM. Safe and dependable harvesting of large outer-table calvarial bone grafts. Arch Otolaryngol Head Neck Surg 1994;120:856–860.