CLINICAL ORAL IMPLANTS RESEARCH

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A randomized clinical trial evaluating the efficacy of the sandwich bone augmentation technique in increasing buccal bone thickness during implant placement surgery

I. Clinical and radiographic parameters

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Abstract

Objectives: Sandwich bone augmentation (SBA) has been proposed to augment the width of edentulous ridges for implant placement. This study aimed to investigate the effect of a membrane on SBA for the regeneration of buccal implant dehiscence defects.

Material and methods: Twenty-six healthy patients, each with a single defect, were randomly assigned into two groups. Both groups received an inner and outer layer of mineralized human cancellous and cortical particulate allograft. In the test group, a bovine pericardium membrane covered the bone grafts, while no membrane was placed in the control group. Cone beam computed tomography (CBCT) scans were taken before and immediately after implant placement and at 6 months post-surgery.

Results: All implants placed were successfully osseointegrated at 6 months. Clinical re-entry measurements showed significant buccal bone gain in the test group compared with the control group ($P < 0.05$). The test group had 1.12, 2.21 and 2.44 mm more buccal bone thickness at 2, 4 and 6 mm below the bone crest. There were no significant differences in the mid-buccal vertical bone height, defect height and width reductions and bone fill between the two groups ($P > 0.05$). Cone beam computed tomography analysis demonstrated significant buccal bone gain of 1.22 mm in the test group. Radiographic vertical bone loss at 1-year post-surgery showed no significant differences between the groups.

Conclusion: Sandwich bone augmentation is a predictable technique for regenerating buccal bone on implant dehiscence defects. Addition of a barrier membrane prevented significant horizontal buccal bone resorption as space was maintained more effectively when compared with sites treated without a membrane.

Research has shown that a dental implant placed in a non-ideal three-dimensional position may lead to peri-implantitis, functional and esthetic failure and eventual removal of the implant (Szmukler-Moncler et al. 1998; Fu et al. 2012). To obtain optimal function and esthetics, the position of the implant in the arch has to be in a biologically accepted and prosthetically driven location (Buser et al. 2004; Bashutski & Wang 2007). When the implant is placed in a compromised position, for example, a bone-dictated position, the use of angulated abutments and/or pink porcelain may be inevitable. In addition, the resulting non-axial masticatory forces directed on the implant-supported restoration may increase the risk of prosthetic complications, such as abutment screw loosening, and fracture of veneering material, abutment, screw and/or the implant fixture itself (Fu et al. 2012). Taking all into consideration, performing predictable bone augmentation procedures to ensure the proper position of the implant in the arch is preferred.

Despite the availability of different techniques, guided bone regeneration (GBR) has been widely used for implant site development (Hammerle et al. 2002; Aghaloo & Moy

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2007). It is because this technique is predictable, easy to use and relatively less invasive compared with other advanced bone grafting methods (Lee et al. 2009). This technique can be performed prior to (Buser et al. 1995, 1996) or simultaneously with implant placement (Oh et al. 2003; Wang et al. 2004; Park & Wang 2006; Park et al. 2008; Lee et al. 2009) and is typically used with bone grafts, such as autograft, allograft or xenograft, and non-resorbable and absorbable barrier membranes.

In recent years, a novel bone grafting procedure known as the sandwich bone augmentation (SBA) technique has been proposed and developed (Oh et al. 2003; Wang et al. 2004; Park et al. 2008; Lee et al. 2009). This procedure, which is performed simultaneously with implant placement, utilizes cancellous and cortical bone allografts in separate layers together with a collagen barrier membrane to simulate a healing environment similar to the composition of native bone. This concept uses the different healing properties of particulate cortical and cancellous bone allografts to achieve bone regeneration. The inner cancellous layer undergoes creeping substitution, which allows for faster bone resorption and apposition, thus facilitating earlier osseointegration and improved bone-to-implant contact. The outer cortical layer undergoes reverse creeping substitution, where bone resorption occurs before bone apposition, thus demonstrating better space maintenance property (Burchardt 1983). Compared with xenografts, allografts have demonstrated complete resorption and thus were selected for this procedure (Skoglund et al. 1997). Other studies have compared the effect of various barrier membranes for bone regeneration of peri-implant defects, and no significant differences between dissimilar membranes were reported (Oh et al. 2003; Park et al. 2008). However, there are limited human clinical trials investigating the use of a bovine pericardium membrane and mineralized bone allografts with the SBA technique in bone regeneration.

Therefore, this study was designed to investigate the efficacy of a bovine pericardium membrane (CopiOs® pericardium membrane; Zimmer Dental Inc., Carlsbad, CA, USA) and mineralized human allograft (Puros®; Zimmer Dental Inc.) in augmenting facial or buccal implant dehiscence defects using the SBA technique. The study objectives were to determine whether there were differences in horizontal bone width gains at different levels on facial or buccal implant dehiscence defects between the test (with pericardium membrane) and control (without pericardium membrane) groups and to determine the incidence of membrane exposure and its effect on horizontal bone width gain.

Material and methods

Patient recruitment

This 12-month-long randomized, controlled, single-masked, clinical trial received approval from the University of Michigan Institutional Review Board (Study e-Research ID: HUM0 0026657) to be conducted from January 15, 2009 to September 19, 2011 (Appendix S1). From the patient population at the University of Michigan, School of Dentistry, 116 patients were screened and 26 patients were recruited into this study, thus achieving a statistical power of 80%. The primary researcher (JHF) screened the patients according to the inclusion and exclusion criteria (Table 1) and enrolled those who fulfilled the criteria for this study. A signed informed consent was subsequently obtained. The enrolled patients were randomly assigned to two experimental groups with 13 patients each in the test and control groups. The process of randomization involved the primary researcher (JHF) picking a number from an enclosed brown bag. Patients who had number '0' were allocated to the control group, while those with number '1' were allocated to the test group.

The control group was treated with the SBA technique, which used only cancellous and cortical particulate allograft (Puros®; Zimmer Dental Inc.) as the inner and outer layers, respectively. The test group was treated in a similar manner but a bovine pericardium membrane (CopiOs® pericardium membrane; Zimmer Dental Inc.) was used to protect the bone grafts, when augmenting the facial or buccal implant dehiscence defect.

Pre-surgical procedures

After the patients were enrolled in the study, a comprehensive oral examination was performed and a baseline periapical radiograph of the surgical site was taken using a radiographic positioning device (XCP®; Rinn Corp., Elgin, IL, USA) and the paralleling technique. Plaque (O'Leary et al. 1972) and Gingival Index (Loe 1967) scores were determined at baseline and during each follow-up appointment. A baseline cone beam computed tomography (CBCT) scan was taken to determine the initial residual ridge width of each patient.

A customized measuring template was fabricated on the study model using light-cured acrylic resin (Triad® TruTray™; Dentsply, York, PA, USA). The measuring template was designed to fit onto the occlusal surfaces of the adjacent teeth to be stable and reproducible. A vertical guide was positioned at 4 mm buccal to the edentulous site and secured onto the occlusal portion of the measuring template (Fig. 1), thus serving to standardize the amount of bone graft placed buccal to the exposed implant surface. After the flap was reflected, grooves at 2 mm intervals, starting from the ridge crest to 6 mm apical to the crest, were made on to the vertical guide.

Surgical templates to serve as guides for the three-dimensional positioning of the implant were fabricated based on the prosthetic location of the restoration using light-cured acrylic resin (Triad® TruTray™; Dentsply; Shotwell et al. 2005). A removable, tooth-supported provisional acrylic prosthesis (Essix; Dentsply®) was fabricated for the purpose of protecting the surgical site from mechanical trauma and soft tissue contact during the healing period.

Table 1. **Inclusion and exclusion criteria**

Inclusion	Exclusion
At least 18 years old, but not more than 80 years old	Poor oral hygiene
Systemically healthy	Severe parafunctional habits, for example, bruxing and clenching
Has good dental health	Untreated oral diseases, for example, periodontitis and caries
Missing a single tooth in the maxillary anterior and premolar region	Maxillary sinus involvement
Crestal residual ridge width of $\leq$4 mm and/or associated with an obvious buccal deficiency	Conditions that complicate wound healing, for example, uncontrolled diabetes (defined as HBA1c level >7%) or smoking
Residual ridge with an adequate band of keratinized tissue ($\geq$2 mm)	Conditions that might lead to a possibly lowered regenerative capacity of the bone, for example, osteoporosis and Paget's disease
Residual ridge with sufficient vertical bone height to safely place a $\geq$ 10 mm long dental implant	Pregnant or expecting to be pregnant
	History of drug and alcohol abuse
	On certain medications like bisphosphonates or steroids currently or within the past three months

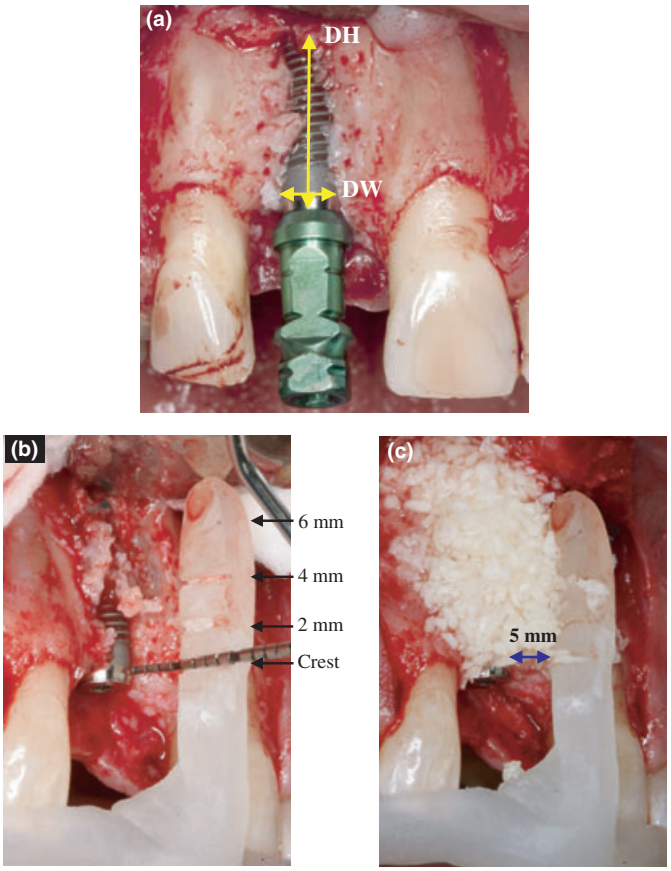

Fig. 1. Defect measurement. (a) Measuring defect height (DH) and width (DW). (b) Measuring defect depth (DD) at crest (DD0), 2 mm (DD2), 4 mm (DD4) and 6 mm (DD6) apical to crest. (c) Amount of bone graft added fixed at 5 mm buccal to the implant surface.

Surgical procedures

All surgical procedures were performed under local anesthesia using local infiltrations of 2% lidocaine with 1 : 50,000 and 1 : 100,000 epinephrine by one surgeon (HLW). One examiner (JHF), who was calibrated before and during the study, performed all clinical measurements. Soft tissue thickness, at 4 mm apical to the ridge crest, was measured using the customized measuring template and an endodontic file (K-flex file s#30; Dentsply International) with a rubber stopper. The distance marked by the rubber stopper was measured using an endodontic finger ruler (Hu-Friedy, Chicago, IL, USA), rounded up to the nearest 0.25 mm.

At the residual ridge, a crestal incision was made 1–2 mm lingual to the mid-point of the crestal bone. Bilateral vertical releasing incisions were made at line angles, one tooth away from the edentulous site, beyond the mucogingival junction. Full thickness mucoperiosteal flaps were elevated on the buccal and palatal sides to access the deficient residual ridge. The exposed bone surface was curetted and irrigated with saline to remove all tissue tags and granulation tissue.

The ridge width was measured using a caliper (Iwanson; Hu-Friedy) at 1 and 3 mm below crest. Implant site osteotomy was performed using the surgical template and a series of drills with increasing diameters at 1200 rpm under copious irrigation. A standard narrow or regular platform implant of 3.7 or 4.1 mm diameter by 11.5 or 13 mm length (Tapered Screw-Vent®; Zimmer Dental Inc.) was placed with 35 Ncm torque. The implant platform was placed flushed with the ridge crest. Primary implant stability was checked physically by tightening and loosening the flat cover screw with rotational motions. Using the customized measuring template and a periodontal probe (UNC Probe; Hu-Friedy), the facial concavity, rounded up to the nearest 0.5 mm, was measured from the implant surface to the inner surface of the template at crest, 2, 4 and 6 mm below crest.

To promote angiogenesis and stimulate regional acceleratory phenomenon (Frost 1983), decortication of the adjacent bone surfaces using a quarter round diamond bur under copious irrigation was performed. A layer of particulate cancellous allograft (Puros®; Zimmer Dental Inc.) was applied onto the exposed implant surface until it was level with the adjacent bone. Subsequently, a second layer of slow-resorbing particulate cortical allograft (Puros®; Zimmer Dental Inc.) was placed the outermost surface of the graft and in contact with the inner surface of the measuring template. As such, the use of the customized template standardized the placement of graft material to be 5 mm buccally from the exposed implant surface (Fig. 1). In the control group, the bone grafts were not covered with a membrane. In the test group, the bone graft was covered with a bovine pericardium membrane (CopiOs®; Zimmer Dental Inc.), which was trimmed to the appropriate size and shape before being closely adapted to the bone graft. No additional fixation of the membrane was performed.

Periosteal releasing incisions were made if there was inadequate coverage of the grafted site when the buccal and lingual flaps were approximated. The flaps were brought together passively and sutured closed with 4.0 and 5.0 resorbable sutures (Vicryl®; Ethicon Inc., Somerville, NJ, USA). Primary wound closure in a tension free approach was thus achieved. A periodontal dressing (Coe-Pak; GC America Inc., Alsip, IL USA) was placed securely over the surgical site. Post-surgical CBCT scan and periapical radiographs were taken. The periodontal dressing and sutures were removed at day 14, with the exception that if the sutures at the mid-crestal incision were tight and in place, they were removed at day 30 instead. The patient returned for follow-up checks at days 60 and 90, where oral hygiene and postoperative wound healing were evaluated.

At day 180, a CBCT scan and periapical radiograph of the surgical site were taken. A re-entry surgery to assess bone healing was performed. Similar to the first surgery, full thickness mucoperiosteal buccal and palatal flaps were elevated to expose the graft site. The exposed bone surface was curetted and irrigated with saline to remove all tissue tags and granulation tissue. Clinical measurements were made in a similar fashion as the first surgery. The healing abutment was subsequently installed. The flaps were approximated and sutured around the healing abutment with 4.0 and 5.0 resorbable sutures (Vicryl®; Ethicon Inc.). The interim prosthesis was adjusted and fitted with no contact at the surgical site.

The sutures were removed at day 194. The patient returned for a follow-up check at day 208 where the prosthetic phase of treatment started with taking a maxillary polyvinyl siloxane impression (Aquasil impression material; Dentsply International) of the implant site.

The definitive implant abutment and crown were subsequently delivered. Patients returned for a 1-year post-surgical evaluation, and clinical and radiographic examinations were performed. Figs 2 and 3 illustrate the treatment rendered to the control and test groups, respectively, during the study.

Radiographic analysis

Periapical radiographs of the surgical site, taken using the paralleling technique, were used to evaluate the change in interproximal bone levels adjacent to the dental implant at three different time points: implant placement (day 0), second stage (day 180) and 1-year post-surgical evaluation (day 360). The distance from the implant platform to the bone crest at the mesial (M) and distal (D) surfaces of the implant was measured under a magnification of 2.5× using a digital caliper, rounded up the nearest 0.01 mm.

CBCT analysis

All patients received three CBCT scans of the maxilla at three different time points: before implant placement (baseline), immediately after implant placement (day 0) and immediately before second-stage surgery (day 180). A scan of the maxilla was taken using the CBCT machine (i-CAT Cone Beam Computed Tomography machine; Imaging Sciences International Inc., Hatfield, PA, USA) in the Radiology Department at the University of Michigan by a radiologist (EB) at a tube voltage of 120 kVp, tube current of 18.66 mA (36.53 mAs), voxel resolution of 0.4 mm and field of view of 6 cm for a scan time of 20 s. The data images obtained were reconstructed using the software (iCAT-Vision™ 1.9; Imaging Sciences International Inc.) in the CBCT machine.

For all CBCT scans, the sagittal view of the maxilla was adjusted such that the long axis of the canine nearest to the surgical site was perpendicular to the floor. The coronal and axial views were adjusted such that they were centered. The focal trough was determined at the center of the maxillary arch. Under a magnification of 2.5×, the mid-sagittal image of the implant and surrounding bone and structures from the second CBCT scan was printed and traced onto a transparent slide. The traced image with a line marking the long axis of the implant was superimposed onto printed mid-sagittal views of the implant and surrounding bone and structures from the first and third CBCT scans. The mid-sagittal view of the implant and the long axis of the implant in the second CBCT scan served as the reference image and line for the first and third CBCT scans from which horizontal bone width gains were measured. All measurements were performed using a digital caliper under a magnification of 2.5× by 1 calibrated examiner (JHF). On the first CBCT scan, the ridge width was measured from the outer surface of the buccal bone to the outer surface of the lingual bone perpendicular to the line marking the long axis of the implant at two levels – at 1 and 3 mm apical to crest. On the second and third CBCT scans, the phenomenon of partial volume averaging around the dense implant fixture was considered. Hence, an outline of the implant, based on the dimensions placed, was drawn centered around the line marking the long axis of the implant. The horizontal bone width changes were measured from the outermost buccal surface of bone or implant to the outline of the implant fixture at four different levels – at implant platform (bone crest), at 2 mm, at 6 mm apical to the crest and apical end of implant.

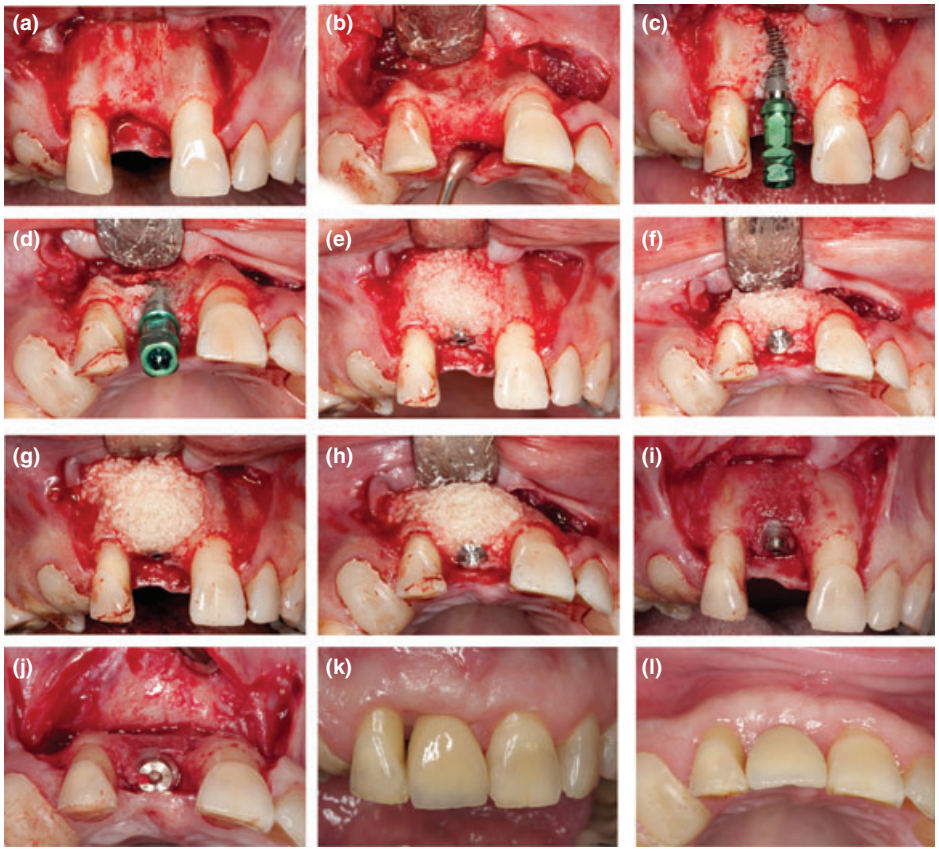

Fig. 2. Clinical photographs illustrate the treatment rendered to the control group. (a, b) Buccal and occlusal views of defect at baseline. (c, d) Buccal and occlusal views of implant placement. (e, f) Placement of Puro® cancellous particulate allograft. (g, h) Placement of Puro® cortical particulate allograft. (i, j) Buccal and occlusal views of surgical site after 6 months of healing. (k, l) At 1-year re-evaluation.

Parameters

Table 2 is a summary of the clinical and CBCT parameters that were analyzed. The clinical parameters measured were as follows:

- Gingival thickness (GT) at 4 mm below the ridge crest at the buccal surface
- Horizontal ridge width at 1 mm (CRW) and 3 mm below crest (CRW3)
- Defect height (DH) taken from the implant platform to the most apical point of the defect
- Defect width (DW) taken as the widest part of the defect
- Defect depth (DD) taken as distance from the implant or bone surface to the inner surface of the measuring template at four levels: Crest (DD0), 2 mm below (DD2), 4 mm below (DD4), 6 mm below (DD6)
- Amount of Horizontal Bone Gain (HBG) taken as the difference between DD at baseline and at Day 180
- Amount of Horizontal Bone Gain at crest (HBG0), 2 mm (HBG2), 4 mm (HBG4) and 6 mm (HBG6) below crest
- Percentage of Defect Height Reduction (% DHR) = [(Baseline DH – Day 180 DH)/ Baseline DH] × 100%
- Percentage of Defect Width Reduction (% DWR) = [(Baseline DW – Day 180 DW)/ Baseline DW] × 100%

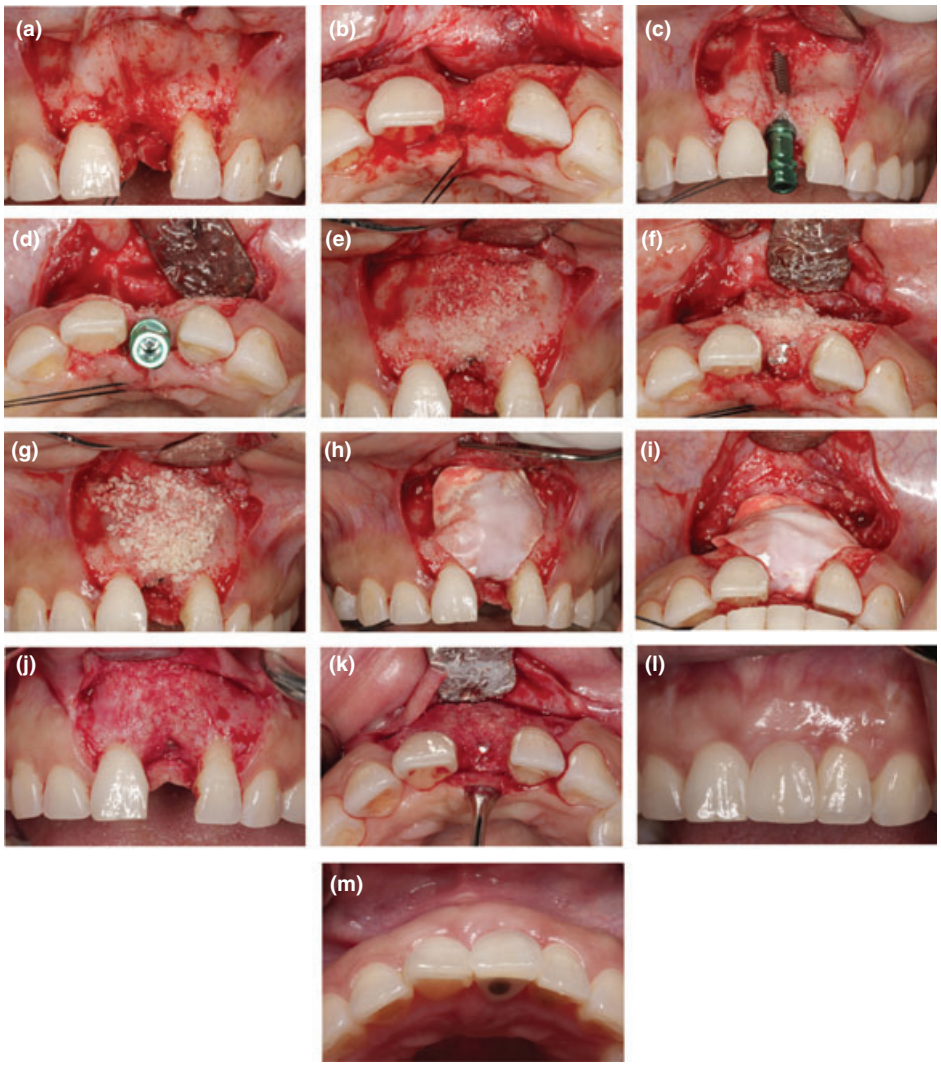

Fig. 3. Clinical photographs illustrate the treatment rendered to the test group. (a, b) Buccal and occlusal views of defect at baseline. (c, d) Buccal and occlusal views of implant placement. (e, f) Placement of Puro® cancellous particulate allograft. (g) Placement of Puro® cortical particulate allograft. (h, i) CopiOs® pericardium membrane placed. (j, k) Buccal and occlusal views of surgical site after 6 months of healing. (l, m) At 1-year re-evaluation.

- Exposed Surface Area of Implant (ESA) = DH × DW × ¼ π (equivalent to 0.785)
- Percentage of Bone Fill (%BF) = [(Baseline ESA − Day 180 ESA)/Baseline ESA] × 100%

The radiographic parameters measured were as follows:

- Ridge width at 1 mm apical to crest (CBCT-CRW) and 3 mm apical to crest (CBCT-CRW3) at baseline, day 0 and day 180
- Horizontal bone width buccal to implant surface at crest (CBCT-HBW0), 2 mm apical to crest (CBCT-HBW2), 6 mm apical to crest (CBCT-HBW6) and apical end of implant (CBCT-HBWE)
- The distance from the implant platform to the bone crest at the mesial (M) and distal (D) surfaces of the implant

Statistical analysis

A power analysis using a two-sided independent *t*-test (nQuery Advisor 7.0; Statistical Solution, Saugus, MA, USA) with a α-level = 0.05 showed that 13 subjects per group would be adequate to obtain 80% power in this study. Using the intraclass reliability analysis, the intra-examiner agreement was 0.975. The statistical analysis was performed using a commercially available statistical package (SPSS® 20.0; IBM Corporation, Armonk, NY, USA). Descriptive evaluation of all experimental parameters was presented as means with standard errors of mean. Patients' demographics, baseline clinical measures and experimental parameters would be compared between the two groups using independent samples *t*-test (two-tailed) and Mann–Whitney *U*-test analyses with the alpha level set as 0.05.

Results

There were 13 women and 13 men between 31 and 64 years old (mean age = 48.6 ± 8.8 years) enrolled into the study. From this population, seven women and six men were assigned to the test group. There was no statistically significant difference ($P > 0.05$) for age, gender, race and implant location in arch between the test and control groups.

At baseline, defects in both groups were comparable with no significant differences found for clinical and CBCT parameters (Table 3). At the implant uncovering surgery (day 180), clinical parameters, DD4, DD6, HBG2, HBG4, HBG6 and CBCT parameter CBCT-HBW6, were statistically significantly greater in the test group compared with the control group ($P < 0.05$; Table 4). This meant that patients in the test group had significantly more clinical horizontal bone width gain at 2, 4 and 6 mm apical to the crest, agreeing with the CBCT measurements at 6 mm apical to the crest. The observations implied that the use of a barrier membrane resulted in less bone resorption and remodeling of the bone graft along the implant. However, horizontal bone resorption and remodeling occurred at the platform of the implant regardless of membrane use. Fig. 4 illustrated the amount of clinical and radiographic horizontal bone gain between the test and control groups.

The mean radiographic vertical bone loss on the mesial surface of the implant at 1-year post-implant placement was 1.62 ± 1.06 mm in the control group and 0.89 ± 0.72 mm in the test group ($P > 0.05$). On the other hand, the mean radiographic vertical bone loss on the distal surface of the implant at 1-year post-implant placement was 1.51 ± 1.04 mm in the control group and 1.44 ± 0.71 mm in the test group ($P > 0.05$). Loading time after implant placement was 54.8 ± 41.3 days in the test group and 53.9 ± 43.4 days in the control group ($P > 0.05$).

Three patients in the control group, with the implant placed in the premolar region, had incision line opening, partial loss of bone graft material and partial exposure of the cover screw at the 2-week post-surgical evaluation. In the test group, three patients with two implants in the central incisor position and one implant in the first premolar position had incision line opening, membrane exposure and partial loss of the bone graft material at the 2-week post-surgical evaluation. Of the three patients, two of them had partial cover screw exposure while the surgical site closed completely at the 1-month re-evaluation. The incidence of membrane exposure (three

Table 2. **Summary of clinical and radiographic parameters**

Clinical parameters	Radiographic parameters
Gingival thickness (GT) at 4 mm below the ridge crest at the buccal surface Horizontal ridge width at 1 mm (CRW) and 3 mm below crest (CRW3) Defect height (DH) taken from the implant platform to the most apical point of the defect Defect width (DW) taken as the widest part of the defect Defect depth (DD) taken as distance from the implant or bone surface to the inner surface of the measuring template at four levels: Crest (DD0), 2 mm below (DD2), 4 mm below (DD4), 6 mm below (DD6) Amount of Horizontal Bone Gain (HBG) taken as the difference between DD at baseline and at Day 180 Amount of Horizontal Bone Gain at crest (HBG0), 2 mm (HBG2), 4 mm (HBG4) and 6 mm (HBG6) below crest Percentage of Defect Height Reduction (%DHR) = [(Baseline DH − Day 180 DH)/Baseline DH] × 100% Percentage of Defect Width Reduction (%DWR) = [(Baseline DW − Day 180 DW)/Baseline DW] × 100% Exposed Surface Area of Implant (ESA) = DH × DW × ¼ π (equivalent to 0.785) Percentage of Bone Fill (%BF) = [(Baseline ESA − Day 180 ESA)/ Baseline ESA] × 100%	Ridge width at crest (CBCT-CRW) and 3 mm apical to crest (CBCT-CRW3) at baseline, day 0 and day 180 Horizontal bone width buccal to implant surface at crest (CBCT-HBW0), 2 mm apical to crest (CBCT-HBW2), 6 mm apical to crest (CBCT-HBW6) and apical end of implant (CBCT-HBWE) Distance from the implant platform to the bone crest at the mesial (M) and distal (D) surfaces of the implant

Table 3. **Descriptive statistics for baseline clinical and radiographic parameters**

Parameter	Mean ± SE		*P*-value	95% Confidence interval
	Control group	Test group		
GT (mm)	2.77 ± 0.187	2.88 ± 0.269	0.737	−0.565 to 0.788
CRW (mm)	3.83 ± 0.543	3.04 ± 0.221	0.189	−2.003 to 0.419
CRW3 (mm)	4.97 ± 0.344	4.23 ± 0.262	0.102	−1.627 to 0.158
DH (mm)	7.77 ± 1.036	7.62 ± 1.201	0.556	−0.849 to 1.542
DW (mm)	3.51 ± 0.419	3.20 ± 0.218	0.851	−0.913 to 0.759
DD0 (mm)	4.08 ± 0.521	4.12 ± 0.363	0.952	−1.273 to 1.350
DD2 (mm)	4.27 ± 0.469	4.27 ± 0.333	1.00	−1.187 to 1.187
DD4 (mm)	4.56 ± 0.440	5.19 ± 0.308	0.254	−0.487 to 1.756
DD6 (mm)	5.08 ± 0.399	6.04 ± 0.465	0.130	−0.304 to 2.227
ESA (mm^2)	21.38 ± 3.349	19.93 ± 3.664	0.773	−11.691 to 8.799
CBCT-CRW (mm)	2.90 ± 0.331	3.11 ± 0.474	0.723	−0.986 to 1.401
CBCT-CRW3 (mm)	6.12 ± 0.321	6.37 ± 0.398	0.630	−0.805 to 1.304
CBCT-CRW after Implant Placement (mm)	6.04 ± 0.383	5.76 ± 0.387	0.603	−1.411 to 0.837
CBCT-CRW3 after Implant Placement (mm)	9.51 ± 0.393	9.33 ± 0.273	0.722	−1.160 to 0.816
CBCT-HBW0 (mm)	1.32 ± 0.287	1.63 ± 0.378	0.517	−0.667 to 1.292
CBCT-HBW2 (mm)	2.90 ± 0.295	2.61 ± 0.291	0.483	−1.151 to 0.560
CBCT-HBW6 (mm)	4.39 ± 0.333	4.13 ± 0.346	0.599	−1.247 to 0.735
CBCT-HBWE (mm)	4.52 ± 0.408	4.12 ± 0.480	0.536	−1.697 to 0.905

GT, Gingival Thickness; CBCT, cone beam computed tomography; CRW, Crestal Ridge Width at 1 mm apical to Crest; CRW3, Ridge Width at 3 mm apical to Crest; DH, Defect Height; DW, Defect Width; DD0, Defect Depth at Crest; DD2, Defect Depth at 2 mm apical to Crest; DD4, Defect Depth at 4 mm apical to Crest; DD6, Defect Depth at 6 mm apical to Crest; ESA, Exposed Surface Area of Implant; CBCT-CRW, CBCT Crestal Ridge Width; CBCT-CRW3, CBCT Ridge Width at 3 mm apical to Crest; CBCT-HBW0, CBCT Horizontal Bone Width at Crest; CBCT-HBW2, CBCT Horizontal Bone Width at 2 mm apical to Crest; CBCT-HBW6, CBCT Horizontal Bone Width at 6 mm apical to Crest, CBCT-HBWE, CBCT Horizontal Bone Width at End of Implant; SE, Standard Error of Mean. Significance was set at $P < 0.05$.

patients) and incision line opening (three patients) in this study was 23.08%.

Within-group comparison demonstrated no significant differences in defect height and width reduction, bone fill and clinical and radiographic horizontal bone gain between sites with wound exposure and those without. However, having wound exposure resulted in significantly lower percentage defect height reduction and bone fill around implants (Table 5). In summary, wound exposure did not have an effect on defect width reduction and clinical and radiographic buccal bone gain, but it negatively affected defect height reduction and percentage of bone fill around the implants.

Discussion

This randomized, controlled, single-masked human clinical trial was designed to investigate the effect of a barrier membrane on GBR of implant dehiscence or fenestration defects during simultaneous implant placement. The GBR technique used was the SBA technique proposed in 2004 by Wang et al. (2004). The rationale of this technique lay in its ability to significantly reduce treatment time, morbidity and cost by combining the properties of different bone graft materials and thus taking advantage of their different healing patterns to regenerate bone around a dental implant (Park et al. 2008).

In this study, the mean ridge width gain at 1 and 3 mm apical to crest, calculated as the difference in the mean ridge width at Day 0 and Day 180, was 0.65 and 0.85 mm in the control group compared with 1.10 and 1.33 mm in the test group, respectively. Statistically significant greater horizontal bone gain was found for the test group at 2, 4 and 6 mm apical to the crest ($P < 0.05$), therefore suggesting that the presence of the bovine pericardium membrane was effective in enhancing bone regeneration. This finding was similar to that reported by Park et al. (2008), where the test group (with membrane) had 0.6–0.7 mm more buccal bone gain compared with the control group (without membrane). However, the amount of horizontal bone gain differed, possibly due to heterogeneity in study design (e.g. types of barrier membranes used and surgical sites).

In contrast, the mean ridge width gain at 1 and 3 mm apical to crest measured from the CBCT scans was 1.75 and 1.63 mm in the control group compared with 1.4 and 1.87 mm in the test group, respectively. These differences were not significant and it would be unreasonable to compare the clinical and radiographic measurements because of the differences in the angle the measurements were taken. In addition, it has been reported that CBCT measurements were inaccurate if the buccal bone thickness was <0.5 mm (Fienitz et al. 2012). This could be because of peri-implant CBCT artifacts that caused inaccuracies in the radiographic measures, despite attempts (e.g. repeated measurements under magnification, accounting for partial volume averaging, to counteract these deficiencies).

Collectively, the presence of a membrane did result in a greater increase in mean ridge width compared with sites without a membrane. This was in agreement with a similar clinical trial, which showed that

Table 4. **Descriptive statistics for clinical and CBCT parameters at Day 180**

	Mean ± SE		
Parameter	Control group	Test group	*P*-value
GT (mm)	3.38 ± 0.376	3.37 ± 0.306	0.880
CRW (mm)	4.48 ± 0.227	4.138 ± 0.177	0.311
CRW3 (mm)	5.82 ± 0.336	5.56 ± 0.345	0.762
DH (mm)	1.92 ± 0.596	0.92 ± 0.348	0.169
DW (mm)	2.23 ± 0472	1.35 ± 0.373	0.139
%DHR	60.82 ± 14.975	81.36 ± 6.641	0.398
%DWR	22.84 ± 18.266	53.57 ± 14.194	0.245
ESA (mm^2)	5.50 ± 2.084	1.92 ± 0.807	0.139
%BF	75.68 ± 10.84	90.60 ± 3.53	0.329
DD0 (mm)	4.44 ± 0.310	4.08 ± 0.304	0.448
DD2 (mm)	4.12 ± 0.306	3.00 ± 0.412	0.064
DD4 (mm)	3.96 ± 0.302	2.38 ± 0.453	0.010
DD6 (mm)	4.27 ± 0.323	2.79 ± 0.480	0.010
HBG0	−0.37 ± 0.319	0.04 ± 0.280	0.266
HBG2	0.15 ± 0.262	1.27 ± 0.342	0.021
HBG4	0.60 ± 0.431	2.81 ± 0.448	0.001
HBG6	0.81 ± 0.485	3.25 ± 0.386	0.001
CBCT-CRW (mm)	4.65 ± 0.203	4.74 ± 0.241	1.000
CBCT-CRW3 (mm)	7.52 ± 0.388	8.24 ± 0.377	0.311
CBCT-HBW0 (mm)	0.19 ± 0.118	0.58 ± 0.277	0.579
CBCT-HBW2 (mm)	1.03 ± 0.229	1.90 ± 0.341	0.072
CBCT-HBW6 (mm)	1.92 ± 0.236	3.14 ± 0.429	0.044
CBCT-HBWE (mm)	1.87 ± 0.509	1.84 ± 0.313	0.511
M	1.46 ± 0.525	0.44 ± 0.301	0.129
D	1.49 ± 0.489	−0.19 ± 0.296	0.109

GT, Gingival Thickness; CBCT, cone beam computed tomography; CRW, Crestal Ridge Width at 1 mm apical to Crest; CRW3, Ridge Width at 3 mm apical to Crest; DH, Defect Height; DW, Defect Width;% DHR, Percentage of Defect Height Reduction;%DWR, Percentage of Defect Width Reduction; ESA, Exposed Surface Area of Implant;%BF, Percentage Bone Fill; DD0, Defect Depth at Crest; DD2, Defect Depth at 2 mm apical to Crest; DD4, Defect Depth at 4 mm apical to Crest; DD6, Defect Depth at 6 mm apical to Crest; HBG0, Horizontal Bone Gain at Crest; HBG2, Horizontal Bone Gain at 2 mm apical to Crest; HBG4, Horizontal Bone Gain at 4 mm apical to Crest; HBG6, Horizontal Bone Gain at 6 mm apical to Crest; CBCT-CRW, CBCT Crestal Ridge Width at 1 mm apical to Crest; CBCT-CRW3, CBCT Ridge Width at 3 mm apical to Crest; CBCT-HBW0, CBCT Horizontal Bone Width at Crest; CBCT-HBW2, CBCT Horizontal Bone Width at 2 mm apical to Crest; CBCT-HBW6, CBCT Horizontal Bone Width at 6 mm apical to Crest, CBCT-HBWE, CBCT Horizontal Bone Width at End of Implant; M, Vertical Bone Loss on Mesial of Implant; D, Vertical Bone Loss on Distal of Implant; SE, Standard error of mean. Significance set at $P < 0.05$.

having a collagen barrier membrane resulted in significant bone width gain when compared with sites treated without a barrier membrane (1.7 mm vs. 1.0 mm; Park et al. 2008).

The implants placed in this study had a turned surface collar of 1 mm and a micro-textured surface of 1.5 mm before the start of the first thread (Tapered Screw-Vent® system; Zimmer Dental Inc.). It was demonstrated that the mean horizontal bone width gain was only significant at 2, 4 and 6 mm apical to the crest with the test group having more bone regeneration. Thus, it indicated that bone regeneration was not successful around the smooth collar even though bone graft material and/or barrier membrane were placed over the cover screw. Studies have demonstrated that smooth surfaces had lower bone-to-implant contact compared with micro-topographically complex surfaces because retention of fibrin, which was the starting point of early peri-implant endosseous healing, favored roughened surfaces (Cooper et al. 1998; Davies 2003). Nevertheless, it is necessary to conduct more research to understand whether bone regeneration is achievable around roughened collar.

In this study, radiographically, vertical bone levels at the mesial and distal surfaces of the implant were found to be approximately 0.9–1.6 mm, which indicated bone resorption down to the micro-textured surface. Several studies have reported an early implant bone loss, ranging from 0.9 to 1.6 mm, around implants that were placed in either in 1-stage or 2-stage approaches (Adell et al. 1981, 1986; Buser et al. 1990; Jemt et al. 1990). Possible causes of early implant bone loss have been attributed to surgical trauma, peri-implantitis, occlusal loading, implant neck design, remodeling of the tissues to establish a biologic width and presence of a micro-gap (Oh et al. 2002). In addition, the depth of implant placement could be a possible causative factor. A recent human case series, reported more marginal bone remodeling around implants that were placed equicrestally compared with subcrestally (Degidi et al. 2011). It was speculated that excessive stress was transmitted to the implant–bone interface at the level of the crest thus resulting in micro-fractures and bone loss around implants placed equicrestally. Comparatively, implants that were placed subcrestally had osseointegration coronal to the implant–abutment junction and less marginal bone loss (Degidi et al. 2011).

The percentage of defect height reduction, defect width reduction and bone fill were not significant between the two groups. But the magnitude of reduction was greater in the test group. The test group in this study had 90.60 ± 3.53% of bone fill, which was approximately 15% greater compared with the control group. The percentage bone fill was found to be slightly higher to the mean percentage bone fill of 81.7% reported by Jensen & Terheyden (2009).

In this study, the incidence of wound dehiscence occurred approximately once in every four patients (23.08%). This value was approximately 10% lower compared with Park et al. (2008) and yet was 10% greater than the mean complication rate reported in a systematic review (Jensen & Terheyden 2009). This could be site specific as four of six exposures occurred at the premolar region, thus suggesting that muscle pull on the flap could have led to incision line opening (Park & Wang 2007). The higher exposure rate in Park et al.'s (2008) study might have been due to difficulty in achieving primary wound closure in the mandibular sites. It was previously reported that the amount of bone regenerated was negatively related to wound exposure (Zitzmann et al. 1997). Although not statistically significant, in this study, the amount of bone regenerated in sites with exposure was approximately half of that in sites without exposure. In addition, incision line opening in the control group resulted in loss of the graft and also resorption of the surgical site. Nonetheless, it is important to bear in mind that this study had only six sites with wound exposure, of which two sites became and remained closed after day 30.

Efforts, such as measuring under magnification, making repeated measurements to ensure intra-examiner agreement, and accounting for partial volume averaging in the CBCT scans, have been made to eliminate measuring errors in the CBCT analysis. However, it is important to highlight that there are inherent errors in CBCT imaging around dental implants. According to the position paper, radiation from imaging

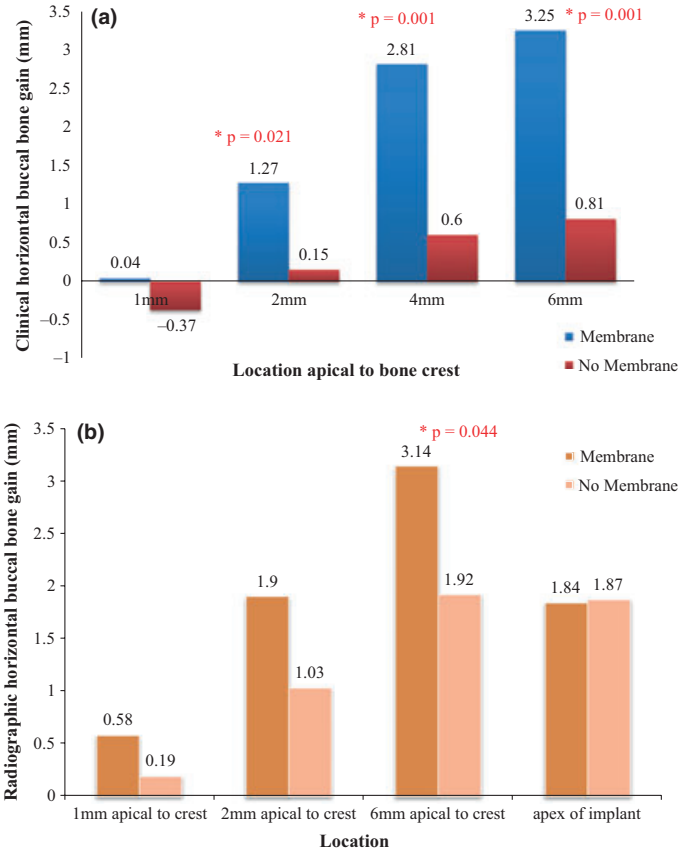

Fig. 4. Bar Charts illustrating the amount of horizontal bone gain (a) clinically and on (b) cone beam computed tomography (CBCT) scans at crest, 2, 4 and 6 mm apical to the bone crest.

tools should be adjusted to the minimum possible (Tyndall & Brooks 2000), therefore in this study, the CBCT scans taken were not at high resolution (0.4 mm voxel resolution compared with 0.25 mm). Consequently, there were more background scattering and noise in the scans because the resolution was insufficient for visualization of the thin cortical bone adjacent to the implant (Razavi et al. 2010). This could be adjusted by changing the voxel resolution to 0.25 mm, with a 46.72 mAs exposure and a scan time of 40 s. This set of specification was recommended by Shiratori et al. (2012), who showed that measurements of buccal bone volume around dental implants were precise in CBCT images obtained with this specification.

Numerous studies have shown that GBR of peri-implant dehiscence defects is a feasible treatment option. The cumulative implant success or survival rate ranged from 79.4% to 100% with follow-up periods between 6 and 133 months (Nevins et al. 1998; Zitzmann et al. 2001; Hammerle et al. 2002; Fugazzotto 2005; Benic et al. 2009). Even in this study, the short-term cumulative implant survival rate was 100%. However, a question that is left unanswered is the quality of osseointegration associated with this GBR technique. It is not known if the regenerated bone is osseointegrated to the implant surface or simply just surrounding the implant. A recent animal model using demineralized bovine bone mineral and collagen membrane showed a bone-to-implant contact of 70.82 ± 20.34% (Guerra et al. 2011). In spite of this, true osseointegration of regenerated bone with the implant surface has not been clinically determined.

It was demonstrated through recent systematic reviews that implant surface roughness is important in osseointegration (Junker et al. 2009; Wennerberg & Albrektsson 2009). It would be interesting to determine the influence of different implant surfaces on the stability of the regenerated bone. In addition, a recent animal model showed that occlusal loading positively influenced bone-to-implant contact of implants placed into native bone and grafted sites (Zambon et al. 2012). Therefore, the effect of functional loading on bone remodeling and stability of the regenerated bone needs to be determined.

Further research is needed to explore the use of biomedical software in implant-related research, to analyze the bone-to-implant contact of the regenerated bone, to investigate the influence of implant macro- and micro-designs on the stability of the regenerated bone and to determine the effect of occlusal loading on the stability and remodeling pattern of the regenerated bone over time.

Table 5. **Treatment outcome comparison between wound exposure and no wound exposure**

	Test (mean ± SD)			Control (mean ± SD)					
Parameter	With exposure (n = 3)	Without exposure (n = 10)	P-value	With exposure (n = 3)	Without exposure (n = 10)	P-value	With exposure (n = 6)	Without exposure (n = 20)	P-value
%DHR	58.33 ± 38.19	88.27 ± 14.51	0.217	−2.46 ± 80.08	79.80 ± 26.96	0.112	27.94 ± 65.25	83.60 ± 22.02	0.039
%DWR	25.00 ± 75.00	62.14 ± 43.46	0.469	−15.48 ± 53.49	34.34 ± 67.16	0.217	4.76 ± 62.34	48.36 ± 58.43	0.139
%BF	50.00 ± 57.28	90.60 ± 12.71	0.217	−20.31 ± 110.96	75.68 ± 39.08	0.101	14.84 ± 87.87	82.47 ± 29.95	0.046
HBG0 (mm)	0.67 ± 1.04	−0.15 ± 0.97	0.217	−0.33 ± 1.15	−0.38 ± 1.21	0.937	0.17 ± 1.125	−0.30 ± 1.088	0.387
HBG2 (mm)	1.67 ± 2.25	1.15 ± 0.91	0.811	0.00	0.2 ± 1.09	0.811	0.83 ± 1.693	0.66 ± 1.119	0.790
HBG4 (mm)	3.17 ± 2.93	2.7 ± 1.23	0.811	0.00 ± 1.32	0.78 ± 1.63	0.469	1.58 ± 2.672	1.72 ± 1.766	0.457
HBG6 (mm)	3.33 ± 2.36	3.22 ± 1.16	0.811	0.17 ± 1.61	1 ± 1.83	0.811	1.75 ± 2.505	2.17 ± 1.908	0.614
CBCT-HBW0 (mm)	0.62 ± 1.07	0.56 ± 1.03	0.937	0.00	0.25 ± 0.48	0.469	1.86 ± 0.759	0.41 ± 0.801	0.744
CBCT-HBW2 (mm)	1.66 ± 1.37	1.97 ± 1.26	0.811	0.35 ± 0.33	1.23 ± 0.83	0.161	6.01 ± 1.145	1.60 ± 1.101	0.219
CBCT-HBW6 (mm)	3.62 ± 1.21	2.99 ± 1.66	0.937	1.47 ± 0.71	2.06 ± 0.88	0.217	14.29 ± 1.563	2.57 ± 1.351	0.744
CBCT-HBWE (mm)	2.15 ± 0.59	1.75 ± 1.26	0.811	1.76 ± 1.93	1.90 ± 1.91	0.692	8.31 ± 0.921	2.00 ± 1.618	0.656

%DHR, Percentage of Defect Height Reduction;%DWR, Percentage of Defect Width Reduction; CBCT, cone beam computed tomography; HBG0, Horizontal Bone Gain at Crest; HBG2, Horizontal Bone Gain at 2 mm apical to Crest; HBG4, Horizontal Bone Gain at 4 mm apical to Crest; HBG6, Horizontal Bone Gain at 6 mm apical to Crest; CBCT-HBW0, CBCT Horizontal Bone Width at Crest; CBCT-HBW2, CBCT Horizontal Bone Width at 2 mm apical to Crest; CBCT-HBW6, CBCT Horizontal Bone Width at 6 mm apical to Crest, CBCT-HBWE, CBCT Horizontal Bone Width at End of Implant; SD, Standard Deviation. Significance set at $P < 0.05$.

Conclusion

The study demonstrated that the SBA technique was effective in regenerating bone in implant buccal dehiscence or fenestration defects. The presence of a collagen barrier membrane did not significantly affect the mean horizontal bone gain along the length of the implant. However, it reduced bone resorption at 2, 4 and 6 mm apical to the bone crest. Addition of a barrier membrane prevented significant horizontal buccal bone resorption as space was maintained more effectively when compared with sites treated without a membrane.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Appendix S1. CONSORT statement 2001 checklist.