KEY WORDS
computer-guided bone regeneration, dental implants, autogenous bone, bone substitute

FUNCTIONAL-AESTHETIC GUIDED IMPLANT PLACEMENT WITH DOUBLE TEMPLATE IN ASSOCIATION WITH ONE-STAGE COMPUTER-GUIDED BONE REGENERATION PROCEDURE FOR AESTHETIC PURPOSES: 18-MONTH OUTCOMES IN A PROSPECTIVE CASE SERIES

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PURPOSE. To evaluate the outcomes of a new computer-guided surgical approach for prosthetically - and aesthetically - driven implant insertion in horizontally atrophic ridges using a double template concept and one-stage guided bone regeneration (GBR) procedure at 1 year and half after loading.

MATERIALS AND METHODS. This study was designed as a prospective case series. Patients in need of rehabilitation with an implant-supported restoration between the upper premolars, Cawood-Howell Class III defects and residual horizontal bone width of less than 6 mm and more than 4 mm were treated with computer-guided implant placement using two templates and simultaneous GBR, and, in cases of bone fenestration with autologous bone, anorganic bovine bone arranged in layers, or in cases of thin buccal bone, using a mix of 20% autologous bone and 80% anorganic bovine bone protected with a resorbable collagen membrane. After 6 months of healing, implants were fitted with temporary screw-retained acrylic resin crowns, and 6 months later permanent screw-retained zirconia-ceramic crowns were delivered. Outcome measures were: implant and prosthesis failures, complications, marginal bone level (MBL) changes, periodontal parameters, and pink aesthetic score (PES).

RESULTS. Twenty-one consecutive patients (mean age 39.2 years) received one computer-guided GBR procedure each, with contemporary placement of 25 conical-connection implants. No patient dropped-out, no implants or prostheses failed, and only two minor complications were observed. Mean marginal bone loss from implant placement up to 18 months after loading was 0.71±0.23 mm (95% CI 0.59 to 0.83 mm), mean BoP was 2.37±5.95 (95% CI -0.17 to 4.92)percent of sites, mean PPD was 2.54±0.49 mm (95% CI 2.35 to 2.73 mm), and mean PES was 11.2±1.2 (95% CI 10.3 to 12.1).

CONCLUSIONS. Acknowledging the limitations of this study, the high survival rate and PES seem to validate the use of a double-template approach in association with one-stage GBR and implant placement in atrophic aesthetic areas. Randomised controlled trials are needed to properly evaluate the utility of this technique versus simple free-hand implant placement with no augmentation procedures.

CONFLICT OF INTEREST STATEMENT. This study was partially supported by Geistlich Biomaterials Italia, Thiene, Italy.

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INTRODUCTION

Although dental implants are a predicable treatment option, implant success can be also related to the amount of crestal bone resorption[1,2]. Adverse local conditions could negatively affect the long-term prognosis of dental implants[3,4]. In 1998, Cawood & Howell classified the size and shape of edentulous jaws into six classes[5]. Within these, class III-IV present a severe horizontal defect known as "knife-edge" ridges. Prosthetically and aesthetically driven implant placement are required to prevent aesthetic complications[6] in such cases, particularly if implants are to be inserted into severely atrophic ridges.

Several techniques for horizontal augmentation of atrophic jaws for implant purposes have been published, performed in either one- (implant placement at the same time as augmentation) or two-stage (implant placement after a period of healing) approaches[7]. Many articles have shown the clinical utility of guided bone-regeneration procedures for crestal bone augmentation using a combination of autologous and heterologous particulate bone with either resorbable or non-resorbable membranes[8-14]; resorbable membranes are more often used due to their easier handling[15-17].

Recently, Meloni et al., in two different prospective studies, demonstrated high survival rates and stable marginal bone remodelling around implants placed in atrophic ridges with implant fenestration or crestal dehiscence and reconstructed with autologous bone and anorganic bovine bone arranged in layers and covered with a collagen membrane[14,18]. Implant placement may also require accurate prosthetically driven positioning. To this end, several articles have shown high survival rate and stable marginal bone remodelling of implants inserted via computer-assisted implant surgery techniques[19-27]. Recently, in a randomised controlled trial (RCT), Tallarico et al. found 0.42 mm less marginal bone loss at implants installed with guided surgery, as compared with a freehand approach[28].

The purpose of this prospective case series was to evaluate a new approach, called "computer-guided bone regeneration", for the rehabilitation of horizontally atrophic ridges. This approach uses a double template for prosthetically and aesthetically driven implant placement in combination with autologous bone and anorganic bovine bone, placed in layers, in association with resorbable collagen membranes. This report was written in accordance with the STROBE (STrengthening the Reporting of OBservational studies in Epidemiology) guidelines[29].

MATERIALS AND METHODS

The present study was designed as a prospective case series. Any partially edentulous patient aged 18 years or older who required at least one implant to be placed between teeth in anterior maxilla (from right to left premolars) with Cawood-Howell Class III defects and residual horizontal bone width between 4 mm to 6 mm was considered eligible for this study, and was treated between December 2015 and October 2016. One clinician (SMM) with expertise in dental implant placement and GBR performed all surgical procedures, and one dentist (MP) experienced in implant-supported prostheses, performed all prosthetic procedures at one private practice centre in Arzachena, Sardinia, Italy. Patients were informed about the nature of the study, and their written consent was obtained.

Patients were not admitted to the study if any of the following exclusion criteria applied:

1. American Society of Anesthesiologist (ASA) class III or IV;
2. Psychiatric contraindications;
3. Pregnancy or breastfeeding;
4. Alcohol or drug misuse;
5. Heavy smoking (>10 cigarettes/day);
6. Radiation therapy to head or neck region in previous 5 years;

7. High or moderate parafunctional activity;
8. Untreated periodontitis;
9. Immediate post-extractive implants;
10. Full mouth bleeding and full mouth plaque index of 25% or higher;
11. Unavailability for regular follow-ups;
12. Two adjacent implants to be inserted.

Surgical and prosthetic protocol

The patients' medical history was collected, and study casts were made. Preoperative photographs (**FIG. 1**) and radiographs, including cone-beam computer tomography (CBCT) scans, were obtained for initial screening and evaluation. After that, the ideal functional and aesthetic position of implants was planned virtually following the Smart Fusion protocol (Nobel Clinician Software, Nobel Biocare, Zurich, Switzerland) by combining the STL files derived from the scanned casts and diagnostic wax-up with the CBCT scan DICOM files (**FIG. 2**). After virtual planning was completed, a computer-guided surgical template for pilot drilling was fabricated (guided template; **FIG. 3**). Then, a second template, with the exact shape and contour of the ideal crown, generated from the scanned wax-up, was manufactured in the technical laboratory (aesthetic template; **FIG. 4**).

Before implant placement, patients received amoxicillin+clavulanic acid 2 g (GlaxoSmithKline, Baranzate, Italy) one hour before surgery and then 1 g twice daily for 1 week. Patients allergic

FIG. 1: *Pre-op picture, frontal view.*

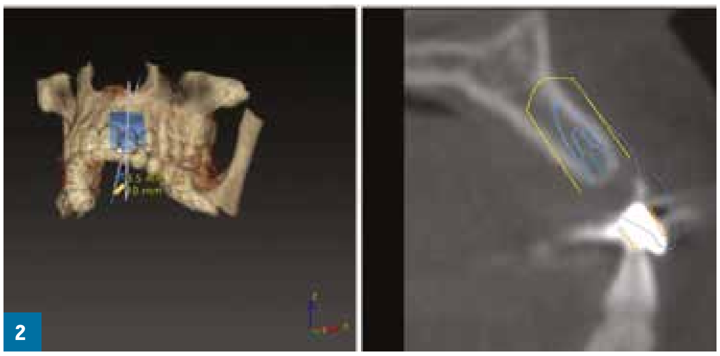

FIG. 2: *3D virtual setup.*

FIG. 3: *Computer-guided template for pilot drill (guided template).*

FIG. 4: *Aesthetic template at the planned final wax-up.*

FIG. 5: *Final implant position in accordance with the aesthetic template planning.*

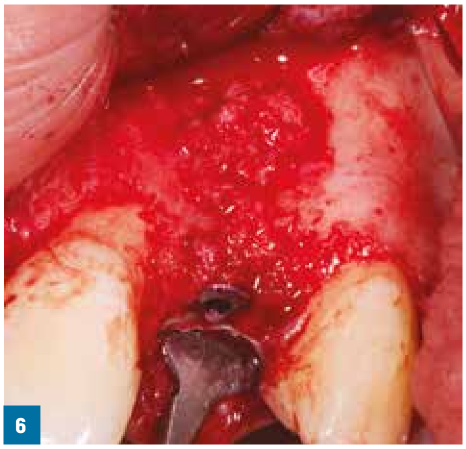

FIG. 6: *Two-mm layer of autologous bone to cover the exposed implant threads.*

to penicillin received clindamycin 600 mg 1 hour before surgery, then 300 mg 4 times a day for 1 week. Patients rinsed with 0.2% chlorhexidine solution (Curasept, Curaden Healthcare, Saronno, Varese, Italy) for 1 minute, and a sterile surgical drape was applied to minimise potential contamination from extraoral sources. Local anaesthetic (Septanest with adrenaline, 1/100,000, Septodont, Saint-Maur-des-Fossés, France) was used.

A midcrestal incision into the keratinized tissue was made, and full-thickness flaps were raised beyond the mucogingival junction and at least 5 mm beyond the bone defect. Two vertical incisions were placed at least one tooth away from the area to receive augmentation. The implant site was prepared using a mixed approach; a pilot drill (2-mm diameter) was used to its full working length to drill pilot holes through the computer-guided surgical template (guided template). Then, the implant site was increased in diameter freehand and the implant placed. The final implant depth was chosen according to the aesthetic template. In particular, the implant neck was positioned 2 to 3 mm apical to the cervical margin of the aesthetic template, depending on the soft tissue thickness and aesthetic requirements. The distance was measured using a periodontal probe (PCP-UNC 15, Hu-Friedy Manufacturing, Chicago, IL, USA. Nobel Biocare Replace tapered CC PMC (Zurich, Switzerland) implants were then installed. When exposed (21 implants) (**FIG. 5**), threads were covered with a first layer of 2 mm of autologous bone harvested locally with a bone scraper (Micross, Meta, Reggio Emilia, Italy) positioned on the titanium surface (**FIG. 6**), and a second layer of 20% autologous bone mixed with 80% anorganic bovine bone (Bio-Oss, Geistlich Biomaterials, Thiene, Vicenza, Italy), covering the top by 2 mm in width (**FIG. 7**). In the event of threads not being exposed (4 implants), only one layer of 2 to 4 mm of 20% autologous bone mixed with 80% anorganic bovine bone (Bio-Oss) was positioned for aesthetic purposes. A resorbable collagen membrane (Bio-gide, Geistlich Biomaterials) was fixed in place using titanium pins (Supertack, MCbio, Lomazzo, Como, Italy; **FIG. 8**). A periosteal incision between the two vertical incisions was performed to allow completely tension-free closure of the flap. Flaps were then sutured in two layers in order to prevent exposure of the resorbable membrane; first, horizontal mattress sutures (4-0 Vycril, Ethicon, Johnson & Johnson, Pomezia, Italy) were first placed 4 mm from the incision line, and then single interrupted sutures were used to close the edges of the flaps (4-0 Vycril, Ethicon). Vertical incisions were sutured with single interrupted sutures. Baseline intraoral radiographs were taken (**FIG. 9**). The single interrupted sutures were

FIG. 7: *Two-mm layer of 80% anorganic bovine bone and 20% autologous bone to cover the layer of autologous bone.*

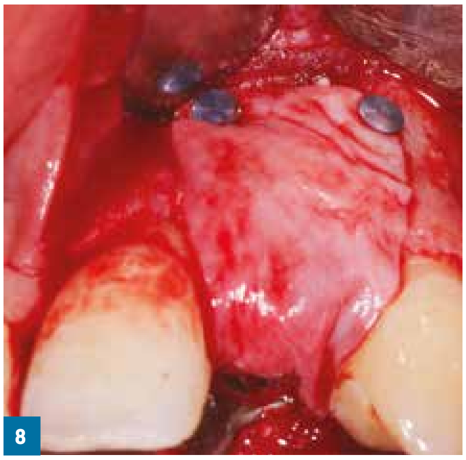

FIG. 8: *Collagen membrane fixed with titanium pins.*

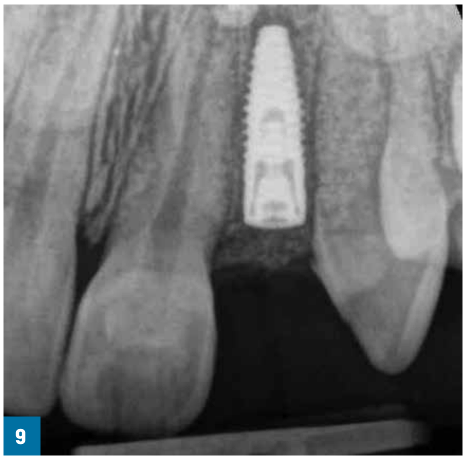

FIG. 9: *Peri-apical x-ray immediate after implant placement.*

FIG. 10: *Connective tissue graft with envelope approach.*

removed between 10 and 14 days post-surgery, and mattress sutures were removed 2 to 3 weeks after surgery.

Postoperatively, 80 mg ketoprofen (Oki, Dompé, Milan, Italy) two or three times daily was prescribed as needed. Betamethasone (Defiante Farmaceutica, Funchal, Portugal) 4 mg on the first day, 3 mg on the second day, 2 mg on the third day and 1 mg on the fourth day, was also prescribed. Patients were instructed to rinse with 0.2% chlorhexidine (Curasept) for 2 weeks, and to adhere to a soft food diet for 10 days. Five months after implant placement, a connective tissue graft harvested from the posterior hard palate was inserted under a split-thickness envelope flap (**FIG. 10**) and healing abutments were connected to the implants.

Six months after implant placement, temporary acrylic crowns were delivered (**FIG. 11**). Six months later, after complete soft tissue remodelling (**FIG. 12**), Computer Aided Designed/Computer Aided Manufactured (CAD/CAM) screw-retained, zirconia ceramic crowns were delivered. All patients were followed-up to 12 months after final loading (**FIGS. 13, 14**), equivalent to 2 years after implant placement and 18 months after loading.

Outcomes measures

Primary outcome measures were the following.

- Implant/crown failure: removal of implants dictated by implant mobility, progressive marginal bone loss, infection, or implant fracture. Crowns were considered failures in the event of fracture or implant failure. The stability of individual implants was assessed by the prosthodontist at the time of temporary and definitive crown delivery by applying 35 Ncm of removal torque. Twelve months after final crown delivery (2 years after implant

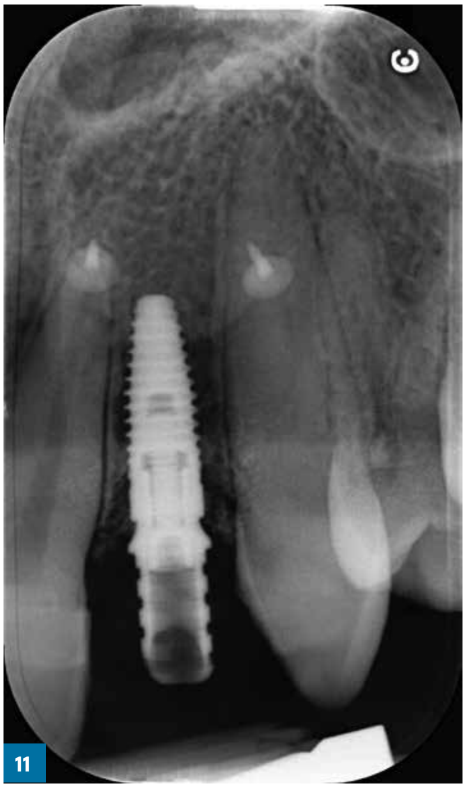

FIG. 11: *Peri-apical x-ray at loading with temporary crown.*

FIG. 12: *Complete soft tissue healing, occlusal view.*

FIG. 13: *Permanent crown 12 months after final loading.*

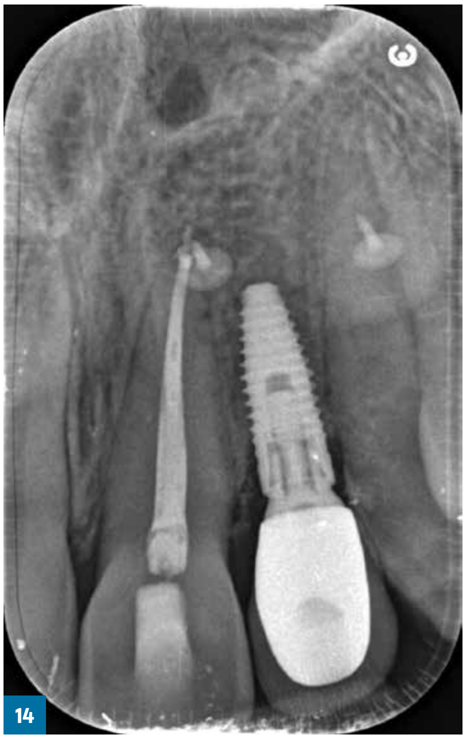

FIG. 14: *Peri-apical x-ray 18 months after loading. The central incisor was endodontically treated in another office in Dublin after a trauma-related injury.*

placement) implant stability was tested manually by the same prosthodontist with two dental mirror handles.
- Complications: any tissue complications, such as membrane exposure, subsequent infection, and/or morbidity associated with the harvest site, as well as any prosthetic complications, such as fractures or chipping of the provisional or definitive ceramic crown, abutment mobility, or biological complications, such as wound or implant infection, mucositis, abscesses, or peri-implantitis, were recorded.

Secondary outcome measures were the following.
- Peri-implant marginal bone loss: the distance from the most coronal margin of the implant collar and the most coronal point of bone-to-implant contact, evaluated on intraoral digital radiographs taken using the paralleling technique and a film-holder (Rinn XCP, Dentsply, Elgin, IL, USA) at implant placement, final loading and 18 months after loading (2 years after implant placement). The radiographs were accepted or rejected for evaluation based on the clarity of the implant threads. All readable radiographs were displayed using image analysis software (DFW2.8 for windows, Soredex) on a 24-inch LCD screen (iMac, Apple, Cupertino, CA, USA). The software was calibrated for each single image using the known distance between two adjacent threads. Measurements of the mesial and distal bone crest levels adjacent to each implant were made to the nearest 0.01 mm by a dentist (MT), and averaged at implant level and then at patient level.
- Soft tissue parameters: probing pocket depth (PPD) and bleeding-on-probing (BoP) were measured by an operator not otherwise involved in the present study (G.S., Giovanni Spano), using a periodontal probe (PCP-UNC 15) at definitive restoration delivery and again 12 months later (2 years after implant placement). Probing pocket depth was measured as the distance (in mm) between the gingival margin to the bottom of the gingival sulcus. The BoP was expressed as the number of sites with positive BoP. Three vestibular and three lingual measurements were collected for each implant, and averaged at site level and then at patient level.
- Aesthetic parameters*:* the pink aesthetic score (PES)[30] was assessed on vestibular images including at least one adjacent tooth per side. PES values were assessed at follow-up examinations at final loading and 12 months after final loading. Seven variables (mesial papilla, distal papilla, soft-tissue level, soft-tissue contour, alveolar process deficiency, soft-tissue colour and texture) were assessed on a 2-1-0 scale (2 being best and 0 being poorest) by the same blinded dentist (G.S.).

Statistical analyses

An *a priori* sample size was not calculated. Data analysis was carried out according to a pre-established analysis plan. A clinician (MT) analysed the data using SPSS for Windows 18.0 (SPSS, Chicago, IL, USA). Descriptive analysis was performed for numeric parameters using means ± standard deviations (95% confidence interval, CI). Comparisons of patient means for continuous outcomes (marginal bone loss, aesthetic parameters, BoP and PPD) at each time point with respect to baseline measurements were made using paired t-tests. All statistical comparisons were conducted at the 0.05 level of significance.

RESULTS

Twenty-nine patients were screened for eligibility, but 8 patients were not enrolled in the study due to their refusal to adhere to the established follow-up. Twenty-one consecutive patients (seven males and 14 females; mean age 39.2 years, range 22 to 64), with 25 implant sites classified as Cawood-Howell Class III[4], received one GBR procedure each, with contemporary placement of 25 conical-connection implants (Nobel Biocare Replace tapered CC PMC), 10-13-mm length RP platform 11 implants, NP Platform 14 implants. Only implants between teeth were included in the study. At follow-up examination 18 months after loading, no patient had dropped out and no deviation from the original protocol had occurred. All data collected were included in the statistical analysis. No implant failed. However, in two patients the collagen membrane was slightly exposed 1 to 2 weeks after bone augmentation. Patients with soft tissue exposures were treated using local application of chlorhexidine gel 0.5% (Curasept ADS 0.5% gel, Curaden Healthcare) twice per day, for 3 weeks. Complete soft tissue healing was observed in both cases.

The mean marginal bone level at implant placement was 0.15±0.07 mm (95% CI 0.12 to 0.18 mm), and at 12 months after final loading (18 months after loading) it was 0.86±0.33 mm (95% CI 0.73 to 0.99mm). The mean marginal bone loss from baseline to final loading was 0.47±0.17 mm (95% CI 0.41 to 0.54 mm), while the mean marginal bone loss from implant placement (baseline) to 18 months after loading (12 months after final loading) was 0.71±0.23 mm (95% CI 0.59 to 0.83). The difference from baseline to 12 months after final loading was statistically significant (P value 0.000) (**TABLES 1A, 1B**).

The mean BoP measured at definitive restoration delivery was 3.18±8.49 (95% CI -0.45 to 6.81) percentage of sites. One year later, the mean BoP was 2.37±5.95 (95% CI -0.17 to 4.92) percentage of sites. The difference was not statistically significant 0.81±3.62 (95% CI -0.74 to 2.35; P = 0.319; **TABLE 2**).

The mean PPD value measured at definitive restoration delivery was 2.57 mm ±0.51 (95% CI 2.37 to 2.77). One year later, the mean PPD was 2.54 mm ±0.49 (95% CI 2.35 to 2.73). The difference, 0.03 mm ±0.32, was not statistically significant (95% CI -0.10 to 0.15 mm; P = 0.679; **TABLE 3**).

At definitive crown delivery, the mean PES was 11.2±1.2 (95% CI 10.3 to 12.1). One year later, the

TABLE 1A MEAN MARGINAL BONE LEVELS (MM)

	Mean±SD	95% CI
Baseline	0.15±0.07	0.12 to 0.18
Final loading (12 months after loading)	0.62±0.16	0.56 to 0.69
12 months after final loading	0.86±0.33	0.73 to 0.99

**Values represent mean ± SD (patients n = 21)*

TABLE 1B MEAN MARGINAL BONE LOSS (MM)

	Mean±SD	95% CI	P value
Baseline/final loading	0.47±0.17	0.41 to 0.54	0.000
Final loading/12 months after final loading	0.23±0.26	0.13 to 0.34	0.001
Baseline/12 months after final loading (18 month after initial loading)	0.71±0.23	0.59 to 0.83	0.000

**Values represent mean ± SD (patients n = 21)*

TABLE 2 MEAN BOP VALUES AND DIFFERENCE

	Mean±SD	95% CI	P value
Final loading	3.18±8.49	-0.45 to 6.81	
12 months after final loading	2.37±5.95	-0.17 to 4.92	
Mean difference	0.81±3.62	-74 to 2.35	0.319

Values represent mean ± SD (patients n = 21)

TABLE 3 MEAN PPD VALUES AND DIFFERENCE (MM)

	Mean±SD	95% CI	P value
Final loading	2.57±0.51	2.37to 2.77	
12 months after final loading	2.54±0.49	2.35 to 2.73	
Mean difference	0.03±0.32	-0.10 to 0.15	0.679

Values represent mean ± SD (patients n = 21)

TABLE 4 MEAN PES VALUES AND DIFFERENCE

	Mean±SD	95% CI	P value
Final loading	11.2±1.2	10.3 to12.1	
12 months after final loading	11.4±1.1	11.0 to 11.9	
Mean difference	0.2±0.7	0.00 to 0.4	0.078

Values represent mean ± SD (patients n = 21)

mean PES was 11.4±1.1 (95% CI 11.0 to 11.9); the difference, 0.2±0.7, was not statistically significant (95% CI 0.0 to 0.4; P = 0.078; **TABLE 4**).

DISCUSSION

The aim of this prospective case series was to investigate the clinical and radiographic outcomes of computer-guided implant placement using a double-template approach in association with one-stage GBR procedures using collagen membranes, autologous bone and anorganic bovine bone in atrophic anterior maxillae 12 months after definitive loading. When restoring upper jaws missing front teeth, achieving a valid aesthetic result is often a challenge[31,32], and bone reconstruction and soft tissue grafts are often required in frontal areas in order to re-establish aesthetics.

Although a guided approach in combination with titanium grid in not aesthetic areas has previously been reported[33], no other studies have previously investigated the use of guided surgery in association with one-stage GBR procedures; consequently, no comparisons are possible. Nevertheless, several considerations can be made if our findings are compared with studies on one-stage GBR; we combined anorganic bovine bone and autologous bone in layers according to the sandwich technique described by Wang et al.[15]. The materials were applied in two different layers, potentially combining the advantages of both with those of collagen membranes[14], although no trials have yet been conducted to test this hypothesis. That being said, our findings seem to confirm other reports on the use of bone grafting materials and resorbable membranes to treat horizontal bone fenestration[13,18].

Despite the lack of any scientific evidence, one aspect to underline is the importance of prosthetically driven implant placement to achieve an ideal aesthetic outcome. In our opinion, this should be associated with three-dimensional implant insertion in accordance with the final aesthetic wax-up, which is why we propose here a new combined approach featuring computer-based aesthetic planning in association with GBR in cases of bone fenestration or thin buccal bone, the so-called "computer-guided bone regeneration" approach. This approach aims to combine the efficiency of guided implant installation in term of mesio-distal distances and the aesthetically driven installation in term of apico-coronal implant position, and our experience was that this approach facilitated the achievement of a biomimetic emergence profile.

The main limitations of the present study were the lack of control group, the low number of patients, the relatively short follow-up, and the self-assessment of failures and complications. We are therefore as yet unable to provide firm scientific evidence supporting (or not) the more invasive procedure we propose as compared to simple implant placement with no grafting or simple soft tissue grafting in term of implant success or even aesthetic outcomes; based on the high implant survival rate and high PES values seen in our case series, however, RCTs to compare this technique with other, simpler procedures are warranted. The approach we propose requires skills in guided surgery, GBR procedures and soft tissue management. That being said, other trained dentists should be able to achieve similar results when applying the same technique in patients with similar characteristics.

CONCLUSIONS

Within the limitations of the present study, the high implant survival rate and high PES values we document seem to validate the use of a double-template approach in association with one-stage GBR procedures with resorbable membranes when installing implants in moderately atrophic aesthetic areas in the presence of bone fenestration or thin buccal bone. However, RCTs are needed to evaluate the actual effectiveness of this approach.

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