Horizontal Augmentation Through the Ridge-Split Procedure: A Predictable Surgical Modality in Implant Reconstruction

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Among alveolar ridge augmentation techniques, the ridge-split procedure demonstrates many benefits, including no need for a second (donor) surgical site, rare risk of inferior alveolar nerve injury, and less pain and swelling, and others. Lateral bone augmentation through the ridge-split works best in a localized lateral bony defect intended for 1 or 2 implants and where the ridge is vertically intact. In this article, the authors present a detailed description of the implant-driven technique of alveolar ridge-split procedure in small and large bone deficiencies, in maxilla and mandible, supplemented by multiple photographs. The authors emphasize the need for careful manipulation of the thin ridge based on knowledge of precise surgical principles and stress that a practitioner needs specialized training and experience to perform this type of alveolar bone augmentation.

Key Words: split-crest, bone expansion, ridge manipulation

INTRODUCTION

Since the introduction of root-form endosseous dental implants, the need to establish a proper alveolar ridge has become essential. Two-dimensional hard-tissue augmentation techniques are mainly designed for vertically preserved but width-deficient alveolar ridges, and 3-dimensional (3D) hard-tissue grafting procedures are intended to gain height and width in volumetrically deficient ridges. Many surgical pre-implant bone augmentation techniques have the goal of reconstructing deficient alveolar width, height, or both, including guided bone regeneration (GBR) with a cancellous graft, onlay/veneer block graft, inlay grafting, ridge split, and vertical and horizontal distraction osteogenesis.[1] Although ridge-widening techniques were used in the pre-implant era as a form of pre-prosthetic ridge plasty for the improved support of partial and full dentures, there has been renewed interest in such techniques in the past 30 years since the advent of osseointegration and root-form dental implants. An edentulous ridge expansion or split-crest technique for implant placement was originally described by Simion et al[2] and later by Scipioni et al.[3] A few literature reports depict different modifications of a ridge-split procedure (RSP) with or without interpositional bone grafting in the edentulous maxilla[4–13] and edentulous mandible.[8,14–17] Following is a description of the classic RSP that has been successfully used for many years in the authors' oral and maxillofacial surgery practices. In this article, the authors describe the RSP as a form of ridge modification (widening or augmentation), a technique that offers many advantages in oral pre-prosthetic implant reconstruction.

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Surgical Technique

Patient selection

An ideal candidate for the RSP is a nonsmoker in reasonably good health, who is committed to oral hygiene and has teeth in a good repair. The classic RSP requires a staged approach with 2 to 3 surgical procedures that culminate with implant insertion into the edentulous region of the jaw.

Before the procedure, a comprehensive oral examination should be done to assess skeletal and dental maxillomandibular relationship, obtain proper radiographs, prepare diagnostic models, and prepare a surgical stent for implant placement, if needed. A collapsed alveolar ridge demonstrating a narrow width (less than 5 mm in many cases) and grossly adequate alveolar height is the most common candidate for the RSP. It is the authors' practice to consider an alveolar width between 3 and 5 mm for the RSP. A 3-mm alveolar ridge generally consists of 3 thin bone layers (in a horizontal sandwich fashion): 2 cortical plates (about 1 mm each) separated by 1 cancellous layer (about 1 mm). In the hands of a skilled surgeon, 2.5-mm and even 2-mm ridges can be split. The wider the cancellous bone layer (the layer where the split is done), the easier it will be to accomplish the RSP. Although panoramic or periapical radiographs are frequently used, cone-beam computerized tomography (CBCT) is the ideal way to evaluate the 3D anatomy of the alveolar ridge. A comparative assessment of postoperative and preoperative scans is often done (Figure 1).

Surgical considerations

As with any surgical technique, the RSP is based on an understanding of distinct surgical principles. The authors suggest that the following 3 characteristics should be evaluated when considering RSP:

The first characteristic is bone density. The maxillary alveolar ridge is generally less dense than the mandibular alveolar ridge and more amenable to a single-stage RSP, whereas the authors usually treat the mandibular alveolar ridge with a two-stage RSP.

The second characteristic relates to the blood supply to the alveolar process and the role of periosteal vascularization. During an RSP, a buccal vascular bone flap is created. The muscular-periosteal soft-tissue envelope provides peripheral (periosteal) vascularization to the gingiva, to the cortical bone, and partly to the cancellous alveolar bone. The complete reflection of a full-thickness buccal soft-tissue flap eliminates the periosteal vascular pedicle to the buccal (labial) cortical plate and results in a devascularized free graft during an RSP. Periosteum plays a critical role in vascularization of the buccal cortex and in graft osteogenesis. Gray et al[18] concluded that at least one-third of early graft osteogenesis could be attributed to the periosteum alone. Meticulous tissue manipulation preserving the periosteum and its role in peripheral vascularization is extremely important in RSP.[19]

The third characteristic relates to the treatment of the wound as a result of the RSP and appreciation of the wound healing by secondary intention. Primary closure is not applicable in most RSP cases. The widened alveolar ridge has to maintain its proper soft-tissue architecture (vestibule and keratinized tissue), and the labial soft tissue has to be undisturbed. After RSP, the alveolar ridges are treated openly and will heal by secondary intention analogous to the grafted extraction socket. A resorbable or nonresorbable membrane is used to retain graft material, isolate the wound from the oral environment, and guide the soft tissue's healing over the graft.

Surgical technique

The authors administer preoperative antibiotics 1 hour before the procedure followed by a 1-week postoperative course of antibiotics as well as a 0.12% chlorhexidine rinse for 3 days before and 1 week after the procedure. Preoperatively, the alveolar ridge is evaluated visually and by palpation. Palpating the ridge with 2 fingers sliding along the alveolar crest helps to develop a tactile sense of the ridge thinness and presence of bone undercuts. The future implant fixture length and position of the inferior alveolar canal (in posterior mandible) usually determine the vertical dimension of the split. Commonly, the vertical extension of the split approximates the future implant length and falls into the 8- to 12-mm range. The length of the ridge to be expanded is practically unlimited and can vary from a single tooth to a full arch. Although there can be many surgical modifications, traditionally the ridge-split technique consists of a single surgical stage in the maxilla and a two-stage approach in the mandible.

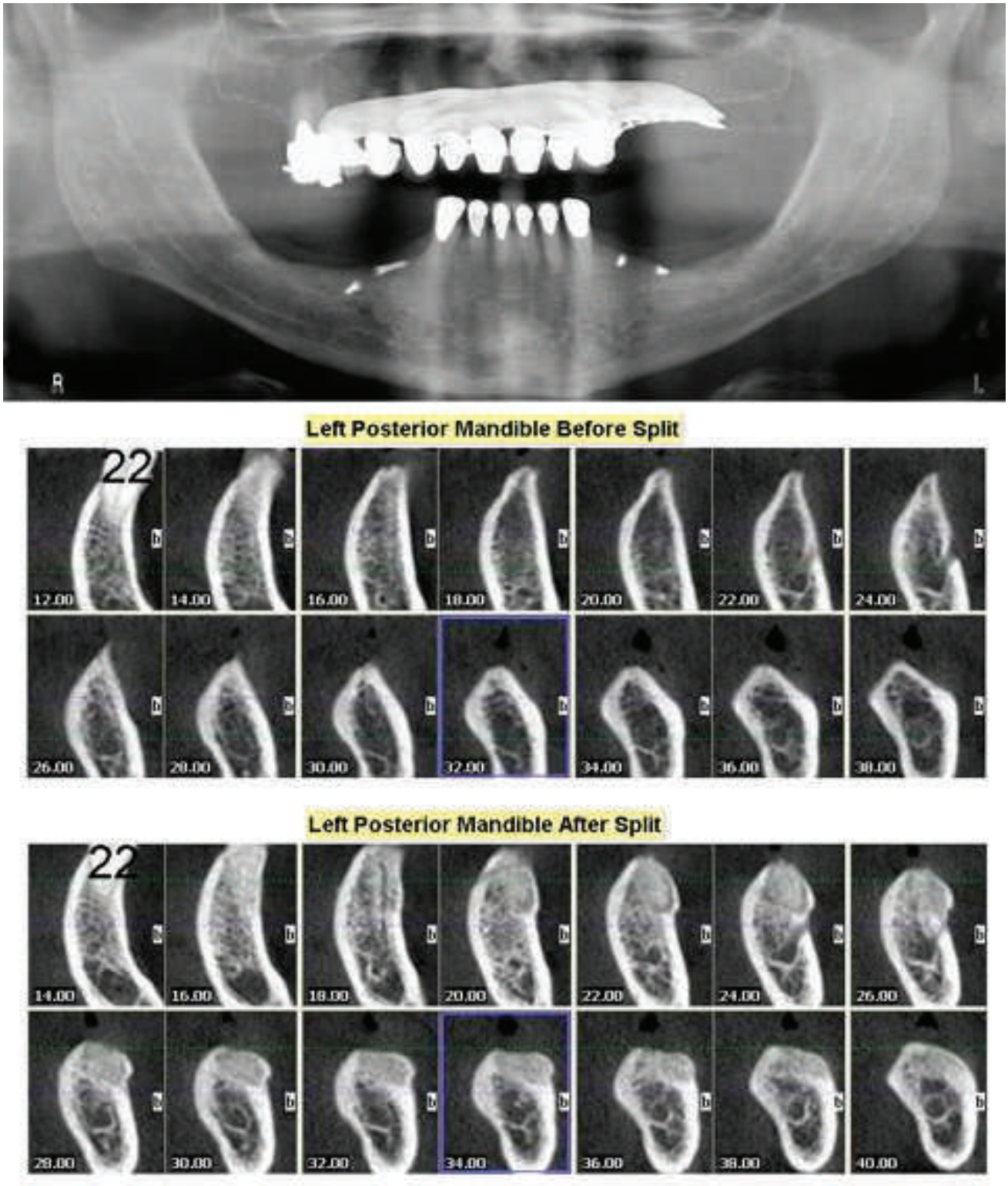


Figure 1. Cone-beam computerized tomography (CBCT) slices are useful in providing necessary information on alveolar thickness, position of the inferior alveolar canal in the mandible or maxillary sinus in the maxilla, and comparative assessments of postoperative and preoperative bone morphology. CBCT demonstrates enhancement in alveolar width after ridge augmentation with the ridge-split procedure.

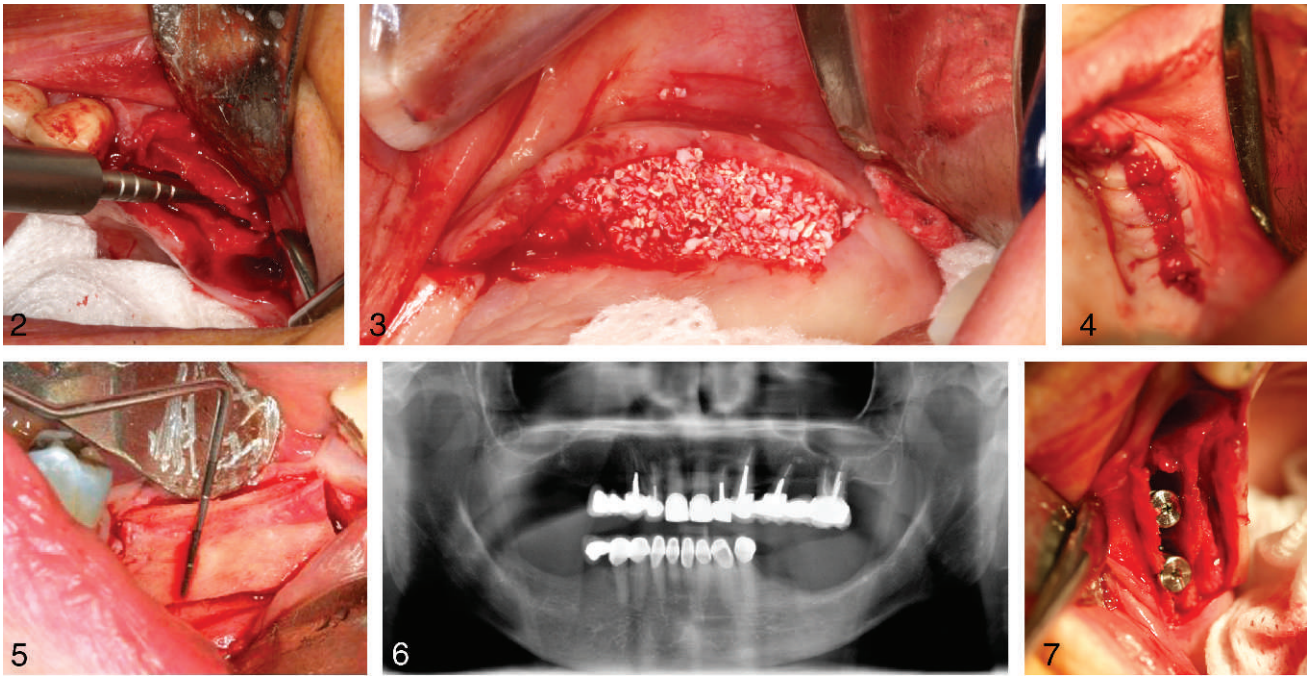
Maxillary single-stage alveolar RSP

This procedure usually consists of a single-stage, though occasionally a two-stage technique can be performed with the delayed placement of implant(s). Generally, 3 mm of alveolar width and 7 mm of alveolar length (between teeth) should be present for a single-tooth edentulous ridge to undergo RSP. The buccal-palatal dimension can be decreased with a more experienced surgeon. A full-thickness incision of the appropriate length is performed in the edentulous area at the crest of the ridge. It is recommended, if possible, to use a papilla-preservation approach. The developed flap is a limited crestal (not buccal) full-thickness flap just large enough to see the top of the alveolar crest; again, no formation or wide reflection of the buccal flap should occur.

Splitting of the ridge is a technique-sensitive procedure that could be done with many different instruments, ranging from scalpel blades to spatula osteotomes, piezoelectric surgical systems, and ultra-fine fissure burs. Thin maxillary alveolar ridges can usually be split along the crest in a single-stage procedure if the anterior-posterior dimension is moderate in size. A two-stage procedure may be appropriate if the segment is greater than 3 teeth in length or if the bone is unusually dense. In the single-stage procedure, a crestal bone cut is initiated as described earlier and carried to depth with a spatula osteotome. A greenstick separation of the deficient (often collapsed) buccal cortical plate from the palatal portion of the alveolar bone, if carefully done, will lead to an opening of the bony gap (like the slow opening of a book) with formation of a buccal vascular osteoperiosteal bone flap (Figure 2). Beginners in RSP should initially choose a 4–5 mm thickness of an even maxillary alveolar ridge and strive to almost double it in width (7–8 mm) to prepare it to accept an average 4-mm implant fixture at the next surgical phase. An overcorrection of approximately 2 mm is recommended because there is some tendency for relapse. The 7-8-9-10 rule can be a guide for the ideal implant-oriented alveolar ridge augmentation after the RSP, where at least 7–8 mm of bone width and 9–10 mm of bone height are necessary.

The second aspect of RSP is grafting/GBR. The grafting in the ridge-split technique is done internally (inside the split). In essence, this procedure is similar to a large socket GBR but with a mobile buccal plate. Any grafting material (eg, autogenous, allogeneic, xenograft, bone morphogenetic protein 2, composite) can be used in these cases; the choice is usually based on the practitioner's preference. The authors' preference for RSP is a bovine xenograft and human allograft. One author (L.T.) believes Bio-Oss cancellous spongiosa granules of a 300–500 particle size (Osteohealth Co, Division of Luitpold Pharmaceuticals, Inc, Shirley, NY) tend to preserve the split opening better because of the crystals' mechanical properties and slow resorption rate. The graft is loosely packed into the created bone gap from the bottom up (Figure 3). The remaining portion of the procedure is concluded with the goal of preserving the created alveolar width and promoting healing by secondary intention. Similar to the socket preservation (Bio-Col) technique described by Sclar,[20] a split and grafted ridge is covered with an appropriately sized membrane (resorbable Colla-Tape membrane (Zimmer Dental Inc, Carlsbad, Calif) or a dense polytetrafluoroethylene (PTFE or Teflon) non-resorbable membrane (Kendal Curity, Tyco Healthcare, Mansfield, Mass). With any membrane, it is important to make sure that most of the graft particles are covered and not exposed. Exposed bone particles will disturb proper healing. After membrane placement, continuous locking or multiple interrupted 4-0 chromic gut or 4-0 silk sutures should be placed without tension (Figure 4). Occasionally, a tissue glue (eg, PeriAcryl,GluStitch Inc, Delta, BC, Canada) can also be placed on top of the wound, creating an extra protective layer. Infrequently, before the grafting, 10–12 mm long 1.5–2.0 mm mini-screws can be used to stabilize buccal and palatal cortical plates in the new separated position. An experienced practitioner may attempt to place implants at this stage, although they are usually placed 4 to 6 months later. For a better prognosis of implant osseointegration, primary (apical) implant stability has to be present if implant insertion is selected at this stage.[21]

The patient is usually instructed to complete a week-long course of antibiotic therapy and chlorhexidine intraoral rinses. It is recommended to wait 4 to 6 months before implant placement at the second surgical phase. A repeat CBCT scan may be done at that time for a comparative assessment of the gain in alveolar bone width (Figure 1). On



Figures 2–7. Figure 2. An intraoral photograph demonstrating a narrow osteotome that is lightly tapped into the cancellous layer of bone with a surgical mallet separating 2 cortical layers during the ridge-split procedure in the edentulous maxillary ridge. **Figure 3.** An intraoral photograph demonstrating a cancellous graft that is packed into the created bone gap. **Figure 4.** An intraoral photograph demonstrating placement of sutures without tension to allow healing by secondary intention; the depth of the vestibule and position of the keratinized tissue are preserved. **Figure 5.** An intraoperative photograph demonstrating 4 corticotomies (1 crestal, 1 apical, and 2 vertical) at stage 1 of the ridge-split procedure; about 9–10 mm of distance is needed between the apical and crestal corticotomy. **Figure 6.** Patient 1: Preoperative panoramic radiograph demonstrating a failing bridge connecting the upper right lateral incisor with a non-restorable canine and extending as a cantilever to the premolar region. **Figure 7.** Patient 1: Intraoperative photograph demonstrating 2 endosseous implants (Biomet 3i) that were placed after the split stage of the ridge-split procedure. Good primary implant stability (20 NCm) was achieved.

occasion, in severely resorbed ridges, additional bone augmentation may be necessary.

The described surgical approach of ridge split/expansion can be successfully used for anterior or posterior maxilla or for a full maxillary arch. On occasion, anterior maxillary alveolar bone may be very dense and difficult to manipulate. In these cases, a staged surgical technique similar to the mandibular RSP described in the next section can be performed.

Mandibular two-stage alveolar RSP

As presented earlier, one of the more common differences between maxillary and mandibular bone is the density. Thus, use of a single-stage RSP is less predictable in mandibular alveolar ridges. In the mandible, the procedure usually has 2 stages: stage 1 consists of corticotomy and stage 2 consists of splitting and grafting, which is performed 3–5 weeks later (3 weeks in younger patients and 4–5 weeks in older patients).

Stage 1: Corticotomy

The goal of corticotomy is to section through the exposed buccal cortex around the periphery of the buccal bony plate (to weaken the most dense portion of the bone), which is to be laterally repositioned at the stage-2 surgery. The two-stage ridge split starts with a crestal incision similar to that performed in stage 1 of the maxillary ridge surgery. In contrast to the RSP in the maxilla, the stage-1 corticotomy requires a full-thickness buccal soft-tissue flap with 2 releasing incisions that should extend beyond the bone cuts. After the appropriate bony exposure is achieved, peripheral corticotomies outlining a "buccal door" are performed: crestal (similar to the maxillary procedure), apical (about 10–12 mm below; it is important to observe the proximity of the mental nerve), and 2 vertical

connecting corticotomies (Figure 5). The corticotomies should all be connected as a continuous rectangular line, extending through the buccal cortical plate into the cancellous layer of the bone, paying particular attention to the 2 apical corners of this outlined bone osteotomies. The crestal corticotomy or trough is very important and will be used at stage 2 with a limited flap for the actual splitting. Attention to details and proper performance of this stage, directed to weakening the buccal cortical plate in the key areas (future split), will guarantee the success of the stage-2 procedure. The buccal flap is repositioned and sutured with interrupted 4-0 chromic gut sutures. This buccal flap, which has been elevated from the alveolar ridge, needs time to heal in order to reestablish the periosteal blood supply to the buccal bone (revascularize it). The buccal cortical bone will be subfractured at the next stage, together with the adhered periosteum (in 4 to 5 weeks).

Stage 2: Splitting and Grafting

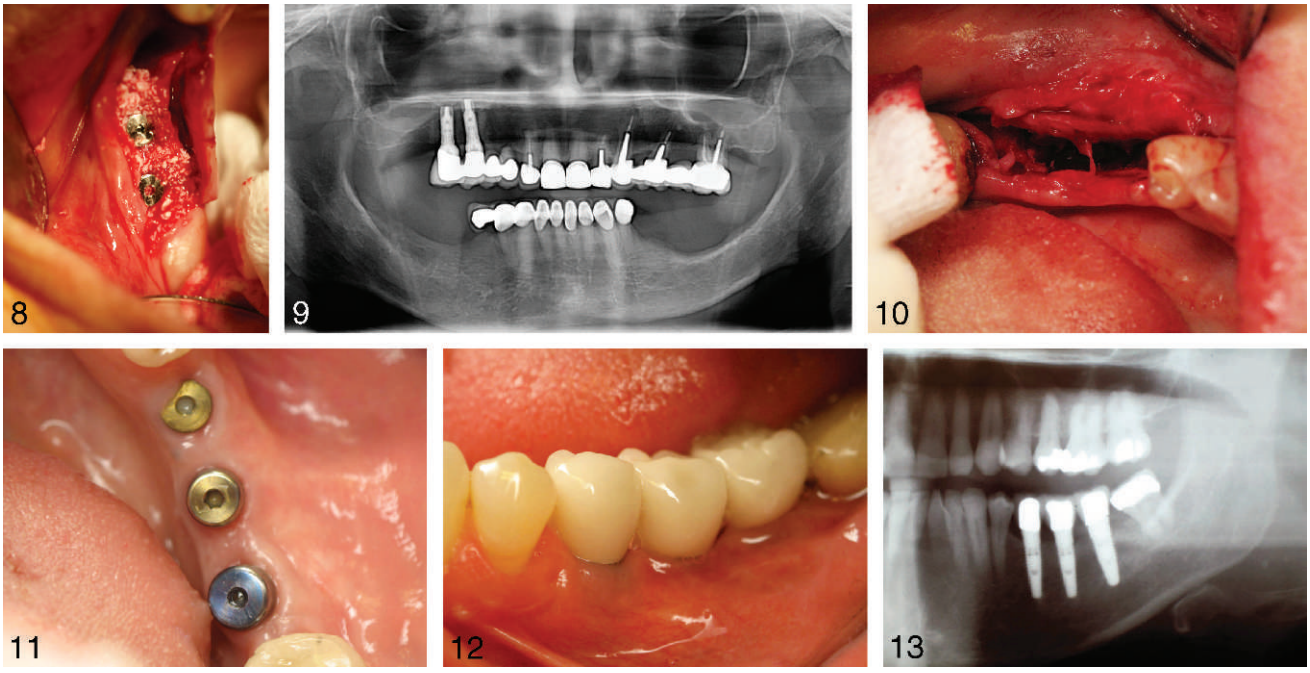
The second stage of the mandibular ridge expansion procedure is done in a manner similar to a single stage of the maxillary ridge split, using a limited-reflection flap. A crestal incision just wide enough to see the crestal corticotomy is performed (closed approach). The operator should feel for the crestal groove created at the stage-1 surgery with the scalpel blade. The blade should be held firmly in this groove and run the full extension of this bony groove. Papilla-sparing curved incisions should be created toward the buccal and lingual side at the mesial and distal extensions of the groove. Tissue should be reflected to the lingual side as needed, but the tissue on the buccal side should only be elevated at the points where the buccal curved incisions are carried onto the adjacent bone. It is important to create flexible relief at the mesial and distal extensions so that the buccal soft-tissue flap will not tear when the bone plate is transported laterally.

Next, the spatula osteotome is tapped to depth with the osteotome of the next thickness and a controlled lateral force should begin to be used to mobilize the buccal plate. Thus, a buccal muco-osteo-periosteal flap with its own buccal soft-tissue blood supply is created and can be manipulated (widened). An overall ridge expansion up to 8–10 mm is usually adequate, and grafting similar to that described previously is performed. Primary closure of the wound is not needed nor is it usually possible. A 4- to 6-month waiting period is suggested before an implant treatment.

The most common regions of the jaws that undergo RSP are the anterior and posterior maxilla and the posterior mandible. Following are 2 reports of patients undergoing RSP: one in the maxilla and one in the mandible.

Case report 1: RSP in the maxilla

A healthy 82-year-old woman interested in implant treatment was referred for the extraction of a fractured upper right canine tooth. Clinical and radiographic findings consisted of a failing bridge connecting the upper right lateral incisor with a non-restorable maxillary right canine and extending as a cantilever to the premolar region (Figure 6). The alveolar ridge in the premolar and first molar region of the posterior maxilla were found to be narrow. Treatment consisted of sectioning the porcelain-fused-to-metal (PFM) bridge between the lateral incisor and the canine, extracting the non-restorable cuspid with bone grafting of the socket, and performing an RSP with simultaneous placement of 2 implants in the premolar/molar region of the right posterior maxilla. The alveolar ridge was narrow, about 2.5 mm thick, and the cancellous layer was practically missing. Careful use of the scalpel helped to separate the 2 cortical plates in the premolar low-density region (behind the extracted cuspid). Paralleling pins were used to visualize the emergent profile of both implants inside the widened alveolar ridge. Two Biomet 3i 4-mm internal hex Certain implants (Biomet 3i, Palm Beach Gardens, Fla) were inserted with a primary stability of 20 Ncm (apical bone stability) between the 2 thin cortical plates (Figure 7). The bone gap between both implants and the socket of the removed canine were filled with cancellous granules of Bio-Oss xenograft (300–500 particle size) (Osteohealth Co) (Figure 8). A layer of Colla-Tape membrane (Zimmer Dental Inc) was placed on top of the graft, and the wound was closed with 4-0 chromic gut sutures (primary closure was achieved in this case). Nine months later, surgical stage 2 was done with placement of the healing abutments into the well-osseointegrated implants. The restorative stage was completed 2 months later and consisted of a splinted



Figures 8–13. Figure 8. Patient 1: Intraoperative photograph showing bone grafting (Bio-Oss) placed between 2 implants into the created gap (split). **Figure 9.** Patient 1: Final panoramic radiograph of the completed case demonstrating porcelain-fused-to-metal implant-supported bridge. **Figure 10.** Patient 2: Intraoperative photograph at stage 2 showing a greenstick fracture widened to a 8-mm width (stabilized with two 2.0-mm tru-fix self-drilling mini screws). **Figure 11.** Patient 2: Intraoral photograph showing the implant surgical stage in which 3 Replace Select 4.0-mm tapered implants were placed in the position of the second and first molars and second premolar 6 months after the ridge-split procedure. **Figure 12.** Patient 2: Clinical post-completion intraoral photograph demonstrating osseointegrated and restored implants; 3 separate porcelain-fused-to-metal implant-supported crowns were cemented to full function and satisfactory occlusion and esthetic results. The patient was satisfied with the results. **Figure 13.** Patient 2: Close-up panoramic radiograph demonstrating osseointegrated and restored implants; 3 separate porcelain-fused-to-metal implant-supported crowns were cemented to proper function and occlusion.

PFM implant-supported bridge connecting both implants and extending as a cantilever to the canine region (Figure 9). The patient was very satisfied with the final restoration, which had been functional for approximately 4 years at the time of publication.

Case report 2: RSP in the posterior mandible

A healthy 60-year-old woman presented with a history of loss of a lower left 4-unit bridge 1 month earlier and the presence of a retained root of the anterior abutment of that bridge. Clinical findings were significant: a 3-mm narrow mandibular alveolar ridge in the first molar and second premolar sites and a non-restorable root of the first premolar. Treatment consisted of removal of the retained first premolar root and the staged RSP. Stage 1 of the RSP (corticotomy) was done in the standard manner described earlier with 4 connecting corticotomies. The buccal flap was repositioned and sutured in a routine fashion. Stage 2 of the RSP (split and graft) was done 4 weeks later. In a closed-flap fashion, sequential osteotomes were used to tap to depth into the crestal osteotomy to create a fully mobilized buccal muco-osteo-periosteal flap (Figure 10). A Teflon non-resorbable guided tissue regeneration membrane (Kendal Curity) was placed inside the buccal side of the split. The membrane was tucked several millimeters under the developed lingual flap after the graft was placed. Puros cortical and cancellous allograft 1:1 was used as the graft material (Zimmer Dental Inc). Six months after the RSP, 3 Replace Select tapered implants, 2 at 4.3 mm $\times$ 13 mm and 1 at 5.0 mm $\times$ 13 mm (Nobel Biocare, Yorba Linda, Calif), were placed in the position of the second and first molars and the second premolar (Figure 11). All implants osseointegrated successfully and were restored 6 months later in the restorative dental office with 3 separate PFM implant-supported crowns to a fully functional

occlusion (Figures 12 and 13). The patient's restoration had been functional for approximately 4 years at the time of this publication.

Modifications of the technique and instruments

The Meisinger split control bone expansion kit (Meisinger, Jacksonville, Fla) uses a screw-type configuration of expansion and condensing burs and threadformers for lateral bone expansion/condensing with a delayed or simultaneous endosseous implant insertion.[22.] It appears that the precondensed bone cavity improves the primary implant stability. Another way to approach the RSP is by using piezosurgical instruments. Although slightly slower, this method is an accurate way to perform the bone cuts in experienced hands. Scopioni et al[5] proposed a graftless "morphogenic bone splitting" technique done through the partial thickness flap in which the bone-mucosa-gingival complex is displaced laterally in its entirety to eliminate the facially inclined hinge displacement often seen with a traditional RSP. A horizontal alveolar ridge widening with a titanium mesh plate using distraction osteogenesis principles[15] or an alveolar crest widening/horizontal distraction device[23] can also be used for a lateral bone augmentation. Induced osteogenesis by periosteal distraction or GBR by dynamic periosteal elevation are other modifications of the lateral wall augmentation technique[24,25] when the bone crest-split is not done but the periosteum is tented to promote bone regeneration and widening. Many other technique-sensitive procedures have been proposed for alveolar expansion, but their description is outside the scope of this article.

Complications of the RSP

Fracture of the buccal plate in the mandible during a single-stage split (the full-thickness flap is fully reflected and the buccal cortex is devascularized) leads to a free bone graft that has to be stabilized with mini screws and postponement of the RSP. Infection and uncontrolled bleeding are rare complications of RSP and are usually controlled with antibiotics/debridement and local hemostatic agents, respectively. Position of the mental foramen has to be determined preoperatively and monitored intraoperatively to prevent neurosensory complications during mandibular RSP. Other complications are rare.

Discussion

In the 1990s, initial reports on the ridge-splitting technique described it as a successful surgical procedure that could be used simultaneously with implant placement. Original reports by Simion et al[2] and Scipioni et al,[3] in 1992 and 1994, respectively, demonstrated an alveolar width gain between 1 and 4 mm after the split-crest procedure and successful immediate implant placement and osseointegration (success rate of 98.9%). In 1997, Engelke et al[26] reported the reconstruction of narrow anterior maxillary alveolar ridges by the preparation of an "artificial socket" (lamellar cortical splitting) with immediate interlamellar implant placement and primary stabilization with microfixation. This report documented a 5-year cumulative success rate of 86.2% for 121 implants and a mean marginal bone loss of 1.7 mm. Also in 1997, De Wijs and Cune[27] described a 4-year cumulative survival rate of 93.7% for 68 implants placed simultaneously with a bone-splitting technique for anterior single-tooth replacement. They also noticed only a minor decrease in marginal bone loss that ranged from 0.8 to 1.3 mm and concluded that the technique was safe and predictable "when performed carefully on selected patients and with the proper instrumentation." In a large case series of 303 patients in 1998, Bruschi et al[28] showed a successful combination of the edentulous ridge expansion with sinus lifting and an immediate implant placement. The success rate of the 499 implants was 97.5%. Also in 1998, Malchiodi et al[29] described a successful use of titanium mesh as a space maintainer after ridge expansion with an immediate implant placement. Only 3 failures from 120 placed implants were recorded. In 2000, Sethi and Kaus[30] reported a 5-year survival rate of 97% for two-stage implants simultaneously placed with maxillary ridge expansion. In 2008, Elian et al[31] demonstrated the possibility of a two-stage full-maxillary arch bone expansion using a ridge-split approach, and highlighted the inability of this technique to be used for a vertical augmentation of the alveolar ridge. In 2011, Gonzalez-Garcia et al[4] demonstrated 98% bone regeneration in the intercortical gap (implant sites) and 100% implant survival rate (delayed implant placement) after more than 2 years of follow-up. At the second procedure, mean loss of the alveolar bone height was 0.542 mm. The authors commented on

predictable results of implant treatment after split-crest osteotomy. In 2010, Sohn and coauthors[14] compared an immediate versus delayed lateral ridge expansion technique that was used on 32 patients (84 implants were placed) with a narrow edentulous posterior mandibular ridge and concluded that the delayed approach (performed on 9 patients) was safer and more predictable in patients with denser bone and a thick cortex (typical for mandibular ridges). One of the complications of an immediate approach (performed on 23 patients) was an intraoperative malfracture of the thin buccal cortical plate (occurred in 5 patients or 22%).

Conclusion

The literature has demonstrated the predictability of an RSP in cases of narrow alveolar ridges that can be widened in preparation for an implant placement. The staged approach to implant reconstruction by ridge splitting tends to have a higher implant success rate and better buccal cortical bone preservation.[4,14]

RSP is a form of alveolar inlay osteoplasty that is usually performed in a closed fashion, uses a tactile sense, and belongs to a category of minimally invasive intraoral surgical techniques for which a practitioner's experience is especially important.

Abbreviations

3D: 3-dimensional
CBCT: cone-beam computerized tomography
GBR: guided bone regeneration
PFM: porcelain fused to metal
RSP: ridge-split procedure

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