KEY WORDS
Computer-guided bone regeneration, Bone lamina

COMPUTER-GUIDED VERTICAL AND HORIZONTAL BONE REGENERATION WITH RESORBABLE CUSTOMIZED BONE LAMINAS FILLED WITH 100% PARTICULATE AUTOLOGOUS BONE: A CASE REPORT

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PURPOSE. To describe a case of novel computer-guided bone regeneration (CGBR) technique used for vertical and horizontal reconstruction of atrophic edentulous maxilla with customized rigid bone laminas filled with 100% particulate bone.

MATERIALS AND METHODS. A healthy female requested an implant-supported fixed prosthesis for rehabilitation of a completely edentulous maxilla. The patient reported pain and discomfort with her complete removable denture, due to severe bone atrophy, and presented a horizontal and vertical bone defect. After virtual prosthetic planning, a 3D bone augmentation procedure was planned. Bone reconstruction was performed using two separate customized bone laminas filled with 100% autologous bone. Nine months after healing, six implants were installed, and three months later a full gingival graft was performed on the maxilla. A titanium resin screw-retained prosthesis was then fitted, and bone volume and linear dimensional changes were measured.

RESULTS. Seven months after augmentation, part of the left lamina had become exposed, albeit with no graft infection. However, one year after loading no implant had failed and the prosthesis was deemed successful. The mean volumetric bone augmentation was 1.583 cm^3. Mean horizontal bone augmentation was 6.3 mm, while mean vertical bone augmentation was 5.5 mm.

CONCLUSIONS. The stable results one year after loading should prompt randomized controlled trials to verify the potential clinical advantages of the approach described.

CONFLICT OF INTEREST STATEMENT
Authors have no conflict of interests to declare for this case report.
Computer-guided bone regeneration is a registered trademark.

INTRODUCTION

The treatment of edentulous patients with horizontal and vertical bone atrophy, especially in the maxilla, is one of the most complex procedures in dentistry[1]. However, reconstruction of severely resorbed alveolar ridges has become more predictable over recent years[1,2], thanks to a wide range of possible grafting biomaterials and techniques[3-6]. Some authors consider autogenous bone grafting as the gold standard due to its favourable osteogenic properties[7-9]; many approaches have been described in the literature, with autogenous bone being harvested from the maxillary tuberosity, the symphysis of the chin, the external oblique line of the mandible, or extra-oral sites. However, donor site morbidity, long healing periods and graft resorption remain the main disadvantages of the autogenous bone-block grafts[9-11].

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Horizontal bone augmentation with resorbable membranes is another well-documented procedure, with favourable outcomes at medium-term follow-up[12]. In cases requiring vertical bone augmentation, on the other hand, non-resorbable e-PTFE (expanded-polytetrafluoroethylene) membranes or titanium meshes have been used[2,4]. The main drawbacks of vertical bone augmentation are exposure of e-PTFE membranes or titanium meshes during the healing phase, with consequent risk of infection[13]. More recently, commercially available allografts, xenografts or synthetic bone grafts have been proposed[14], as well as customized autogenous bone blocks[15]. However, no long-term follow-up data is yet available.

As far as prosthetics are concerned, one of the most fundamental factors for predictable results, especially when treating challenging cases such as severe atrophic ridges, is precise prosthetically and aesthetically driven implant placement[4,16].

The purpose of this case report is to describe a novel technique for vertical and horizontal reconstruction of the atrophic maxilla, using rigid customized bone laminas filled with 100% particulate bone as per a previously described computer-guided bone regeneration approach for partially edentulous patients with resorbable membranes[16]. Customization was planned using a prosthetic virtual wax-up and implants were installed according to a prosthetically-driven virtual plan.

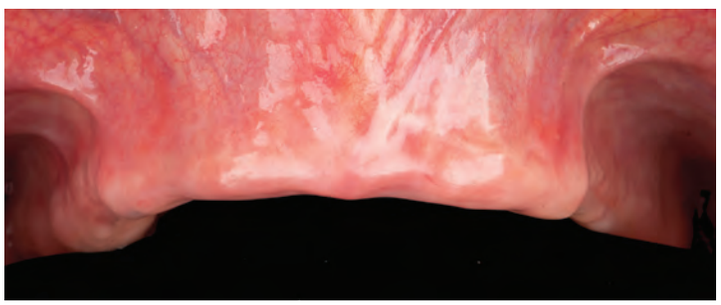
MATERIALS AND METHODS

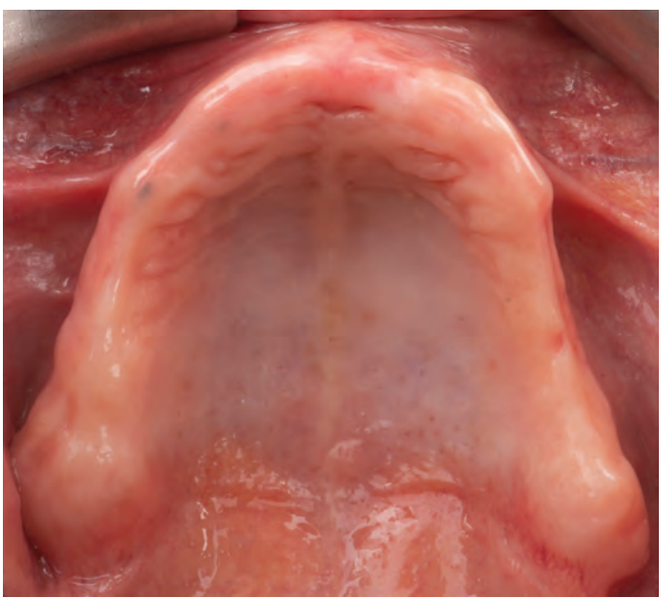
A healthy 63-year-old female non-smoker with no relevant medical, family or psychosocial history was referred by a colleague to a private clinic (M.P.) in Arzachena, Italy. She requested an implant-supported fixed prosthesis for complete rehabilitation of her edentulous maxilla

The patient's primary concerns and symptoms were related to pain and discomfort caused by her complete removable denture due to severe bone atrophy.

After clinical examination, severe labiopalatal atrophy with evident bone resorption and a severe deficit of the crestal keratinized mucosa was diagnosed (**FIGS. 1, 2**).

A cone-beam computed tomography (CBCT) scan evidenced a severe reduction in the width and height of the alveolar crest, with insufficient bone volumes for implant installation (**FIG. 3**).





FIGS. 1, 2: *Severely atrophic maxilla: pre-operative frontal and occlusal views.*

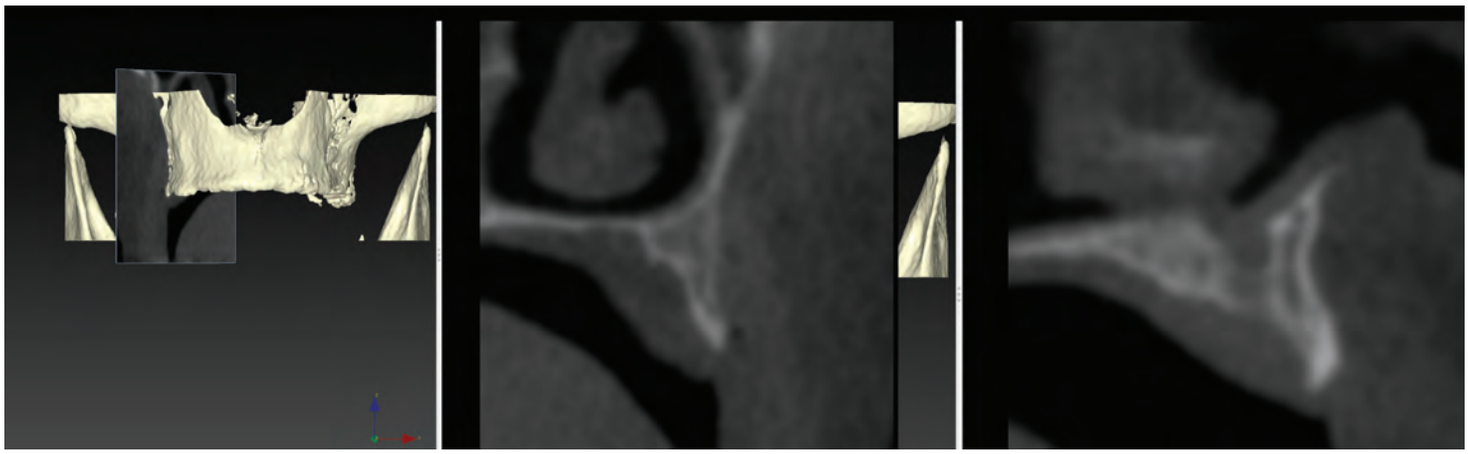


FIG. 3: *Pre-operative CBCT scan showing a severe horizontal bone defect.*

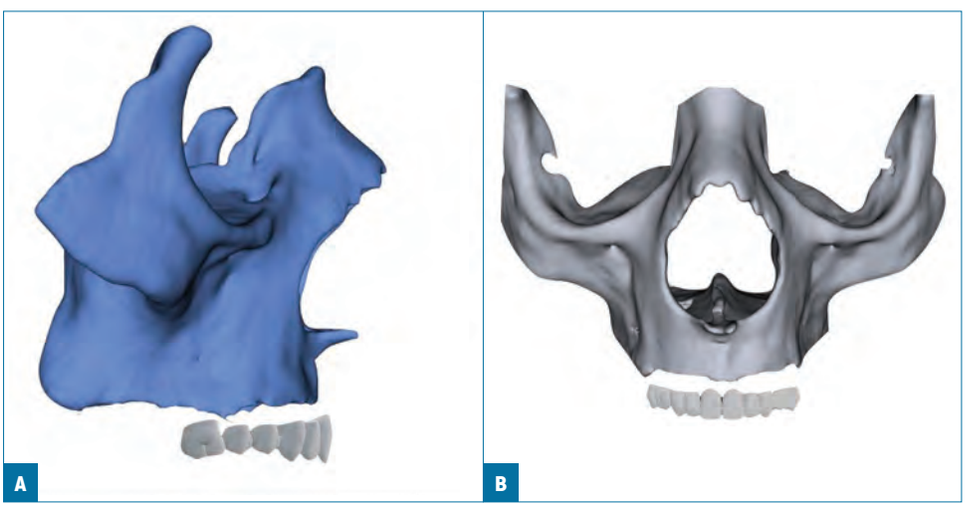
Preoperative assessment also included study photographs and models.

A virtual wax-up was generated to evaluate the ideal implant position (**FIGS. 4A, B**); the CBCT images were converted from a DICOM to STL file to create a digital model of the upper jaw (Mimics Innovation Suite, Materialise, Lovanio, Belgium).

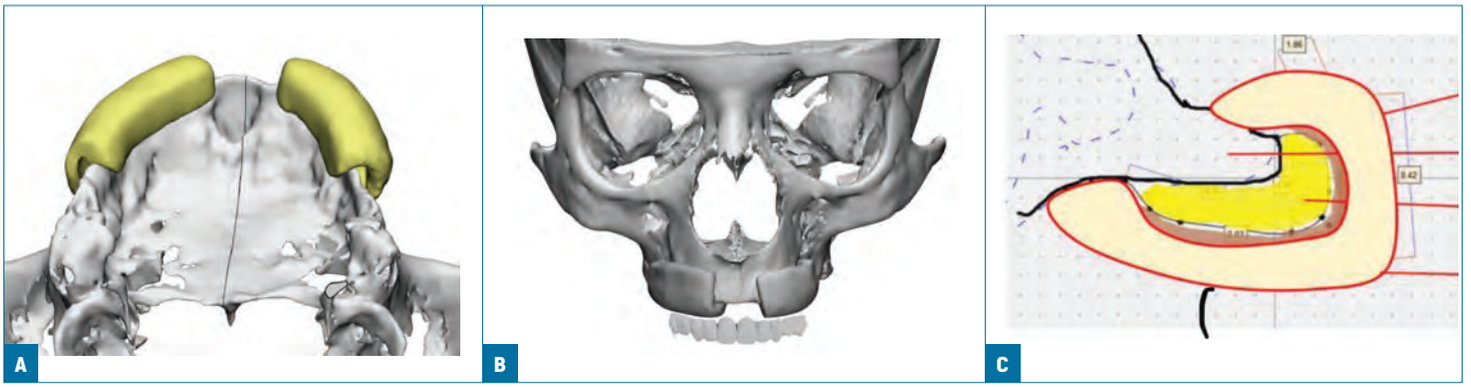
After that, two separate custom-made bone laminas were designed to cover the alveolar crest defects (**FIGS. 5A-C**), in line with the prosthetic plan, using a computer-guided bone regeneration approach[16]. As such, two customized bone laminas, with a mean thickness of 2 mm were then produced using a five-axis milling machine and computer-aided manufacturing (CAM) technology.

The two laminas were made by combining natural mineral bovine bone matrix with bioresorbable polymers and collagen fragments (SmartBone On Demand, Industrie Biomediche Insubri, Mezzovico-Vira, Switzerland)[17].

After the production process, the custom-made laminas were sterilized and ready for clinical application.



FIGS. 4A, B: *Pre-operative virtual wax up: lateral and frontal views.*

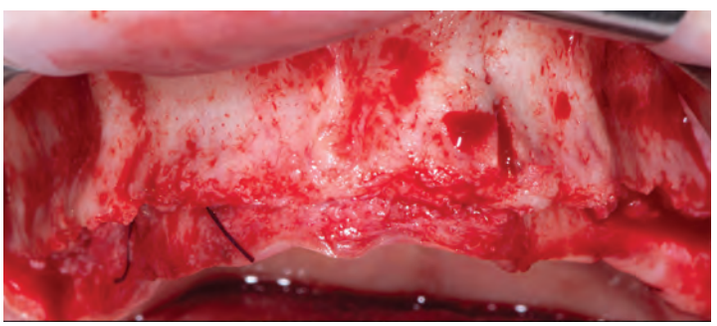


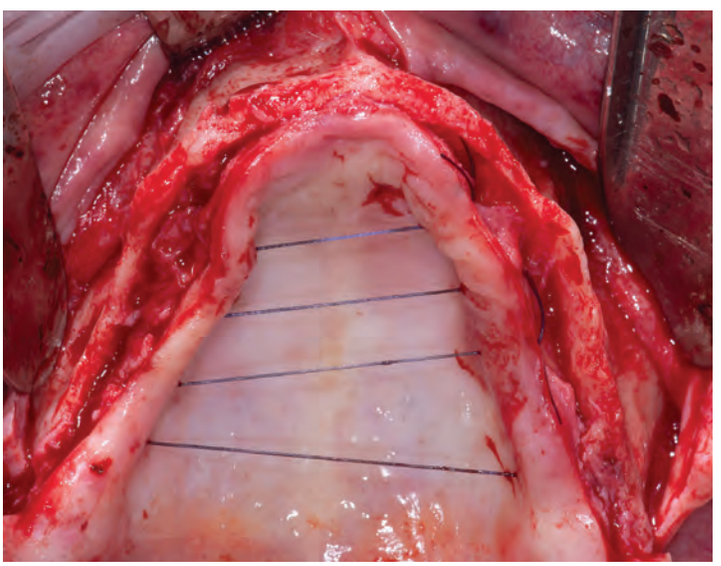
FIGS. 5A-C: *Virtual customization of the bone laminas.*

Clinical procedures

The patient received two grams of amoxicillin (Zimox, Pfizer, Rome, Italy) one hour before surgery, and then one gram twice a day for two weeks. Immediately before surgery, the patient rinsed with 0.2% chlorhexidine solution (Curasept, Curaden Healthcare, Saronno, Italy) for one minute. The surgery was performed under conscious sedation (Diazepam Hoffmann-La Roche, Basel, Switzerland) and local anaesthesia (Septanest with adrenaline 1/100,000, Septodont, Saint-Maur-des-Fossés, France).

Specifically, a mid-crestal incision was made into the residual keratinized tissue using a n°15 surgical blade. Two vertical incisions were then made bilaterally at the tuberosity, and one vertical incision on the medial vestibular frenulum. A full-thickness flap was raised beyond the mucogingival junction, at least five mm beyond the bone defect (**FIGS. 6, 7**), and the recipient site was cleared of all soft tissue remnants. An envelope incision was made in the alveolar mucosa at the mandibular ramus, and a full thickness flap was raised in order to harvest autologous bone, using a minimally invasive cortical bone collector (Safe Scraper, Micross, Meta, Reggio Emilia, Italy). The flap was subsequently sutured with a continuous Vicryl 4-0 suture (Simit-Dental, Mantua, Italy).





FIGS. 6, 7: *Severely atrophic upper jaw: frontal and occlusal surgical views.*

Multiple decortication holes were drilled in the recipient site using a two-mm round bur under irrigation with saline solution. The two separate custom-made bone laminas were tried to assess their correct fit.

The rigid bone laminas had a mean thickness of two mm, and they were shaped to leave sufficient space to be filled with particulate bone graft. Both laminas were filled extra-orally with 100% particulate autologous bone (**FIG. 8**), and then fixed intra-orally using titanium screws (MCbio, Lomazzo, Italy) (**FIGS. 9, 10**).

The external sites of the customized bone laminas were hydrated with blood and saline, and covered with a layer of autologous bone. The entire graft was then covered with a slow re-sorption 0.8-mm-thick pericardium membrane (Ubgen, Vigonza, Italy), stabilized by titanium pins (3P Implafavourite, Scalenghe, Italy) (**FIG. 11**).

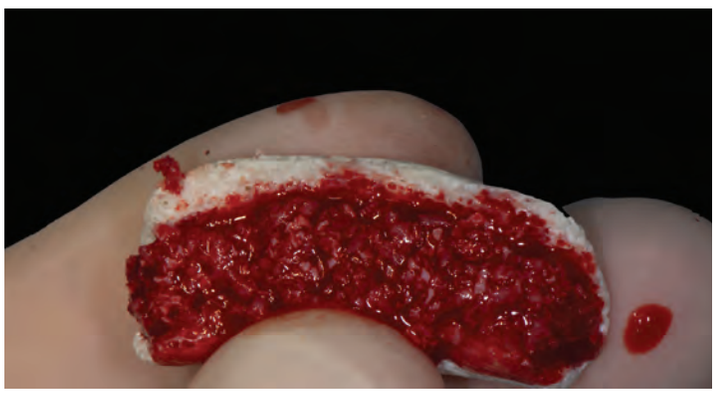
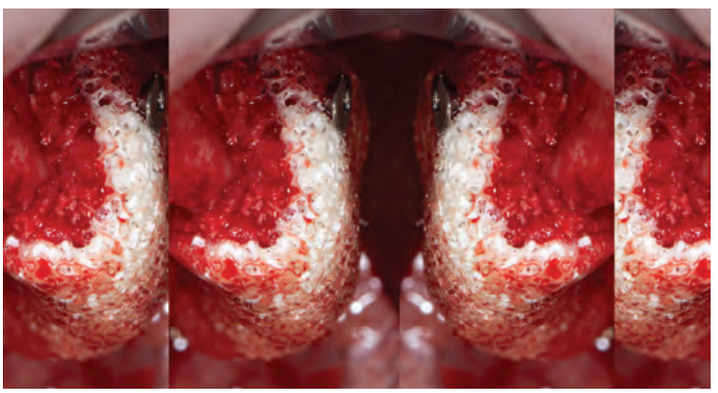
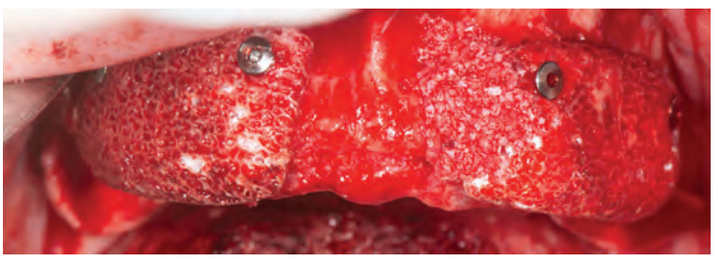


FIG. 8: *Customized rigid bone lamina filled with 100% autologous particulate bone.*





FIGS. 9, 10: *Customized rigid bone lamina: lateral and frontal intra-oral views.*

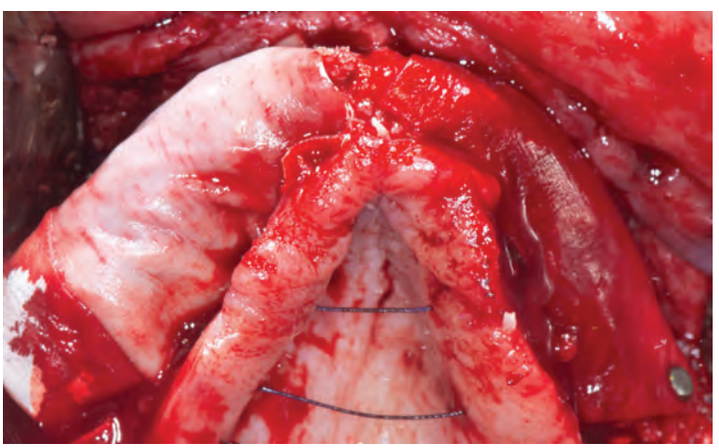


FIG. 11: *Slow-resorption pericardium membranes covering the customized bone laminas.*

Periosteal incisions were performed between the two vertical incisions to allow the flap to be released and closed without tension. The flaps were sutured in two layers to prevent exposure of the laminas, the deep layer with Vicryl 4-0 (Simit-Dental), and the superficial layer with an e-PTFE 4-0 suture (Elastin, Braun Italia, Milan, Italy).

Postoperatively, 80 mg of ketoprofen (Oki, Dompé, Milan, Italy) as needed was prescribed. A four mg/day dose of betamethasone (Bentelan, Glaxo, Verona, Italy) was administered for two days. The patient was instructed to rinse with 0.2% chlorhexidine (Curasept) three times per day for two weeks, and to eat only soft food for 30 days. The patient was also asked to avoid using any removable prosthesis for 30 days. Sutures were removed after 21 days, and after 30 days the removable prosthesis was adapted to the reconstructed alveolar crest and relined with soft material (Viscogel Laviosa, Mineraria, Livorno, Italy).

Nine months after bone healing, a 3D reconstruction of the CBCT scan was made to assess the regenerated bone, and to plan implant sizes and positions, taking into consideration all the anatomical landmarks and the prosthetics plan (**FIGS. 12A-C**).

Pilot holes were drilled according to the computer-assisted implant installation plan, and six implants of 3.8 mm diameter 10 mm length (Cono-in 3P Implafavourite) (**FIG. 13**) were installed with an insertion torque of 30 to 35 Ncm. All implants were submerged for three months, when a full-maxilla gingival graft was performed to increase the amount of keratinized tissue (**FIGS. 14, 15**). Two months after complete healing (**FIG. 16**), impressions were taken with the implants in situ, and a customized screw-retained titanium-resin prosthesis was fitted one month later (**FIG. 17**).

Periapical x-rays were taken at prothesis fitting and one year after loading (**FIG. 18**). Clinical follow-up exams were performed every three months during the first year of loading.

Outcome measures were implant and prosthesis failures, and any complications were recorded. Implant failure was considered removal of any implants dictated by implant mobility, progressive marginal bone loss, infection or implant fracture, while prosthesis failure was prosthesis refitting for any reason. In addition, 3D bone augmentation was measured by superimposition of two CBCT scans, one taken before the surgery and the other nine months later, just before implant placement.

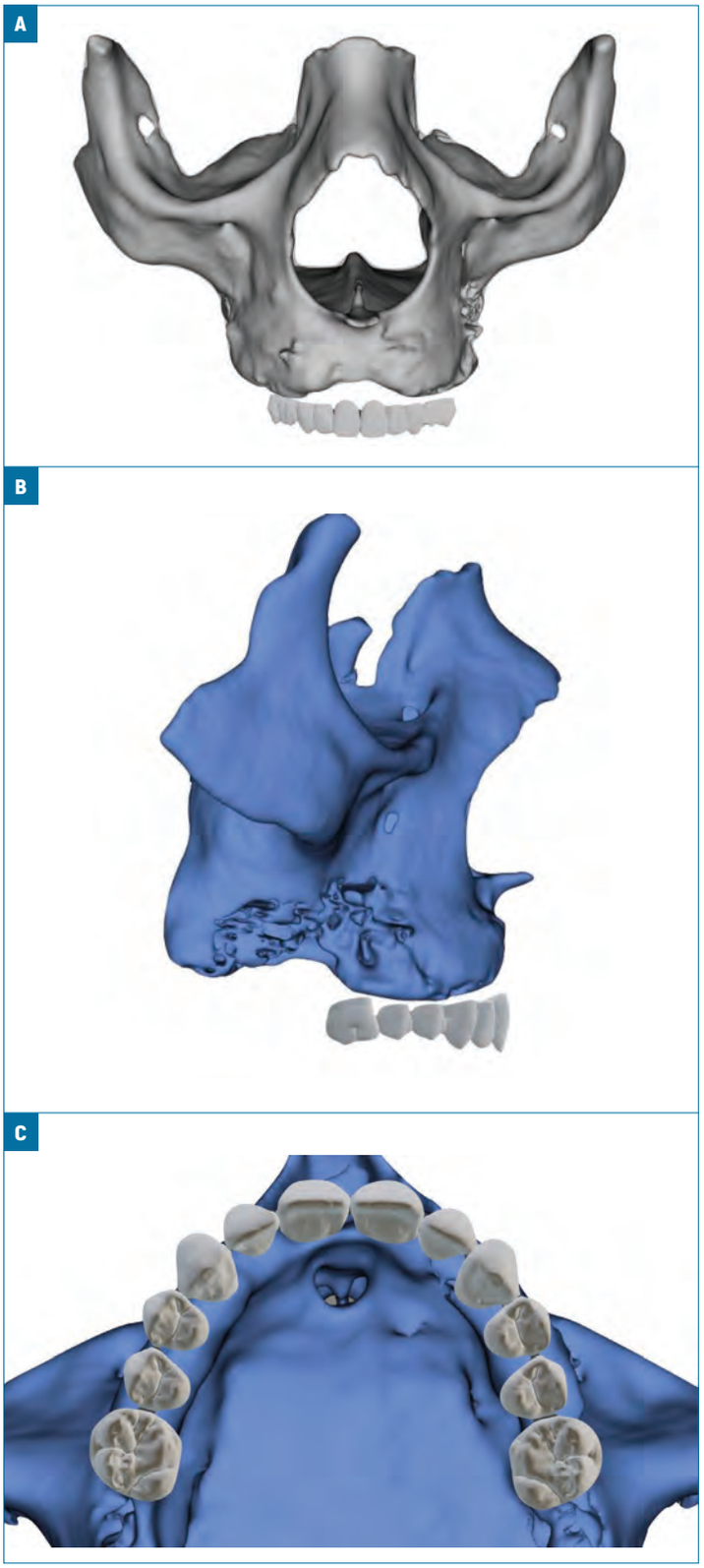
To this end, the DICOM files were imported into dedicated software (RealGuide ver. 5.0, 3DIEMME, Cantù, Italy). Each set of DICOM files was segmented into an STL file, and then matched point by point using same region of interest (ROI, **FIGS. 19, 20**). The matching was improved using a best-fit algorithm. Finally, Boolean operations were performed on the matched STL to subtract the first volume from the second (**FIG. 21**).

Volumetric bone augmentation was then measured automatically on each side using the RealGuide software tool (ver. 5.0, 3DIEMME), and then averaged. Horizontal and vertical linear measurements were made at same three points (mesial, central, distal) for each side, as illustrated in **FIG. 22**, and averaged to evaluate the amount of bone augmentation achieved.

RESULTS

Twelve months after loading, no implant had failed and the prosthesis remained successfully in function. Only one complication was recorded: the left bone lamina became partially exposed seven months after bone augmentation. This exposure was most likely caused by trauma from the removable prosthesis in the oral cavity. The exposed part of the lamina was treated with 0.2% chlorhexidine (Curasept) and scraped out at implant installation surgery.

The mean volumetric bone augmentation was 1.583 cm^3. Mean horizontal bone augmentation was 6.3 mm, while mean vertical bone augmentation was 5.5 mm (**TABLE 1**).



FIGS. 12A-C: *Virtual wax-up after alveolar crest bone regeneration: frontal, lateral and occlusal views.*

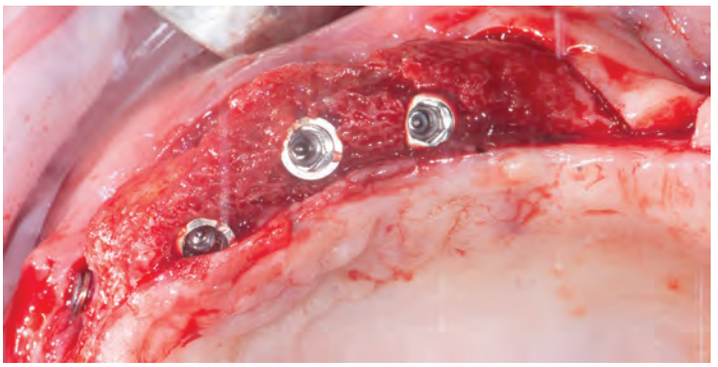


FIG. 13: *Implant installation in the reconstructed ridge, nine months after augmentation.*

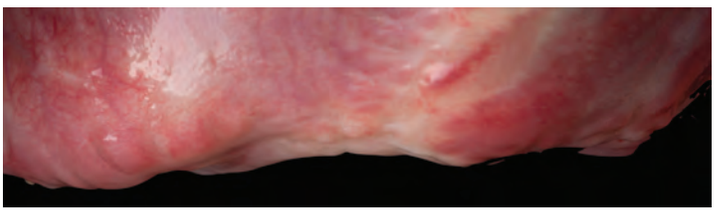


FIG. 14: *Soft tissue before gingival graft: the keratinized mucosa is lacking.*

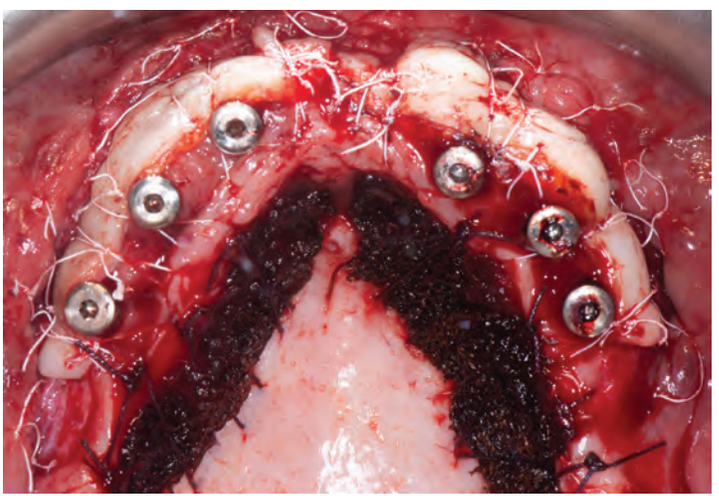


FIG. 15: *Full palatal free gingiva graft.*

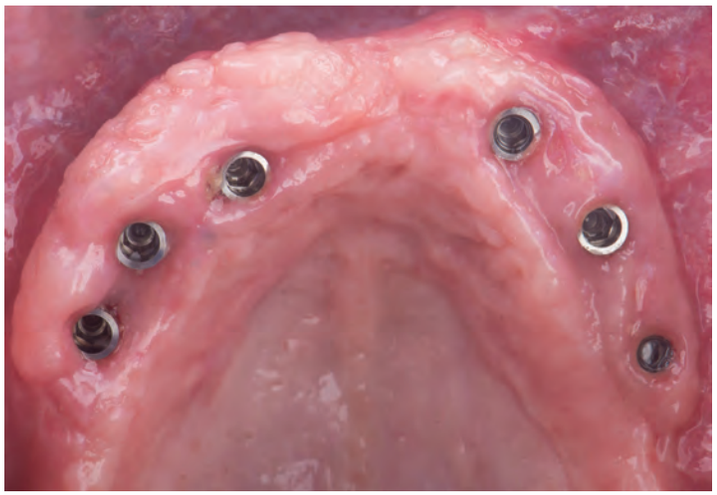


FIG. 16: *Soft tissue healing three months after gingival graft: implants are totally surrounded by keratinized mucosa.*

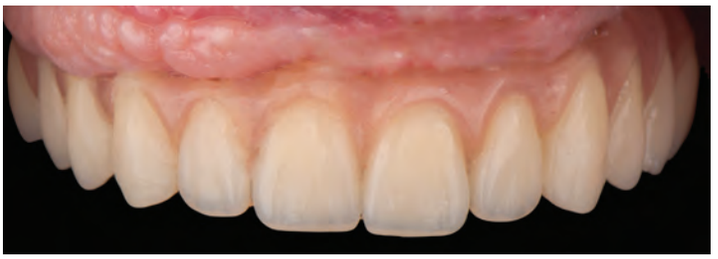


FIG. 17: *Screw-retained metal resin prosthesis 12 months after loading.*

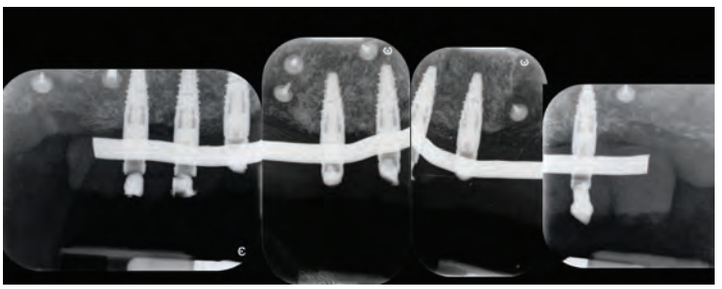


FIG. 18: *Periapical radiographs 12 months after loading.*

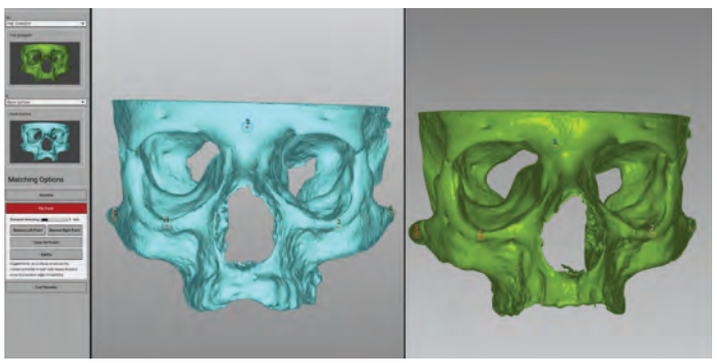


FIG. 19: *Point matching STL to STL: pre and post CBCTs after segmentation.*

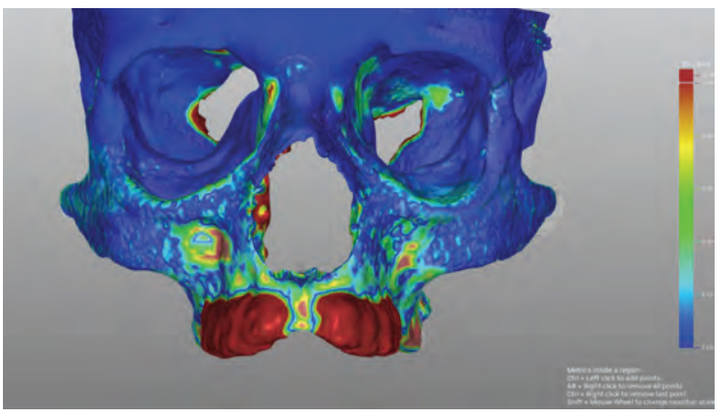


FIG. 20: *Matching between pre and post CBCT (GOM geometry).*

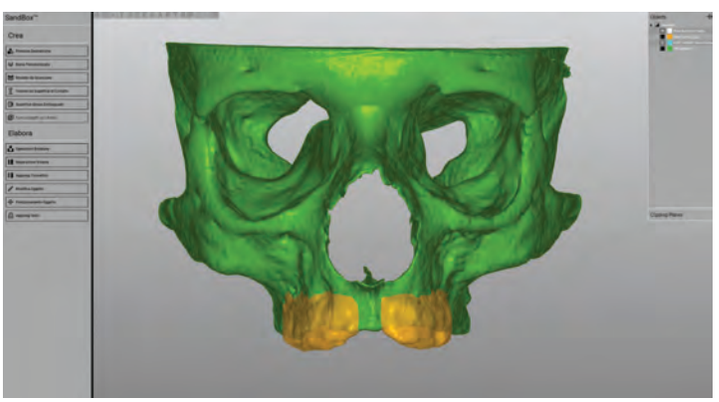


FIG. 21: *Boolean subtraction of the augmented volume.*

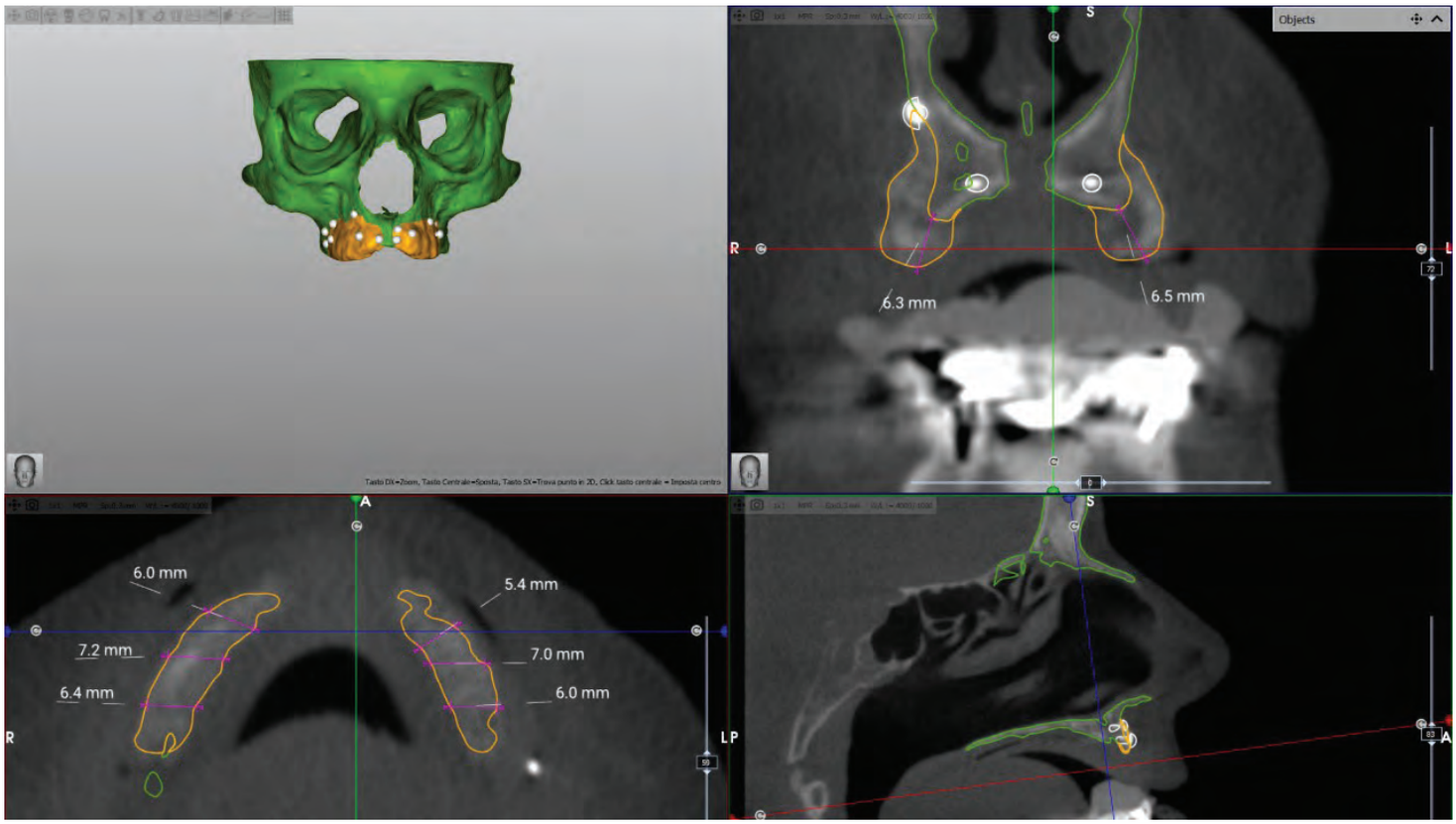


FIG. 22: *Linear horizontal and vertical measurements at three points of interest.*

TABLE 1 VOLUMETRIC AND LINEAR BONE AUGMENTATION

		Mesial	Middle	Distal	Mean
Volume (cm^3)	Right Lamina				1.606
	Left Lamina				1.560
	Mean				1.583
Horizontal (mm)	Right Lamina	6.0	7.2	6.4	6.5
	Left Lamina	5.4	7.0	6.0	6.1
	Mean				6.3
Vertical (mm)	Right Lamina	6.3	6.0	3.8	5.4
	Left Lamina	6.5	5.5	4.7	5.6
	Mean				5.5

DISCUSSION

This case report describes a clinical case of severely atrophic maxilla treated via two CAD/CAM custom-made bone laminas and delayed implant placement. To the best of the authors knowledge, this is the first case treated using the workflow reported.

The main difference with previous similar reports on vertical and horizontal bone augmentation was that in this case a resorbable rigid customized natural mineral bovine bone structure with bioresorbable polymers and collagen fragments was used instead of customized titanium mesh[4,18-20]. Indeed, non-resorbable devices such as titanium grid or e-PTFE titanium-reinforced membrane need to be removed, and in the event of exposure during bone healing, major complications, such as infection, may occur[20].

Some articles have reported interesting preliminary results with the use of customized bovine bone blocks[15]. However, the major drawback of block grafts is the poor vascularization, which could be a problem even with autologous blocks[21].

The case presented here is noteworthy for the combination of digital solutions used, which included CAD/CAM alveolar-ridge augmentation with custom-made bone laminas, guided implant placement, and the design and manufacture of rigid customized materials for bone augmentation.

In the authors' opinion, there are several potential advantages to this approach, specifically:

- the possibility of planning the vertical and horizontal amounts of bone augmentation for guided regeneration in advance in accordance with the virtual implant planning, as described in the computer-guided bone regeneration approach[16]. This option could be especially appealing in aesthetic areas;
- the use of rigid customized resorbable lamina could allow for an easier GBR procedure, unlike e-PTFE membranes, which require specific skills to be shaped and fixed correctly, especially in accordance with prosthetic pre-planning;
- this approach could potentially simplify vertical and horizontal bone reconstructions in severely resorbed ridges;
- the use of resorbable rather than non-resorbable materials could have advantages in term of tissue healing, and in the event of complications such as graft exposure, since it is believed that infections are less likely to occur in the presence of resorbable biomaterials.

On the other hand, there are some possible disadvantages to take into consideration:

- a customized bone lamina is more delicate than a customized titanium grid, and fixation should be performed gently to avoid fractures of the lamina itself;
- other drawbacks are the higher costs, especially as compared to e-PTFE membranes.

CONCLUSIONS

The good results one year after loading should prompt randomized controlled trials to verify the potential clinical advantages of this novel augmentation approach in treating challenging atrophic cases.

ACKNOWLEDGEMENTS

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