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Horizontal guided bone regeneration on knife-edge ridges: A retrospective case–control pilot study comparing two surgical techniques

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Abstract

Introduction: Studies evaluating guided bone regeneration (GBR) on knife-edge ridges using absorbable membranes with staged approaches have reported various horizontal bone gains. This study compared the horizontal bone gain obtained via a conventional technique of GBR and a recently-reported technique. Bone loss during the healing process was also measured.

Methods: Consecutive patients who underwent GBR on knife-edge ridges via a conventional technique (control group) or the Sausage Technique (test group) were included in this study. GBR was performed using a collagen membrane and deproteinized bovine bone mineral combined with an autogenous graft at a 1:1 ratio. Cone-beam computed tomography (CBCT) was performed preoperatively, postoperatively, and after the patient healed. Horizontal bone width was measured on CBCT images 2 mm apical from the top of the crest. The preoperative CBCT and posthealing CBCT were superimposed to calculate the bone gain after healing, and the preoperative and postoperative CBCT scans were superimposed to calculate the bone gain after surgery. Bone loss during healing was calculated by subtracting the width of the ridge after healing from the postoperative width.

Results: The mean horizontal bone gain was significantly lower in the control group (2.7 ± 1.8 mm; 83.2%) than in the test group (5.3 ± 2.3 mm; 216.8%) ($p = 0.003$). The average horizontal bone loss between regeneration and implant placement was 0.9 mm in the control group (27.9%) and 2.1 mm in the test group (29.4%). While the absolute bone loss was significantly different ($p = 0.012$), the percentage of bone resorption was not ($p = 0.608$).

Conclusion: The new technique resulted in significantly more bone gain than a conventional GBR technique. The rate of graft resorption during healing was stable regardless of the amount of grafted material.

KEYWORDS

biomaterials, bone gain, bone resorption, guided bone regeneration, horizontal ridge augmentation, resorbable membrane, sausage technique

What is known

Guided bone regeneration (GBR) techniques using resorbable membranes with staged approaches sometimes fall short of the recommended peri-implant bone volume criteria. A recently-reported technique results in increased horizontal bone gains. In addition, few studies have reported bone resorption during the healing process.

What this study adds

This is the first study to directly compare a conventional GBR technique and the Sausage Technique via bone measurements. The bone gain and the bone resorption has been measured and analyzed for both techniques.

1 | INTRODUCTION

Several studies have reported that thin peri-implant bone walls lead to more vertical bone resorption following implant placement.[1–3] Therefore, a peripheral peri-implant bone volume of 2 mm is recommended to allow for long-term dimensional stability of the tissues.[1,3–6] As the diameter of a standard implant is approximately 4 mm, the preferred ridge width is approximately 8 mm. Thin ridges (<4 mm) do not allow for simultaneous implant placement in the bony envelope with the correct prosthetic axis[4] (class 4 of Cawood and Howell's descriptive classification,[7] class 4 of Benic's bone defect classification,[8] and class 3 of Chiapasco's bone defect classification[4]). The thickness of these ridges can be increased via blocks,[4,8] using guided bone regeneration (GBR) with titanium-reinforced nonresorbable membranes,[5,8] titanium meshes,[9] absorbable membranes,[10] or using a combination of blocks and GBR.[11,12] In similar indications, the alveolar ridge-splitting/expansion technique allows clinicians to perform one-step surgical procedures and to shorten the treatment time.[13]

Several studies regarding GBR for horizontal augmentations[14] have reported reproducible results with implant success rates comparable to those obtained in native bone.[8,14,15] While nonabsorbable polytetrafluoroethylene membranes were used traditionally, resorbable membranes are easier to use and have more manageable complications.[16,17]

In 2011, Urban and colleagues[17] reported that a 100% autogenous bone mixture did not result in more favorable outcomes than a 1:1 mixture of autogenous bone and deproteinized bovine bone mineral (DBBM) for horizontal class IV regenerations. A mixture of particulate autogenous bone and DBBM is now commonly used, and the resulting bone quality has been confirmed histologically.[15,17–20] The particulate structure of this mixture allows for rapid vascularization, increases the exposure to growth factors, increases the osteoconduction surface area (compared to that of a block), and naturally adapts to the shape of the ridge.[4,17,18,21–23] This use of this mixture allows for the combination the complementary properties of the two materials.

Studies evaluating bone regeneration on knife-edge ridges using absorbable membranes with staged approaches (bone regeneration followed by implant placement) have reported horizontal gains of 1.5–3.8 mm, allowing for the achievement of a ridge width of 4.9–6.9 mm.[8,24–39] One systematic review reported an average horizontal gain of 3.3 mm, resulting in a final ridge width of 6.2 mm.[40] Techniques using a combination of autogenous blocks and GBR with a collagen membrane were also applied successfully and made it possible to obtain a 4.6 mm increase of bone width.[11,12,41]

In a recent meta-analysis, Naenni and colleagues[42] reported that 6 of 25 studies were required to use complementary bone augmentation on the day of implant placement or an implant with a narrower diameter than originally planned, suggesting that the horizontal augmentation techniques used in these studies may not completely restore sufficient bone volume.

A technique using a collagen membrane that can lead to greater bone gain than other GBR techniques using only particulate grafts, has recently been reported.[14,43] Horizontal gains of 5.56–7 mm resulting in final ridge widths of 7.68–9.14 mm have been achieved using this technique.[17,18,23] The purpose of this retrospective study was to evaluate the horizontal bone gain obtained with two different GBR techniques: a conventional technique and the Sausage Technique developed and trade marked by Urban and colleagues[17,18,23] This study also measured the bone loss during healing between bone regeneration and implant placement.

2 | MATERIALS AND METHODS

2.1 | Study design

This retrospective study was a noninterventional, single-center, case–control study. All GBR procedures were performed by the same surgeon (H.A.) with over 15 years of experience in oral surgery. All patients were informed of the research, and all procedures performed in this study were in accordance with the ethical standards of the national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. The study complies with the Reference Methodology MR-004 of the National Commission for Information Technology and Civil Liberties (CNIL) and is validated under the registration number 2222406v0. The study was registered on the Health Data Hub under the number F20210610083138.

2.2 | Patients

Patients with a horizontal bone defect with a thin ridge (<4 mm wide at the top of the ridge) measured on preoperative cone-beam computed

tomography (CBCT) who underwent GBR via the conventional or the new technique were included in this study. Patients who underwent GBR via the conventional technique between May 2015 and June 2018 were included in the control group, and those who underwent GBR via the new technique between December 2018 and January 2020 were included in the test group. At least one preoperative CBCT scan and one posthealing CBCT scan (6 months after GBR) were obtained for each patient. All patients were followed-up at least once after prosthetic rehabilitation.

Patients with conventional surgical contraindications or uncontrolled general pathologies, those receiving bisphosphonate treatments, those who consumed >10 cigarettes per day, and those who were noncompliant to restore his or her oral health prior to GBR were excluded from the study.

2.3 | Clinical procedures

All patients were administered 8 days of antibiotic treatment (2 g/day of amoxicillin and clavulanic acid or 600 mg/day clindamycin with 1.5 g/day metronidazole in patients with allergies or intolerance to amoxicillin and/or clavulanic acid). Ketoprofen and/or paracetamol (codeine) were administered in patients with who complained of pain. Chlorhexidine mouthwashes were prescribed for 10 days, starting 24 h postoperatively.

2.4 | Surgical technique

All surgeries were conducted using local anesthesia.

2.4.1 | Control group

In conventional GBR, a full-thickness flap was elevated using vertical vestibular incisions away from the surgical site. Cortical perforations were made, and a reticulated resorbable membrane (OsseoGuard CE mark; Zimmer Biomet) was fixed using lingual/palatal pins (Geistlich Titan-fix set CE mark; Geistlich Pharma AG) that were impacted in bone with a pin holder and a mallet. A 1:1 mixture of particulate autograft and DBBM (Bio-Oss CE mark; Geistlich Pharma AG) was placed on the defect, and the membrane was folded over the mixture then fixed using pins (Figure 1, C1–C3 and Figure 3, C0). The autogenous bone was collected near the site using a bone scraper. Buccal flap advancement in the control group was performed using a classical periosteal releasing incision connecting the two vertical incisions.

The flap was sutured in two layers: horizontal mattress sutures, then single interrupted sutures.

2.4.2 | Test group

The surgical technique has been described previously.[17,18,44] Briefly, a full-thickness flap was elevated using vestibular vertical incisions made two teeth from the surgical site and a mesiolingual or mesiopalatal vertical incision at the mesial tooth bordering the surgical site. Cortical perforations were made, and a resorbable collagenous membrane (Bio-Gide CE mark; Geistlich Pharma AG) was fixed with lingual/palatal pins (mostly Master-Pin-Control CE mark; Hager and Meisinger GmbH) that were impacted in bone with a pin holder and a mallet. A 1:1 mixture of particulate autograft and DBBM (Bio-Oss CE mark; Geistlich Pharma AG) was placed on the defect. The membrane was pulled back over the mixture, stretched, and held in place using buccal pins. After placing a pin at the distal buccal part, a second pin was placed by stretching the membrane at the buccal mesial part (Figure 2, T1–T3 and Figure 3, T0). Care was taken to position and immobilize the graft by stretching and fixating the membrane with additional titanium pins until complete crestal stability of the graft was achieved. The elasticity of the membrane was key in the successful immobilization of the bone graft. Once the membrane had been secured with all the pins, a blunt periosteal instrument was used to evaluate the compaction: the construction should feel as dense as possible.

Autogenous bone was collected near the site or from the retromolar mandibular area. A bone scraper or trephines and a bone mill (Bone management Master-Core and Master-Mill CE mark, Hager and Meisinger GmbH) were used depending on the patient's anatomy.

Buccal flap advancement was performed using the periosteoelastic technique which has been described previously.[44,45] Briefly, a gentle periosteal incision connecting the vertical incision was done. Then the periosteal cross-bundles underneath were carefully cut with sweeping incisions. The last step was the elastic fiber separation, completed using a blunt periosteal instrument in a coronal pushing motion.

On mandibular cases, a lingual flap advancement was also done in the test group using the modified lingual flap advancement technique.[46]

The flap was sutured in two layers: first, horizontal mattress sutures placed 5 mm from the crestal incision, every 5 mm. Then, single interrupted sutures were used to finalize the closure. This creates a 5 mm connective tissue barrier that protects the graft from exposure.

2.5 | Data collection

Patient age, sex, health status, periodontal condition, history of bone defects, and GBR healing times were recorded. CBCT images were performed preoperatively, immediately after GBR surgery, and posthealing. Posthealing CBCT scans were obtained at least 6 months after GBR at the time of implant placement. All CBCT images were obtained using Planmeca ProMax 3D (PLANMECA OY). Measurements were obtained by two independent examiners (H.A. and C.A.), including one who was blinded to the patient group allocations and not involved in the treatment of patients (C.A.). If a difference of more than 0.6 mm was observed between the observers' measurements, the measurements were repeated. The ridge width was measured 2 mm apical to the top of the crest[17,18,24–26,47–49] and perpendicular to the major axis of the ridge.[25,26,33,38,50–52]

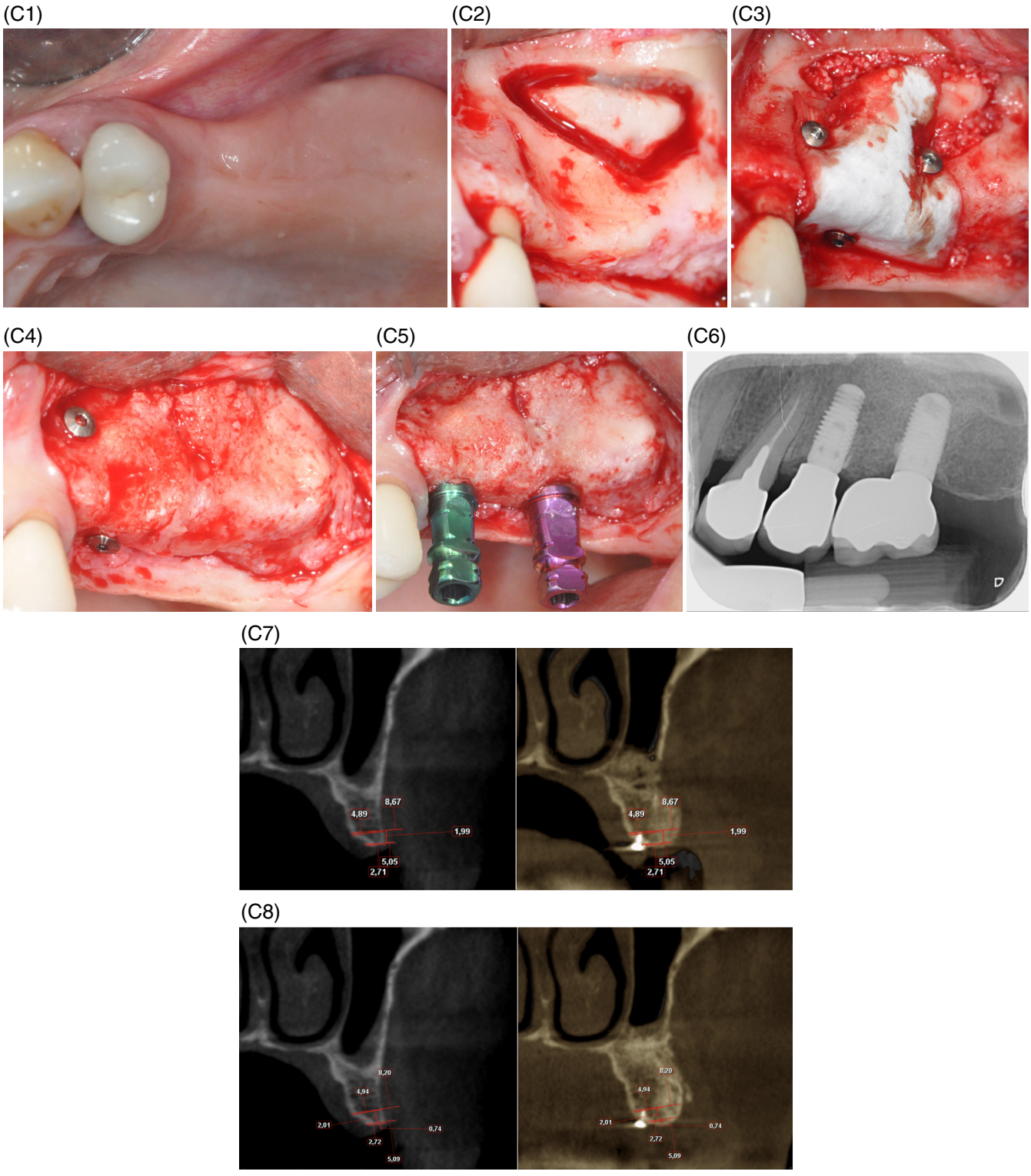

FIGURE 1 Representative case treated with a conventional GBR technique. Images of a representative case from the control group are shown. (C1) Preoperative view. (C2) View of the horizontal defect under the sinus access window. (C3) Classical guided bone regeneration technique using a reticulated collagen membrane and deproteinized bovine bone mineral combined with autogenous graft at a 1:1 ratio. (C4) View of the ridge after 6 months of healing. (C5) Implant placement. (C6) Intraoral radiograph of prosthetic rehabilitation. (C7) Superimposition of cone-beam computed tomography (CBCT) images obtained pre- and postoperatively. (C8) Superimposition of the CBCT images obtained preoperatively and posthealing

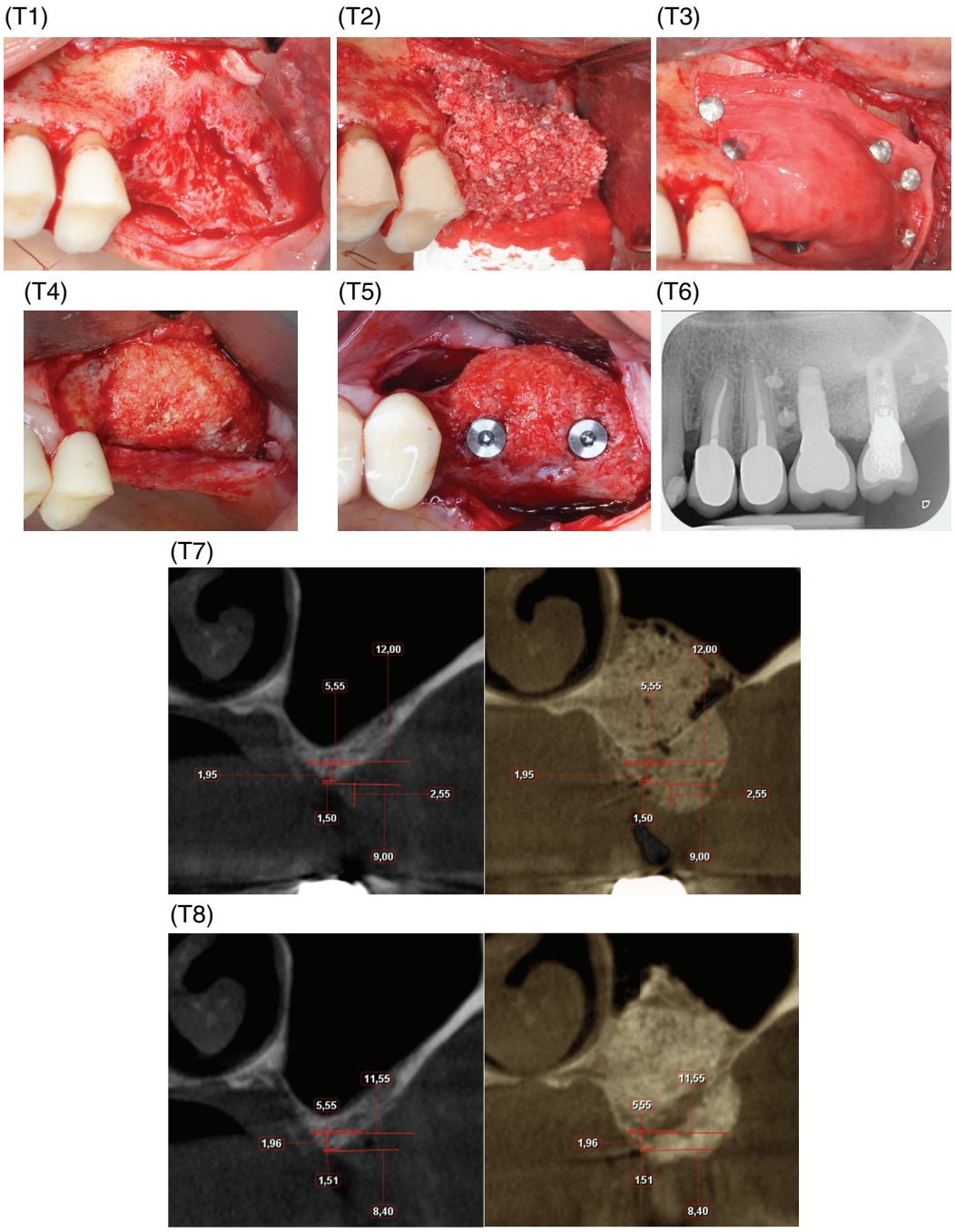

FIGURE 2 Representative case treated with the Sausage Technique. Images of a representative case from the test group are shown. (T1) Clinical view of the horizontal defect. (T2) Placement of the particulate graft containing deproteinized bovine bone mineral combined with autogenous graft at a 1:1 ratio. (T3) Collagen membrane fixation. (T4) View of the ridge after 6 months of healing. (T5) Implant placement. (T6) Intraoral radiograph of prosthetic rehabilitation. (T7) Superimposition of cone-beam computed tomography (CBCT) images obtained pre- and postoperatively. (T8) Superimposition of CBCT images obtained preoperatively and posthealing

2.6 | Endpoints

The study's primary endpoint was bone gain obtained after the GBR healed. The preoperative CBCT and posthealing CBCT images were superimposed using Planmeca Romexis software (PLANMECA OY)[51,53–55] (Figure 1, C8 and Figure 2, T8).

The secondary endpoints were bone gain and bone loss. Bone gain after surgery was measured by superimposing the preoperative CBCT and postoperative CBCT images using Planmeca Romexis software (PLANMECA OY) (Figure 1, C7 and Figure 2, T7).

Bone loss was measured between the day of surgery and after healing by subtracting the width of the ridge after healing from the

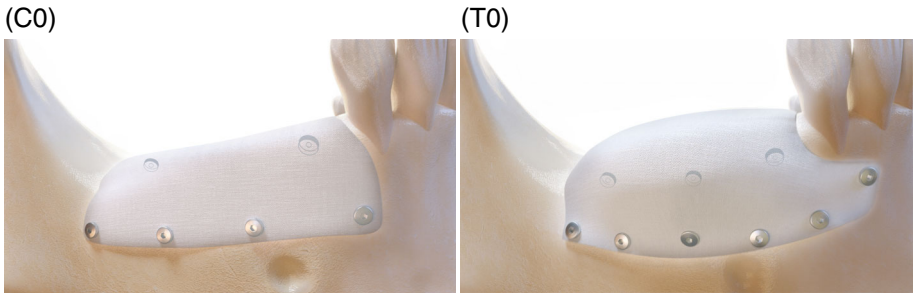

FIGURE 3 Schematic drawing of a posterior mandibular GBR showing bone graft fixation using pins. C0, control group; T0: test group

postoperative width. The mean bone loss was also calculated for two subgroups within the test group: patients who underwent GBR at anterior sites (incisors and canines) and those who underwent GBR at posterior sites (premolars and molars).

2.7 | Statistical analysis

Nonparametric Wilcoxon rank tests were conducted to compare non-normal data. The average of the measurements obtained by two observers was used for all analyses. The mean bone gain ratios were calculated as percentages. The mean bone loss ratios between the day of surgery and healing were also calculated as percentages. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines[56] were followed during the preparation of this manuscript.

3 | RESULTS

3.1 | Enrolment and clinical course

A total of 15 patients (16 defects and 30 implants; 60% men) were included in the control group, and 16 patients (16 defects and 25 implants; 37.5% men) were included in the test group. One patient in the test group was lost to follow-up and was excluded from the study.

3.2 | Patients

The mean patient age was 57.6 years (standard deviation [*SD*] = 13.8 years) in the control group and 56.2 years (*SD* = 14.4 years) in the test group (Table 1). Three patients in the control group had a systemic disease, including one with stabilized thyroid disease, one with sickle cell disease, and one with stabilized hypertension. The test group also included three patients with systemic diseases, including one with stabilized coronary heart disease, one with stabilized thyroid disease, and one with a stabilized psychiatric disorder. Four patients (26%) in the control group and three (18.7%) in the test group had stabilized early or moderate chronic periodontal disease. The causes of the bone defects included alveolar resorption following extraction >5 years prior to the study (13 sites), implant failure (3 sites), and dental pathology (trauma, infection, or inflammatory pathologies) (10 sites). In six cases, the teeth were extracted by an outside provider and no data regarding the cause was provided. The implant sites are shown in Table 2.

TABLE 1 Patient demographics

	Control group $n = 15$	Test group $n = 16$
Age (years)	57.6 (13.8), 27.0–73.0	56.2 (14.4), 20.0–70.0
Female	7 (43.8%)	10 (62.5%)

Note: Data are shown as mean (standard deviation), minimum–maximum or number and percentage.

3.3 | Control group

The average healing time in the control group was 9.2 months (*SD* = 3.3 months). The osseointegration of the implants (Tapered Screw-Vent CE mark; Zimmer Biomet) was tested at least 2 months after insertion (mean duration: 3.5 months, *SD* = 1.1 months). Some patients have had very little postoperative discomfort, including oedema, pain, and/or bruising, though no discomfort lasted longer than 2 weeks. One patient had a wound dehiscence after 1 month. Two implants failed and were removed. They were not replaced as prosthetic rehabilitation was possible on the remaining implants.

3.4 | Test group

The average healing time in the test group was 8.1 months (*SD* = 1.7 months). The osseointegration of the implants (Tapered Screw-Vent CE mark; Zimmer Biomet) was tested at least 2 months after insertion (mean duration: 4 months; *SD* = 2 months). Some patients have had very little postoperative discomfort, including oedema, pain, and/or bruising, though no discomfort lasted longer than 2 weeks. One patient presented with paraesthesia that lasted 6 months.

3.5 | Primary endpoint

The mean horizontal bone gain obtained after healing was 2.7 mm (*SD* = 1.8 mm; 83.2%) in the control group and 5.3 mm (*SD* = 2.3 mm; 216.8%) in the test group ($p = 0.003$) (Tables 3 and 4).

3.6 | Secondary endpoints

Data regarding the width of the ridge on the day of surgery was available for 12 patients in the control group and 15 patients in the test group (Table 4). The mean bone loss between the day of surgery and posthealing was 0.9 mm ($SD = 0.8$ mm) in the control group and 2.1 mm ($SD = 1.6$ mm) in the test group ($p = 0.012$). The rate of bone resorption was 27.9% in the control group and 29.4% in the test group ($p = 0.608$).

Among patients who underwent GBR using the new technique for posterior sites ($n = 10$), the mean bone loss was 1.7 mm ($SD = 1.7$ mm), and that among patients who underwent GBR using the new technique for anterior sites ($n = 5$) was 2.9 mm ($SD = 1.1$ mm), ($p = 0.126$) (Table 5).

TABLE 2 Implant sites

Implant site	Control group $n = 16$	Test group $n = 16$
Incisors	3 (18.75%)	5 (31.25%)
Canines	3 (18.75%)	1 (6.25%)
Premolars	8 (50.0%)	3 (18.75%)
Molars	2 (12.5%)	7 (43.75%)
Lower jaw	2 (12.5%)	4 (25.0%)
Upper jaw	14 (87.5%)	12 (75.0%)

Note: Data are presented as number (percentage).

4 | DISCUSSION

The mean horizontal bone gain obtained after healing was significantly greater with the new technique than with the conventional technique.

4.1 | Horizontal gain

The average horizontal gain obtained via the conventional GBR technique in this study is consistent with previously published results regarding atrophic ridges treated with similar techniques (bone regeneration with particulate graft and resorbable membrane) which reported horizontal gains from 1.5 to 3.8 mm.[10,24–40,57] The average horizontal gain obtained via the new technique in this study is also consistent with previously-reported results of studies using, or inspired by this technique which reported horizontal gains of 5.03–7 mm.[17,18,47–49]

TABLE 3 Ridge width

	Control group		Test group		*p* Value
	N	Ridge width (mm)	*N*	Ridge width (mm)	
Preoperative	16	4.5 (1.8), 1.9–7.6	16	3.1 (1.3), 1.4–5.7	0.017
Postoperative	12	8.1 (2.0), 4.3–12.7	15	10.5 (1.4), 8.0–12.7	0.002
Posthealing	16	7.2 (1.9), 4.5–11.3	16	8.4 (2.0), 4.4–11.9	0.169

Note: Ridge width is measured 2 mm apical from the top of the crest on cone-beam computed tomography. *p* Values are determined using the Wilcoxon rank-sum test with continuity correction. Data are shown as mean (standard deviation), minimum–maximum values.

TABLE 4 Bone gain and loss

	Control group		Test group		
	N	Bone change	*N*	Bone change	*p* Value
Posthealing bone gain (mm)	16	2.7 (1.8), −0.3 to 6.0	16	5.3 (2.3), 0.8 to 9.0	0.003
Postoperative bone gain (mm)	12	3.5 (1.6), 1.3 to 6.4	15	7.4 (2.0), 4.6 to 10.7	<0.001
Posthealing bone loss (mm)	12	−0.9 (0.8), −2.8 to −0.2	15	−2.1 (1.6), −4.2 to 1.3	0.012
Posthealing bone loss (%)	12	−27.9 (25.8), −99.9 to −5.7	15	−29.4 (26.7), −84.5 to 24.5	0.608

Note: Bone gain and loss are measured 2 mm apical from the top of the crest on cone-beam computed tomography. *p* Values are determined using the Wilcoxon rank-sum test with continuity correction. Data are shown as mean (standard deviation), minimum–maximum values.

TABLE 5 Posthealing bone loss in anterior and posterior sites

	Test group anterior sites ($n = 5$)	Test group posterior sites ($n = 10$)	*p* Value
Posthealing bone loss (mm)	−2.9 (1.1), −4.2 to −1.7	−1.7 (1.7), −4.2 to 1.3	0.126

Note: Bone loss is measured 2 mm apical from the top of the crest on cone-beam computed tomography. The *p* value is determined using the Wilcoxon rank-sum test with continuity correction. Data are shown as mean (standard deviation), minimum–maximum values.

The mean ridge width was significantly different between the groups in this study. This may be due to the fact that the conventional GBR technique used in this study did not allow for sufficient volume gains, and excessively atrophic ridges were treated via autogenous blocks. In a meta-analysis by Naenni and colleagues,[42] the thinnest ridges were associated with a slightly greater newwidth gain (0.35 mm of difference per millimeter of ridge width). The authors of the meta-analysis assumed that larger grafts were performed on the thinnest ridges or that the resorption pattern tended to follow the original anatomy of the ridge.

It is difficult to achieve mechanically stable grafts of large volumes using the conventional technique. In the control group the membrane used was a nonstretchable reticulated membrane.

The bone graft was positioned under but could not be packed. As a consequence, the graft volume placed was limited. Some studies have reported relatively high bone loss during healing, which may be related to the nonspace-maintaining nature of some defects.[35] However, when the new technique is used, the volume can be maintained by itself, without the use of a form-stable device, even in nonspace-maintaining defects. In the test group the membrane used was a stretchable collagen membrane. This property allowed the graft material to be compressed and to add more graft volume under the membrane.

In this study, the postoperative ridge width obtained using the new technique was significantly higher than that obtained using the conventional technique, and there was also a nonsignificant tendency for a greater final crest width in patients who underwent GBR via the new technique. The new technique allowed for the treatment of thinner ridges and resulted in twice the final bone gain after healing.

4.2 | Horizontal bone loss between surgery and implant placement

The average horizontal bone loss between regeneration and implant placement was higher in the test group in this study. Previous studies using particulate allografts or xenografts (alone or in combination with particulate autogenous bone) reported a wide range of bone loss (0.54–3.1 mm).[28–30,33–35,42,47,58] A systematic review[43] noted that the greatest bone gains were reported by Urban[18] and Gultekin,[47] and theorized that these bone gains were due to the composition of the particulate grafts used in these studies (1:1 mixture of particulate autograft and DBBM), as xenografts slow the resorption of autogenous bone,[15,19,20] promoting volume gain. A meta-analysis[42] also reported a lower resorption (−11.6%) for augmentations using xenografts compared to augmentations involving only autogenous bone. However, studies using xenografts obtained different values of bone gains, as in this study. Therefore, the grafting technique must be considered to improve bone gain.

Bone loss may be due to the resorption of particles and clots, soft tissue pressure, or displacement of graft material.[33,35,59,60] Soft tissue and muscle pressure may have led to greater bone loss at the single anterior sites in this study. Pressure from the orbicularis muscle at the beginning of the healing process may promote anterior graft resorption.

The postoperative bone gain and posthealing bone loss were greater among patients who underwent new GBR in this study. However, the percentage of bone resorption was not significantly different between the two groups. Amorfini and colleagues[54] reported a positive correlation between the grafted volume and the percentage of bone resorption at 1 year in dehiscence defects that had been treated with GBR (resorbable membranes and 1:1 mixture of particulate autograft and DBBM). Gultekin[47] reported an overall bone volume loss of 12.48% in the GBR group (1:1 mixture of particulate autograft and DBBM) and a positive correlation between the postoperative graft volume and the graft resorption rate. However, these findings are not consistent with another study that did not report a correlation between the grafted volume and the percentage of graft material resorbed during healing.[35] According to the results of this study, the resorption rate may be stable regardless of the amount of grafted material.

4.3 | Technique

Following the principles of the Sausage Technique the bone grafts of the test group were well condensed in this study. Several studies have demonstrated the benefits of better compaction on the bone quality. A previous study compared the compaction of particulate grafts in rabbits at a pressure of 4.1 g on one side and 8.2 g on the contralateral side.[61] Histomorphometry examination revealed a higher amount of newly formed bone, greater bone density, and higher proportion of defect filling on the side compacted with 8.2 g, suggesting the importance of compacting grafts well and using a membrane to compress them. A study regarding socket preservation in dogs reported that greater compaction forces of the particles resulted in greater quantities of newly formed bone.[62] Similar results have been reported in humans in a histological study regarding alveolar ridge preservations with Geistlich Bio Oss Collagen with a force of 5 or 30 N. Approximately twice as much bone formed in the 30 N group compared to the 5 N group at 4 months.[63] These previous results indicate that the compressive forces may allow for more intimate contact between the particles, resulting in easier bony bridging. These forces also allowed for better stabilization of the particles. It is theorized that compression accelerates bone formation by stimulating angiogenesis and the expression of genes involved in cell proliferation.[63] However, these results are not consistent with another previous study that did not observe histological differences between groups with different compressive forces.[64] In the field of orthopedics, studies regarding the placement of acetabular cup prostheses have shown that the impaction of particulate bone grafts in the acetabulum has positive effects on the quality and kinetics of bone formation and on particle stabilization.[65] Therefore, the benefits of compacting have now been reported histologically in these recent studies, except for one.

4.4 | Limitations

There is however a limitation to the GBR techniques described here: the staged approach and the need for a prolonged treatment time

when compared to ridge-split technique with simultaneous approach. Positive results have been reported with this technique.[13]

This study is not without limitations. First, measurements were made only radiologically, not clinically. There is a possibility that radiographs showing bone ossification were misread, although clinical observations made at the time of implant placement support ossification. The relative precision of clinical and radiological measurements is controversial, and CBCT measurements are sometimes preferred.[35,42] This study is also limited by its retrospective nature and small sample size.

In addition, as this is the first series conducted with this technique, the procedures were conducted within the operator's learning curve, and greater precision in the compaction of the mixture and the tension of the membrane would likely provide more homogeneous results and less bone loss. It was observed that much better results can be achieved using the new technique than with the conventional technique, even at the beginning of the learning curve. To the best of our knowledge, this study is the first study to directly compare the new technique to a classic GBR technique. Further prospective studies are needed to verify the outcomes achieved using this technique.

5 | CONCLUSION

The new technique resulted in superior bone gain compared to the conventional GBR technique. In this study, the rate of graft resorption during healing was stable regardless of the amount of grafted material. The use of the Sausage Technique allows for a more predictable treatment of horizontal bone defects by meeting the current criteria for required peri-implant bone volume. In addition, this technique does not require space-maintaining defects or form-stable devices. Further studies are needed to confirm these results in the long term.

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CONFLICT OF INTEREST

Istvan A. Urban and Helene M. Arnal received honorarium for speaking for Geistlich Pharma. Others authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Helene M. Arnal: Concept/design, data collection/analysis, drafting and approval of the manuscript. **Charles D. Angioni:** Data collection, critical revision, and approval of manuscript. **Frederick Gaultier:** Study design, critical revision, and approval of manuscript. **Renaud Urbinelli:** Statistics, critical revision, and approval of manuscript. **Istvan A. Urban:** Surgical technique development, data interpretation, critical revision, and approval of manuscript.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author.

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