This report details surgical procedures for ridge expansion by means of splitting the crest of an edentulous ridge. Atrophic bony ridges present a unique challenge to the dental implant surgeon. In the past, onlay grafts of bone harvested from the hip, maxillary tuberosity, symphysis of the chin, or external oblique ridge have all been used with success in reconstruction of atrophic ridges. However, bone onlay grafting procedures require a secondary surgical site, which exhibits typical postoperative morbidity associated with bone harvesting performed with chisels and burs. Additionally, onlay grafts often require a healing period of 6 months to a year before dental implants can be placed, and the onlay graft sometimes fails to fuse to the augmented site. The segmental ridge-split procedure provides a quicker method wherein an atrophic ridge can be predictably expanded and grafted with bone allograft, eliminating the need for a second surgical site. 

The segmental ridge-split procedure presented here is a modification of the procedures originally developed by Simion et al.¹ and Scipioni et al.² and later discussed by Nevins and Stein.³ We have added some alterations to those original techniques, which we have found to be supplemental to preserving bone plates while enhancing reconstruction of lost bone. In this light, we wish to present the segmental ridge-split procedure (SRSP), a procedure that we believe affirms the efficacy of the split-crest¹ and the ridge expansion² techniques.

Lyophilized bone allografts have been known in periodontal surgery for over a quarter of a century,⁴ and the usefulness of freeze-dried bone allografts (FDBA) has been reported repeatedly in periodontal bone grafting procedures.⁵-⁸ It was not until the late 1950s that it was understood that demineralized grafts are replaced faster than non-demineralized grafts when used in surgical procedures.⁹ Calcium concentrations in mineralized grafts fall prior to rising, which suggested that these grafts had to undergo demineralization in situ before being converted to mature bone.¹⁰-¹² This distinction between FDBA and demineralized freeze-dried bone (DFDBA) was both recognized and studied in the treatment of periodontal defects.⁷,⁸ DFDBA has been used with varying levels of success in periodontal bone grafting procedures.¹³-¹⁷ However, a number of well-designed studies also failed to identify any positive effect from the use of DFDBA in bone grafting procedures.¹⁸-²¹ One study specifically examined the potential of augmenting atrophic ridges with DFDBA and found that the material showed little, if any, potential.²² Some of the reported differences in the efficacy of DFDBA may be related to the reconstitution and preparation of the allograft bone material. When it is possible to obtain autogenous bone, the combination of DFDBA and autogenous cancellous bone has proven to be an especially effective grafting material. This is particularly true when the combination graft is encased within an area surrounded by bone and periosteum.²³ The importance of periosteum in osteogenesis during bone grafting techniques has been demonstrated by a number of researchers.²⁴-²⁷ Bone re-formation is not generally independent of soft tissue management and closure. When autogenous or allogenic bone graft
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materials are isolated within an area surrounded by bony walls and periosteum, preosteoblasts and functional osteoblasts can readily enter the graft. At least one-third of early graft osteogenesis can be attributed to the periosteum alone. These observations suggest that successful bone reconstruction might be influenced by graft selection combined with carefully designed tissue manipulation and tissue management. The segmental ridge-split procedure (SRSP) creates a crypt surrounded by bone and periosteum into which implants and bone graft materials can be introduced with reasonable confidence that new bone can be constructed and that this new bone will provide a solid base for dental implants.

PRESURGICAL ASSESSMENT

Patients should be healthy and mentally adjusted to the rigors of implant procedures. Although younger patients generally have better bone quality and seem to have better postoperative healing, there has been no identified age limitation to segmental ridge-split procedures. Our patients have ranged from 13 years to 67 years of age.

Assessment and reassessment of the patient are performed before, during, and after the surgical procedures. Good oral hygiene is crucial to the success of the surgery and the ensuing dental implant prosthesis. Any inadequacy in this important area is unacceptable and may immediately disqualify the patient for consideration for the procedure. The patient who smokes is also a rather poor candidate for implants. In our experience, this has been found to be particularly true for ridge-split procedures.

Presurgical planning is essential to the success of ridge-split procedures. Panoramic, periapical, occlusal, cephalometric, and tomographic radiographs can all add invaluable information prior to entry into the site of the atrophic ridge. Most offices are equipped to take at least occlusal and periapical films. In addition, it is recommended that practitioners placing implants should have access to panoramic films of their patients.

It is best to advise the patient that implants may not be placed at the initial ridge-split procedure owing to the challenge of attaining implant fixation or difficulty manipulating the bone plates. Procedures confined to single-tooth sites can often be treated with simultaneous ridge-split and implant placement.

MATERIALS AND METHODS

Razor-sharp bone chisels were used when performing ridge-split procedures described here. A surgical mallet is necessary, and should be an instrument that is comfortable to the surgeon. The split of an atrophic ridge can be likened to an art form, and the surgical mallet should be a balanced instrument, which can be used to impart gentle but precise blows to the chisels and osteotomes. Often, practitioners will experiment with several different styles of mallets to find the one that suits their tactile sense.

Kirschner drills or small spiral drills must be available to create holes for the passage of stainless-steel ligature wires. The 0.025 mm dead-soft stainless-steel wire is ligated across the bone plates if there is any looseness in the plates after the ridge has been split.

The space between the plates is generally grafted with 300 to 500 µm DFDBA combined with autogenous bone when possible; plus, we feel that the DFDBA should always be reconstituted with the patient’s blood.

When the patient has no known allergies to achromycin, the incisions are coated with a copious application of 3% achromycin ointment after suturing is complete. The patient is also instructed to use twice-daily rinses of chlorhexidine mouthrinse.**

SURGICAL TECHNIQUE

Since periodontal disease and/or endodontic pathology may lead to destruction of alveolar bone (Fig. 1), even when precautions are taken such as bone grafting the extraction sites (Fig. 2), it is not extremely
uncommon to open an edentulous ridge only to find thin atrophic bone (Fig. 3). Rather than abandoning the implant procedure, a segmental ridge-split procedure may be performed. In this procedure (SRSP), the entire edentulous bony segment is opened like an envelope to receive the implants. During the course of these procedures, it is important to maintain the vitality of the bone to every degree possible. Irrigation of the field should be with saline rather than tap water, plus it is advisable to keep a manageable amount of blood pooled around the bone plates. Any saline irrigation should be cold, especially during drilling procedures. The surgical site may be dabbed with gauze or lightly suctioned for visualization or photography of the site. However, the site should never be completely dried and blood vessels should never be cauterized. Additionally, it is inadvisable to use high-concentration vasoconstrictive agents during the surgery or photography.

The entry incision into the surgical site should be planned to allow for primary closure of the site. This will be discussed in greater detail, as the requirements for that closure are considered. However, the entry is generally made palatal to the crest of the ridge. Though mid-crestal incisions can be managed, the shift of the incision line toward the palate tends to facilitate closure. However, excessive palatal rugae or other anatomical considerations may affect the exact position of this incision.

In the maxillary anterior region, it is not uncommon to find that the atrophy of the ridge has been at the expense of the facial bone (Fig. 4). The crest of the ridge may be less than 3 mm in bucco-palatal width, and a facial bone concavity is often present superior to the crest of the ridge. Any attempt to place implants in this situation would result in a dehiscence at the osteotomy opening, and often result in a fenestration at the facial concavity. Even when implant placement is possible, the surgeon is often forced to place the implants with a significant facial flare. Flared implants tend to be more challenging to restore. SRSP can often resolve many of these problems.

The first step in the segmental ridge-split procedure is the creation of a 1 to 3 mm deep seam along the length of the ridge (Fig. 5). The seam should come to within 2 mm of the adjacent teeth, but no closer (Fig. 6). The entire length of the seam should be...
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established prior to deepening the split. The seam should be turned vertically at the point where it is within 2 mm of the line angle of the adjacent teeth (Fig. 7). Once the crestal seam and adjoining vertical bone releases have been defined, the bone chisel can be progressively driven deeper (Fig. 8).

After establishing the initial ridge split, spiral drills or small spade drills are used to enlarge the implant osteotomy sites (Figs. 9 and 10). As the diameter of the drills increases, there is likely to be an increasing amount of chatter on the facial plate of the bone. Finger pressure on the 2 plates of bone during drilling procedures tends to help stabilize the facial plate of the bone (Fig. 10). Periodically, it is wise to reaffirm proper position of the drill path in regards to angu-

Figure 5.
Using a razor-sharp chisel to set a score line along the crest of the bone ridge.

Figure 6.
Score line completed to a depth of 3 mm along the crest of the bone ridge.

Figure 7.
Creation of vertical releases at ends of ridge-split and progressive deepening of the split.

Figure 8.
Careful and gradual opening of the buccal plate of the bone.
pared, the osteotomy sites can be prepared to their full size (Figs. 13 and 14). The implants are then transferred to their respective osteotomy sites (Figs. 15 and 16). We have found that either threaded or cylindrical implants†† may be used. The 2 primary requirements are: 1) the implants are firmly secured once they are in their fully seated position (Fig. 17), and 2) the implants should be well aligned. If either of these criteria is not met at this point, we recommend that the furrow between the bone plates should be bone grafted, and the site should be closed in anticipation of future implant placement.

Once the implants are aligned and secured, then the facial and palatal plates of bone are firmly but carefully compressed against the length of the implants (Fig. 18). Many times the plates will be reasonably stable, and no further bracing will be necessary. However, a loose plate is subject to sequestration, and if there is any doubt about plate stability, the plates should be ligated. When ligating the plates, it is important to prepare the hole for the wire apical enough to the crest of the ridge to engage solid, non-brittle bone. A Kirschner drill or small spiral drill can be used (Fig. 19). Very thin ligature wire is then passed through the holes. Orthodontic ligature wire has worked well for us in these instances (Fig. 20). When tightening the ligature wire, bracing finger compression on the plates is wise. If the surgeon relies solely on the tightening

†† TPS-coated Bio-Vent Implants, Paragon, Encino, CA.
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Twist in the wire to compress the plates, the twist is likely to kink and break. Finger compression of the plates also helps to steady the plates as the wire is properly twisted (Fig. 21). The wire is then clipped, and the twisted end is turned downward into the furrow so it will not poke through the tissue during healing.

Freeze-dried decalcified bone (300 to 500 \( \mu \)m) is then reconstituted with the patient’s own blood. Any bone collected during drilling procedures is also added to the mix. We never add tetracycline to this mixture. In previous instances where we attempted to use bone that was reconstituted with saline and tetracycline, the postoperative results were poor. The heme-reconstituted bone is gently packed into the ridge-split furrow using tissue elevators and amalgam condensers (Fig. 22). Every effort is made to try to fill all voids in the bone between the implants, but the bone is never condensed to a point where it begins to lose its red color due to significant expression of the blood from the mix. This procedure is not at all unlike condensing amalgam (i.e., in the manner of filling all voids). The mixture of bone is also packed into the vertical splits at the edges of the ridge-split furrow (Fig. 23).

Primary closure of the surgical site is important to every extent possible. Although membranes may be used, it is best to strive for precise, tension-free closure of the flaps. Backing the seams of the gingival flaps with a connective tissue graft under the flaps sometimes works well, but it is important to exclude connective tissue from juxtaposition to the blood/bone.
In all cases, it is necessary to relieve tension on the flaps prior to closure. The most effective way of relieving the tension is by means of a Rehrman plasty (Fig. 24). This procedure entails splitting the periosteum to relieve flap tension. The best place to split the periosteum is high up into the vestibule, where it is completely removed from the ridge-split furrow. Underlying connective tissue is exposed any place where the periosteum has been split. This connective tissue is a ready source of fibroblasts. Fibroblast infiltration into the bone graft material can lead to the formation of connective tissue rather than bone. In that regard, it is important to keep a complete sheath of periosteum over the ridge-split furrow to every extent possible. When the periosteum is split high in the vestibule, any stretching of the flap and subsequent break in the periosteum occur in this area where the exposed connective tissue is removed from the ridge-split furrow. An intact periosteal sheath may be drawn up and over the furrow. At this point, it is wise to briefly review the initial entry incision. When the initial incision is toward the palatal, the incision line does not generally end up directly over the ridge-split furrow. In fact, our best results have been achieved with a beveled incision, which facilitates approximation of the incision edges rather than having to close butted edges.

Since the periosteal split opens fibroblasts to the blood/bone mixture, bone graft material is still transferred under the facial flap, with the hope of retard-
ing fibroblast infiltration into the furrow (Fig. 25). This bone graft material is packed under the facial flap (Fig. 26), and a copious amount of bone is placed over the furrow and vertical release areas (Fig. 27).

When suturing the flaps, the gingival incision over the ridge is closed prior to closure of the vertical gingival incisions. A vertical mattress suture at the center of the gingival ridge incision is used to draw the wound edges together. Thereafter, simple interrupted sutures are used to close the remainder of the crestal incision and the vertical incisions (Fig. 28). The bone graft material in the buccal vestibule sometimes gives an exaggerated appearance to the amount of bone reconstructed on the facial aspect of the ridge (Fig. 29).

The surgical site should be adequately protected to avoid any masticatory pressure on the ridge. Any type of removable prosthesis that bears down on the ridge is contraindicated. When possible, directly bonded temporary teeth are useful to maintain form and function. These bonded teeth offer some protection to the ridge (Fig. 30). If there has been any difficulty in achieving complete flap closure, barrier membranes may be used. However, better flap closure has been seen with the use of connective tissue grafts in lieu of membranes. With good flap closure and adequate protection of the ridge, good healing can be seen within 4 weeks of the procedure (Fig. 31). It is not uncommon for some of the bone graft material to resorb and
Figure 25. The blood/bone mixture is packed up into the periosteal split.

Figure 26. The blood/bone mixture must remain thoroughly saturated with blood.

Figure 27. A large bolus of the saturated blood/bone mixture is placed into the surgical site.

Figure 28. Because of the periosteal split, the buccal flap can be drawn over the surgical site.

remodel. Periodic radiographs should be taken to confirm continued healing of the bone (Fig. 32).

In both the maxillary and mandibular arches, it is recommended that the earliest uncovering of the implants is 6 months. Occasionally, the ligature wires may need to be removed at an earlier date if they start to emerge through the tissue. However, when the ligature wire has been properly tucked into the furrow, this seldom happens. Often, the regeneration of the bone in the ridge-split furrow is so exuberant that bone will actually creep up over the edges of the implant surgical cover caps (Fig. 33). A sharp Ochsenbein chisel may be used to clear the excess bone (Fig. 34). After the implants have been exposed, tissue healing caps are placed. The flaps are sutured adjacent to the healing caps to provide a zone of keratinized tissue around the implant heads. The case is returned to the restorative doctor for final restoration (Fig. 35).

RESULTS

When compared, preoperative radiographs (Fig. 1) and postoperative radiographs (Fig. 36) show that substantial bone can be reconstructed with the segmental ridge-split procedure. The results demonstrated in this case presentation are representative of the results that we have generally seen in cases treated in our private practices and at the university. Mitigating factors that may lead to results less favorable include infection, implant loosening, sloughing of the flap edges, and loss
of bone graft material. We have not had a case where there was sequestering of either bone plate, but great care has been given to stabilization of the plates. Nonetheless, this would represent one other substantial negative consequence of the surgical procedure. However, most of these potential problems exist in onlay graft procedures as well. We have also delayed the immediate placement of implants in a number of cases where we split the ridge, and a follow-up report will be presented on that variation. Principally, it is strongly recommended that any surgeon attempting these procedures should be very comfortable with the overall protocol of implant placement, and then it is recommended that ridge expansion efforts be confined to single-tooth or small ridge segments.

**DISCUSSION**

The segmental ridge-split procedure (SRSP) represents another method for the augmentation of edentulous ridges. SRSP may be used prior to or at the time of implant placement. The procedure facilitates the placement of implants into areas that otherwise would not be suitable for implants. The use of heme-reconstituted DFDBA in our technique is a distinguishing difference between our procedure and earlier procedures reported by Simion et al. and Scipioni et al. Because bone grafting in the SRSP all takes place within a surgically created bony crypt, the potential for bone reconstruction is significant. In creating this crypt, it is important to encapsulate the bone graft material within bone plates and overlying periosteum. The exclusion of
fibroblasts from the surgical site seems to enhance bone regeneration. Continued research might be directed at better flap management and bone manipulation, which, in turn, could lead to enhanced results. This surgical protocol might lend itself to other areas where bone reconstruction is desired.

The results of these surgical procedures have now been tracked for over 5 years (involving 400 to 500 cases since 1995). We are compiling cases with presurgical and postsurgical tomographic scans to further assess the volume of reconstructed bone, and there will be subsequent reports on these cases. One item of note is a tendency for early saucerization of the crestal bone around those implants that were placed flush with the crest of the ridge (Fig. 36).

Although this could be a phenomena associated with the newly constructed bone, we believe it to be similar to bone loss seen in other reports, where minor bone loss after the first year was also reported.34-36 Still, this saucerization must be accounted for in explaining anticipated results to the patient because this loss of interproximal bone may be reflected in partial absence of interproximal papillae, which, in turn, may create a challenge to achieving maximum esthetics (Fig. 35). Moreover, even though subsequent yearly bone loss of less than 0.2 mm was seen in this case (Fig. 37), an amount of bone loss considered to be consistent with successful implants,37,38 additional gingival recession and papilla loss were noted (Fig. 38). We believe this lack of perfect gin-
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Figure 37.
Four-year postoperative panoramic radiograph demonstrating favorable bone levels.

Figure 38.
Four-year postoperative examination demonstrating some soft tissue loss.

Gingival architecture may be due to the resultant relationship between the crest of the interproximal bone and soft tissue morphology as noted by Tarnow et al.39 Our experience in establishing and maintaining interproximal papillae has been similar to other investigators in this regard,40 in that interproximal bone loss creates a greater potential for deficiency of interdental papillae.

We have employed different implant designs and have noted varied results in maintaining interdental papillae. For instance, when using 1-stage seamless implants, we noted less saucerization of bone when the top edge of the implant was positioned 1 to 2 mm supraosseous to the bone crest. These results were similar to those seen by Hermann et al.41 Additionally, our preliminary observations included the fact that, even when using 1-stage seamless implants, saucerization would still occur if the polished collar were submerged below the bone crest, a finding also in accord with Hermann et al.42,43 These differences are identified because they help to point out the importance in understanding that while any innovative technique may yield consistent results in the hands of one group, a different group of surgeons could find significantly different results simply by slight variation in the use of materials. We believe this to be especially true in the reconstitution of the DFDBA with the patient’s own blood. Our earliest cases were all grafted with heme-reconstituted DFDBA, and the results were consistently good. Then, at a certain point, it seemed more convenient to simply reconstitute the DFDBA with saline and tetracycline. The resultant grafted areas were clinically inferior to our previous results, and we feel this difference in the efficacy of the DFDBA as a bone grafting material may account for the conflicting results of DFDBA as found by Becker et al.18,19 Similarly, our limited experience with reconstituting the DFDBA with platelet-rich plasma has thus far been less than favorable. It is unclear if this is indigenous to this surgical procedure, an operator variable, or a deficiency in the material. We think that the retention of clotted whole blood within the mass of bone grafting material enhanced our results, although further testing of this theory is in order. We hope to identify and describe a number of these variables in future reports.

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