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Evolution of tunneling techniques in periodontics: A narrative review

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Abstract

Over the past several decades, a trend toward minimally invasive surgery has emerged in various disciplines of medicine and dentistry. In periodontics, one manifestation of this phenomenon is the use of tunneling techniques for mucoperiosteal flap reflection. Tunnel flaps are characterized by the establishment of a space between the alveolar bone or periosteum and the overlying soft tissue while maintaining intact interdental gingiva and/or crestal keratinized mucosa. The oral and facial interdental papillae and col areas remain intact during the procedure. Retaining interproximal tissue integrity may enhance wound stability during early healing, and limited evidence suggests that tunnel flaps can improve several patient-reported outcome measures, such as comfort level, initial esthetics, and time required for return to normal activities. Multiple refinements have been promulgated since the introduction of the first tunneling techniques, and clinical applications have expanded into numerous areas of the field, including surgical treatment of periodontitis, periodontal plastic surgery, and alveolar ridge augmentation. The purpose of this narrative review is to describe the evolution of tunneling techniques over time and suggest opportunities to further develop tunneling applications. Two clinical circumstances are described in which multi-surface tunneling at oral, facial, and proximal tooth surfaces can be employed to achieve favorable clinical and patient-oriented outcomes.

Keywords: Alveolar bone loss; Gingival recession; Minimally invasive surgical procedures; Patient-reported outcome measures; Periodontitis; Tissue grafts

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1. Introduction

Although no universally accepted definition exists, minimally invasive surgery encompasses techniques that seek to accomplish surgical goals while limiting incision size, maximizing wound stability, and enhancing patient-oriented outcomes. Over the last several decades, virtually every surgical specialty of medicine and dentistry has

integrated minimally invasive techniques into the clinically accessible repertoire of procedures.[1] Multiple examples can be found in periodontics. Few studies have assessed clinical efficacy and long-term stability following laser periodontal therapy.[2] However, this minimally invasive procedure aims to provide definitive periodontitis treatment despite accessing intrabony defects (IBDs) through the gingival sulcus only, without any external incisions.[2] In contrast, the modified minimally invasive surgical technique (M-MIST) involves the use of limited incisions and minimal reflection of the defect-associated papilla to access the alveolar bone and root surface.[3] Long-term follow-up of a randomized controlled clinical trial demonstrated that IBDs treated with M-MIST alone or M-MIST and regenerative materials exhibited periodontal stability over a 10-year observation period.[3]

Tunnel flaps comprise a broad subset of minimally invasive techniques utilized within the field of periodontics (Figure 1). Derivations have been applied in periodontal plastic surgery, regenerative treatment of periodontitis, and alveolar ridge augmentation (ARA) (Table 1). The unifying feature of a tunnel flap is the avoidance of crestal incisions that establish distinct buccal/facial and palatal/lingual mucoperiosteal flaps. The interdental gingiva and crestal soft tissue at edentulous sites remain intact but may be freed from the alveolar bone. The surgeon may employ intrasulcular incisions only or add limited vertical vestibular incisions that do not extend to the gingival margin. Specialized suturing techniques or implantation of biomaterials may coronally position the tunnel flap. Irrespective of the procedure type, the rationale for selecting a tunnel flap usually includes enhancement of patient-reported outcome measures (PROMs), such as reduced post-operative swelling and discomfort, improved esthetics in the short term, and early return to normal activities.

Across all tunnel-based procedures in periodontics, the main limitation is the paucity of evidence confirming superior or equivalent clinical outcomes compared with procedures that rely on classic flap designs. Direct clinical comparisons between tunnel and conventional flaps are rare, and contradictory results appear in the literature. Nevertheless, outcomes achieved with tunnel-based periodontal surgeries are generally positive, and consistently, the procedures are well accepted by patients. The purpose of this report is to review the tunnel flaps that have been applied in periodontics and suggest further derivations of the technique.

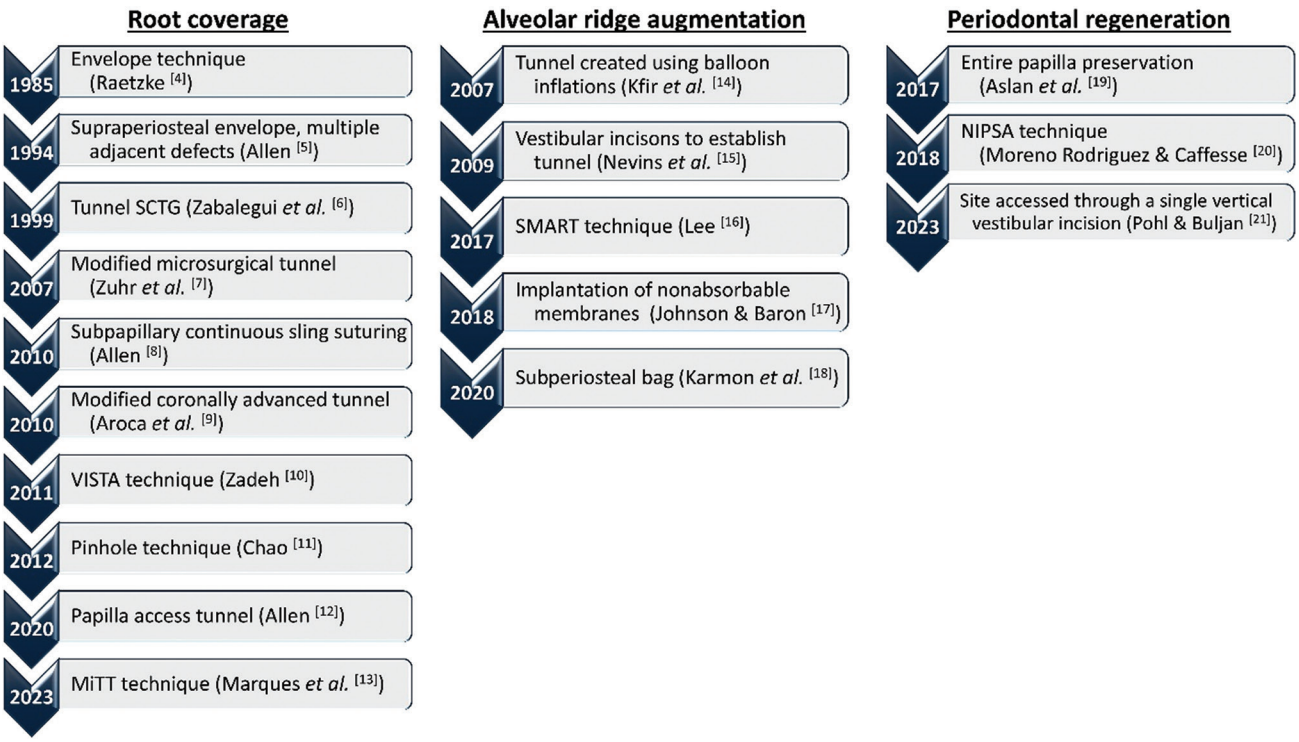

Figure 1. Evolution of tunnel flaps in periodontics for root coverage, alveolar ridge augmentation, and periodontal regeneration. Image created by the authors.

Abbreviations: MiTT: Mixed-thickness tunnel access; NIPSA: Non-incised papilla surgical approach; SCTG: Subepithelial connective tissue graft; SMART: Subperiosteal minimally invasive esthetic ridge augmentation technique; VISTA: Vestibular incision subperiosteal tunnel access.

Table 1. Evolution of tunneling procedures in periodontics

Year	Authors	Procedure
		Periodontal plastic surgery
1985	Raetzke[4]	Envelope technique. Applicable to isolated recession defects.
1994	Allen[5]	Supraperiosteal envelope. Applicable to single and multiple adjacent recession defects. Sharp dissection when tissue thickness permitted.
1999	Zabalegui *et al.*[6]	Tunnel subepithelial connective tissue graft. Partial-thickness dissection beyond the mucogingival junction. Use of sutures for graft positioning.
2007	Zuhr *et al.*[7]	Modified microsurgical tunnel technique. Use of specialized tunneling knives with sharp edges toward the periosteum.
2010	Allen[8]	Subpapillary continuous sling suturing method. Use of a single continuous suture to stabilize both the acellular dermal matrix and the overlying tunnel flap.
2010	Aroca *et al.*[9]	Modified coronally advanced tunnel. Composite stops at proximal contact areas to facilitate suturing. Use of a specialized knife-elevator instrument for tunnel preparation. Application of ethylenediaminetetraacetic acid and enamel matrix derivative. Papillae are freed from the interproximal alveolar crest. Mucoperiosteal dissection extended beyond the mucogingival junction.
2011	Zadeh[10]	Vestibular incision subperiosteal tunnel access (VISTA) technique. Use of vertical vestibular incisions to facilitate subperiosteal tunnel reflection. Use of polypropylene sutures bonded to the facial surfaces of the teeth.
2012	Chao[11]	The pinhole surgical technique. Use of specialized transmucosal papilla elevators to reflect full-thickness mucoperiosteal flaps through small incisions in the alveolar mucosa. Stabilization of marginal tissue in coronal position by implanting absorbable porcine collagen membrane strips.
2020	Allen[12]	Papilla access tunnel. Reflection of papilla to facilitate tunnel preparation in the presence of shallow recession defects and thin tissue.
2023	Marques *et al.*[13]	Mixed-thickness tunnel access. Vertical incisions terminating apical to the mucogingival junction. Split-thickness separation of the alveolar mucosa from the underlying muscles. Full-thickness tunnel flap reflected from the mucogingival junction to the gingival margin. Papilla tip intact.
		Alveolar ridge augmentation
2007	Kfir *et al.*[14]	Use of a tunnel created using a series of balloon inflations for guided bone regeneration (GBR).
2009	Nevins *et al.*[15]	Tunneling technique for alveolar ridge augmentation involving vestibular incisions to create subperiosteal pouches into which recombinant human platelet-derived growth factor-BB (rhPDGF-BB) and various biomaterials were implanted. No barrier membrane.
2017	Lee[16]	Subperiosteal minimally invasive esthetic ridge augmentation technique. Similar to the method described by Nevins *et al.*[15] Implantation of anorganic bovine bone mineral (ABBM) and rhPDGF-BB. No barrier membrane.
2018	Johnson and Baron[17]	Tunnel access for GBR in the maxillary anterior. Intrasulcular and vestibular incisions to facilitate subperiosteal tunnel preparation. Use of a dense polytetrafluoroethylene membrane and an allogeneic bone derivative.
2020	Karmon *et al.*[18]	GBR tunneling technique involving placement of a subperiosteal bag—a perforated, folded, and sutured collagen membrane filled with ABBM.
		Regenerative periodontal surgery
2017	Aslan *et al.*[19]	Entire papilla preservation technique. A "tunnel-like" approach to papillae at intrabony defect (IBD) sites.
2018	Moreno Rodríguez and Caffesse[20]	Non-incised papilla surgical approach. Defect-associated papillae remain completely intact. IBDs are accessed through a single horizontal or oblique incision in the alveolar mucosa.
2023	Pohl and Buljan[21]	VISTA approach to periodontal regeneration. IBDs are accessed through a single vertical vestibular incision.

2. Tunnel flaps in periodontal plastic surgery

2.1. Early tunnel flap techniques

Although not originally termed a tunnel flap, the "envelope" technique, introduced by Raetzke[4] in 1985, involved maintenance of the integrity of the interdental gingiva. In this technique, the marginal gingiva adjacent to the recession defect was excised to remove the sulcular epithelium, the root surface was scaled and planed, and citric acid was applied to condition the root. A partial thickness envelope was created, extending apically several millimeters beyond the gingival margin and laterally to the line angles of adjacent teeth. A small subepithelial connective tissue graft (SCTG) was harvested, tailored to the dimensions of the recipient site, implanted within the envelope, and stabilized with a tissue adhesive rather than sutures. After treating 12 recession defects in 10 patients,

Raetzke observed a mean gain in keratinized gingiva of 3.54 mm and a mean residual recession depth of 0.67 mm. Notably, the benefits of the technique that the author identified included PROMs commonly reported for tunnel-based root coverage procedures—minimal surgical trauma, favorable early healing, limited post-operative discomfort, and an esthetic appearance. Raetzke's technique has been described as elegantly simple, requiring neither external incisions nor sutures.[5] However, the technique's applicability was limited to isolated recession defects.[4]

Dr. Allen[5] presented the supraperiosteal envelope for root coverage procedures at isolated and multiple adjacent recession defects in 1994. At sites exhibiting gingiva of adequate thickness, sharp dissection was used to establish a supraperiostal envelope extending 3–5 mm lateral and apical to the recession defects. Full-thickness envelope preparation was used at sites presenting excessively thin gingiva. Allen advocated a uniform SCTG thickness of at least 1.5 mm. Placement of the SCTG within the envelope was accomplished using a temporary mattress suture to guide the graft into position while also using tissue forceps. Simple interrupted sutures at the mesial and distal graft margins introduced slight tension in the SCTG, and vertical mattress sutures in papilla areas stabilized the graft at the appropriate apicocoronal level.

In 1999, Zabalegui *et al.*[6] modified Raetzke's envelope technique—the tunnel SCTG—for the treatment of multiple adjacent recession defects. The authors described a "multi-envelope" recipient bed in which adjacent supraperiosteal envelopes were connected to form a tunnel. The partial thickness flap preparation established through the gingival sulcus extended to the mucogingival junction (MGJ) apically, and although the papilla tips remained intact, the base of the papillae was undermined using sharp dissection. To position and stabilize the SCTG, two sutures were introduced through the tunnel—one from the mesial aspect and the other from the distal. The suture needles entered the tunnel through attached gingiva lateral to the most mesial and distal recession defects and exited the largest or most central recession defect. The needles engaged the mesial and distal aspects of the graft, and then traveled back through the tunnel before emerging from the attached gingiva approximately 2 mm from the original insertion points. Gentle tension in the sutures pulled the SCTG into position, and after the sutures were tied, the graft was stabilized. Portions of the SCTG overlying the recession defects remained exposed, and no attempt was made to coronally advance facial flap margins to or beyond the cementoenamel junctions (CEJs). In a multi-center randomized trial, SCTG + tunnel and SCTG + coronally advanced flap (CAF) exhibited no significant difference in mean root coverage attained.[22] However, the tunnel procedure resulted in statistically greater gains in keratinized tissue width as well as less post-operative morbidity and pain.

Various modifications of the original tunnel technique have been proposed, including the use of specialized microsurgical instruments,[7] full-thickness elevation of the interproximal gingiva,[9] coronal advancement of the flap margin (Figure 2),[8,9,23] use of a biomaterial rather than an autologous graft,[8,9] and use of specialized suturing techniques.[8] In 2010, Dr. Allen[8] described a subpapillary continuous sling suturing technique for acellular dermal matrix (ADM) + tunnel flap. In this technique, a single continuous suture stabilized the ADM while coronally positioning the tunnel flap margin. A systematic review and meta-analysis found that when observations were limited to a single graft type (ADM or SCTG), CAF produced superior mean root coverage and complete root coverage (CRC) frequency compared with tunnel flaps.[23] Nevertheless, root coverage procedures that incorporate tunneling may yield superior patient-oriented outcomes.[7-9,22,23]

In the same year, Dr. Aroca *et al.*[24] introduced the modified coronally advanced tunnel (MCAT)—also called the coronally advanced modified tunnel—which included placement of "composite stops" at proximal contact areas to facilitate stabilizing the facial/buccal flap in a coronal position using sutures. The sulcular incisions and tunnel flap release were completed using a specialized knife-elevator instrument.[7] In addition, the root surfaces were chemically modified using ethylenediaminetetraacetic acid (EDTA), and enamel matrix derivative (EMD) was applied.[24] To permit coronal advancement of the tunnel flap, each papilla was freed from the interproximal alveolar crest, and the mucoperiosteal dissection extended apically beyond the MGJ.

Anatomic factors make gingival augmentation and root coverage at lingual recession defects in the mandibular anterior region uniquely challenging. This area presents the narrowest apicocoronal gingival width in the mouth, with an average measurement <3 mm.[25] Depending upon the proclination of the mandibular incisors, direct visualization can be extremely challenging intraoperatively, and the proximity of vital structures such as Wharton's duct adds additional complexity to the procedure.[26] A post-operative infection following this procedure type could involve the sublingual space, and by extension, the adjacent submandibular space and other deep fascial orofacial spaces.[27] For these reasons, risk-informed clinicians and patients may elect to defer treatment. Nevertheless, tunnel-based procedures may offer a more favorable risk profile when treating lingual

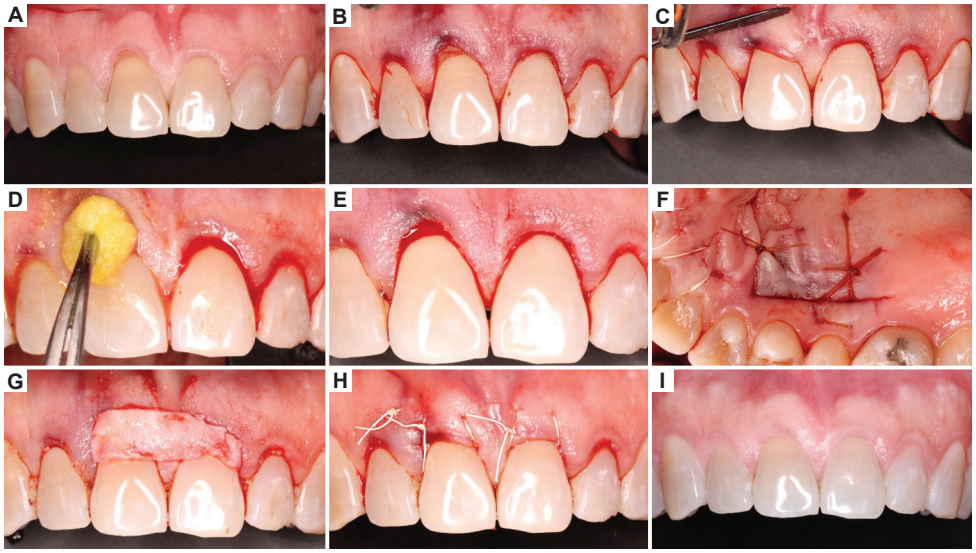

Figure 2. Coronally advanced tunnel with subepithelial connective tissue graft (SCTG). (A) Gingival recession defect <2 mm in depth at the maxillary right central incisor. (B) Appearance after tunnel preparation between the two lateral incisors. (C) Coronal advancement of the tunnel. (D) After mechanical debridement with ultrasonic and hand instruments, chemical root surface modification was accomplished with tetracycline hydrochloride (50 mg/mL). (E) Close-up view of tunnel preparation prior to SCTG insertion. (F) Subepithelial connective tissue graft harvest site. (G) The SCTG was trimmed to the dimensions of the recipient site. (H) The SCTG and tunnel flap were stabilized using interrupted sling sutures (4-0 dense polytetrafluoroethylene). (I) Complete root coverage was noted 9 months following the procedure.

recession defects in the mandibular anterior (Figure 3). Although controlled clinical research is lacking, multiple authors have successfully adapted tunneling techniques to root coverage and gingival augmentation in this anatomic region.[26,28,29]

2.2. Techniques incorporating external incisions

The methods described by Allen[5] and Zabalegui *et al.*[6] involved tunnel flap preparation through the gingival sulcus only. However, subsequent authors have suggested the addition of external incisions to facilitate recipient site preparation. In 2011, Dr. Homayoun Zadeh[10] introduced the vestibular incision subperiosteal tunnel access (VISTA) flap. This procedure began with thorough scaling and root planing, odontoplasty to reduce cervical prominences and bring the root within the alveolar housing, and root conditioning with 24% buffered EDTA gel. Four substantive distinctions between the VISTA approach and earlier tunnel flaps were the placement of vestibular access incisions to begin the tunnel preparation, elevation of a subperiosteal tunnel rather than utilizing a partial-thickness design, implantation of an absorbable porcine collagen membrane saturated in 0.3 mg/mL recombinant human platelet-derived growth factor-BB (rhPDGF-BB) rather than an SCTG, and use of bonded 6-0 polypropylene sutures to advance the facial flap margins coronally. However, a VISTA flap design can be applied when ADM or SCTG is implanted, and various suturing techniques can be utilized (Figure 4). A systematic review and meta-analysis found that a VISTA flap design with an ADM or SCTG yielded superior root coverage outcomes compared with tunnel flaps.[30]

Dr. Chao[11] introduced the pinhole surgical technique in 2012. In this technique, a small incision, 2–3 mm in length, was placed near the depth of the vestibule adjacent to the recipient site. A specialized transmucosal papilla elevator was inserted into the vestibular incision and used to elevate a full-thickness flap, which was extended laterally to include a minimum of four papillae. The flap was maintained in a coronal position by implanting two to four 2 × 12-mm absorbable porcine collagen membranes. No sutures, surgical dressings, or adhesives were applied to maintain the coronal position of the flap, and the vestibular access incisions were permitted to heal without suturing. In a long-term case series with a mean follow-up of 14.5 years, the pinhole technique demonstrated a CRC frequency of 78% and a mean root coverage of 94%.[31] Furthermore, in a split-mouth randomized clinical trial comparing clinical and patient-centered outcomes of the pinhole technique to those attained with CAF + SCTG, no significant difference between the two treatments was found.[32]

Tunnel flap preparation can be complex in the mandibular anterior region at sites presenting minimal recession depth and thin gingiva. In such situations, manipulating the flap with tunneling instruments can cause substantial trauma to the delicate marginal gingiva. Thus, in 2020, Dr. Allen[12] presented the papilla access

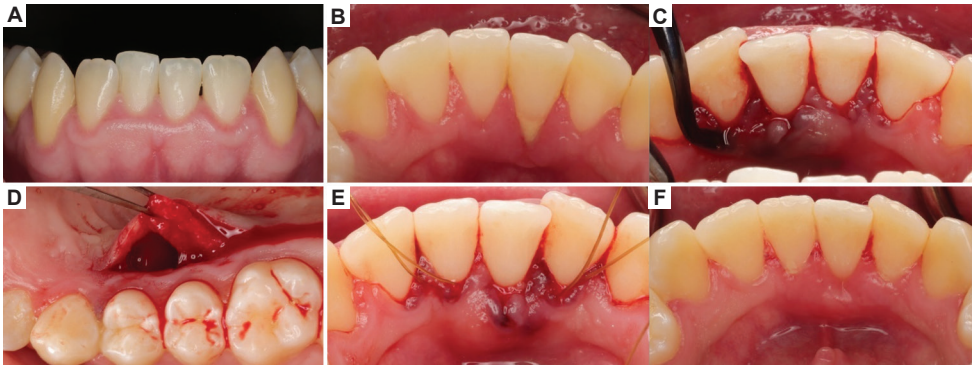

Figure 3. Tunnel flap with subepithelial connective tissue graft (SCTG) for treatment of lingual recession defects at mandibular incisor sites. (A) Baseline appearance of mandibular anterior teeth, facial view. (B) Baseline appearance of mandibular anterior teeth, lingual view. The mandibular right central incisor demonstrated a recession defect 3 mm in depth, a veneer of calculus, marginal erythema and edema, and bleeding upon periodontal probing. The apicocoronal dimension of the attached gingiva at this site was <1 mm. The remainder of the mandibular incisors exhibited lingual recession defects of <1 mm. (C) Preparation of the subperiosteal tunnel. (D) SCTG harvest. (E) Use of two 4-0 chromic gut sutures to position the SCTG within the tunnel. A subpapillary continuous sling suture (5-0 polypropylene) was used to stabilize the graft and tunnel flap (not shown). (F) Appearance of the site at post-operative week 6.

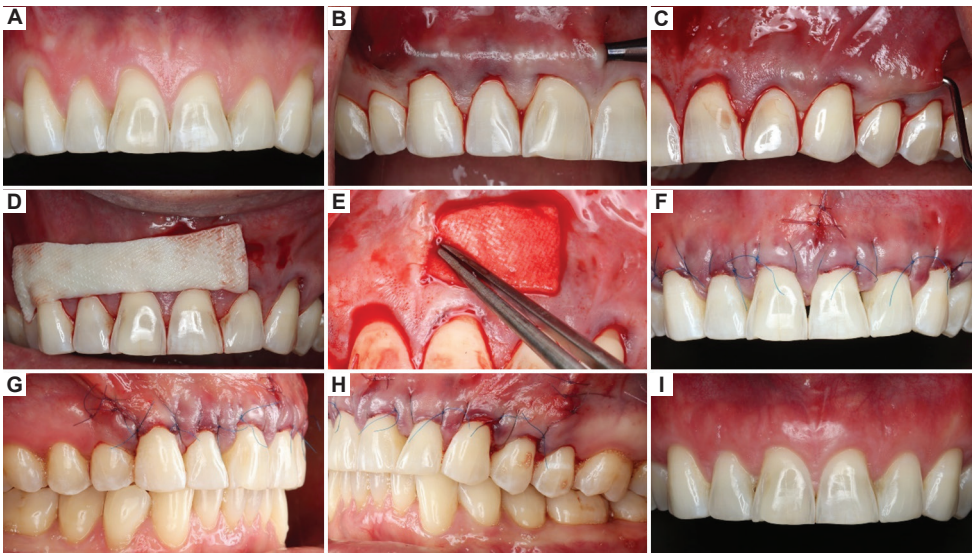

Figure 4. Vestibular incision subperiosteal tunnel access (VISTA). (A) Baseline clinical appearance of gingival recession defects at maxillary anterior teeth. (B) Periosteal elevator inserted through a small midline vestibular incision, demonstrating coronal advancement of the tunnel flap. (C) Tunneling instrument inserted in a vestibular incision distal to the maxillary left first premolar. (D) Acellular dermal matrix (ADM) overlying the vestibular incision. (E) The ADM was inserted through the midline vestibular incision and positioned at the cementoenamel junctions of the maxillary anterior teeth. (F) Closure using a subpapillary continuous sling suture (7-0 polyglycolic acid). Simple interrupted sutures were used to close vestibular incisions. (G) Closure viewed from the right side. (H) Closure viewed from the left side. (I) Clinical appearance eight weeks following the procedure.

tunnel (PAT) as an alternative to vestibular access incisions. The technique involved sharp dissection of one or more facial papillae to permit access for tunnel flap preparation (Figure 5). When treating all mandibular anterior teeth, the author recommended partial-thickness dissection and reflection of the papillae between the lateral incisors and canines bilaterally. The adjacent tunneled papillae were detached from the interdental alveolar bone using a curette. After positioning of the selected graft/biomaterial—SCTG, ADM, or xenograft—the PAT was coronally positioned to the CEJs and stabilized using interrupted or continuous sling suturing.

In 2023, Marques *et al.*[13] published the mixed-thickness tunnel access (MiTT) technique. The MiTT involved vertical access incisions terminating approximately 2 mm apical to the MGJ and split-thickness separation of the alveolar mucosa from the underlying muscles using specialized tunneling instruments. From the MGJ, a full-thickness tunnel flap was reflected to the gingival margin,

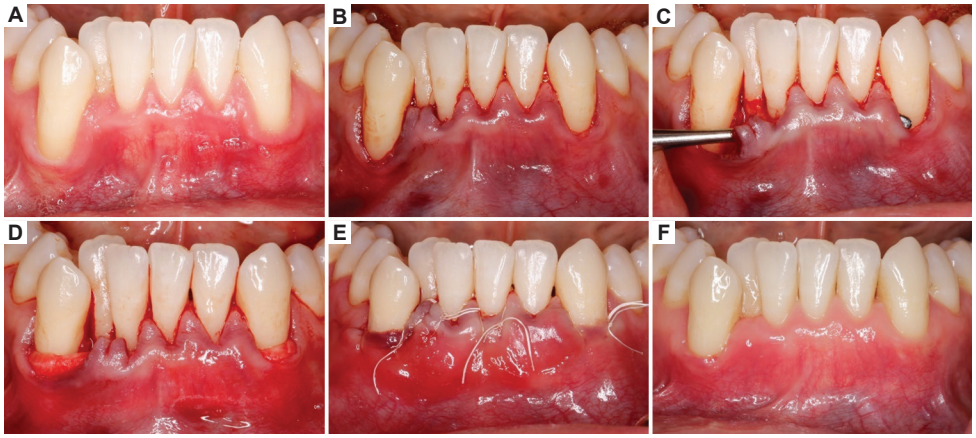

Figure 5. Modified papilla access tunnel (PAT). (A) Baseline appearance of mandibular anterior teeth. Crowding, supereruption of the incisors, and malposition of multiple teeth were noted. (B) Initial incisions and tunneling. A PAT typically involves reflection of one or more papillae. Due to the crowding in this case, the technique was modified. The small segment of facial gingiva overlying the right lateral incisor was reflected. (C) A subperiosteal tunnel was accomplished through the gingival sulcus and the modified PAT. A scalpel was used to release the tunnel flap apically. (D) An acellular dermal matrix (ADM) was implanted in the tunnel from canine to canine. (E) The ADM and coronally advanced tunnel were stabilized with interrupted sling sutures. (F) Appearance of the outcome at post-operative week 6.

with or without the use of intrasulcular incisions. The base of each papilla was reflected. However, the tip remained intact. Within the tunnel, the authors recommended positioning the coronal margin of an SCTG or a de-epithelialized gingival graft 1 mm coronal to the CEJ.

3. Tunnel flaps in ARA

Various tunneling techniques have been applied to ARA in an attempt to reduce the risk of the most common complication associated with the procedure—wound dehiscence and exposure of implanted biomaterials.[33] In 2007, Kfir *et al.*[14] presented a series of 11 cases demonstrating the use of tunnel flaps for guided bone regeneration (GBR). The technique involved placement of a vertical vestibular incision through which a full-thickness mucoperiosteal pouch was established with the aid of a silicone catheter and an inflation syringe. An absorbable membrane was inserted through the vestibular incision, and a mixture of autologous fibrin and beta-tricalcium phosphate was implanted between the membrane and the alveolar bone.

Nevins *et al.*[15] published a series of 12 cases involving a tunnel-based minimally invasive ARA technique in 2009. In this method, subperiosteal pouches were established through vestibular incisions, and mixtures of rhPDGF-BB and anorganic bovine bone mineral (ABBM), ABBM with mineralized collagen bone substitute (MCBS), or freeze-dried bone allograft were applied without the use of membranes. In two patients who had received ABBM + MCBS, implant placement was not possible due to the quality or volume of hard tissue. Histologic analyses revealed combinations of residual biomaterial particles, newly formed bone, and fibrous connective tissue. Multiple specimens from sites that had received MCBS revealed biomaterial particles encapsulated in connective tissue.

In 2017, Dr. Lee[16] introduced the subperiosteal minimally invasive esthetic ridge augmentation technique, which involved establishing a subperiosteal tunnel and implanting ABBM hydrated in rhPDGF-BB, without the use of a barrier membrane. One or more vestibular incisions were placed distant to the deficient alveolar ridge, through which a tunnel flap was prepared. The bone biomaterial and growth factor mixture was applied through the vestibular incisions. Most patients reported little or no discomfort and/or swelling. Histologic analysis revealed new bone in direct apposition with ABBM particles and dense connective tissue. This approach was applied at 60 sites in a series of 21 patients; the mean increase in horizontal ridge width was approximately 5 mm.

Johnson and Baron[17] utilized tunnel access for GBR with a nonabsorbable membrane in the maxillary lateral incisor area (Figures 6 and 7). The authors made two vestibular incisions adjacent to the alveolar ridge deficiency, reflected a full-thickness mucoperiosteal tunnel flap extending palatally over the alveolar crest, and inserted a dense polytetrafluoroethylene membrane, which was tailored to the dimensions of the site. A particulate freeze-dried bone allograft was packed between the alveolar bone and the barrier membrane. The gingival attachment at the adjacent teeth was released, permitting coronal advancement of the tunnel flap. The patient reported minimal discomfort limited to the first 2 post-operative days, and the procedure resulted in a favorable alveolar ridge volume for implant placement.

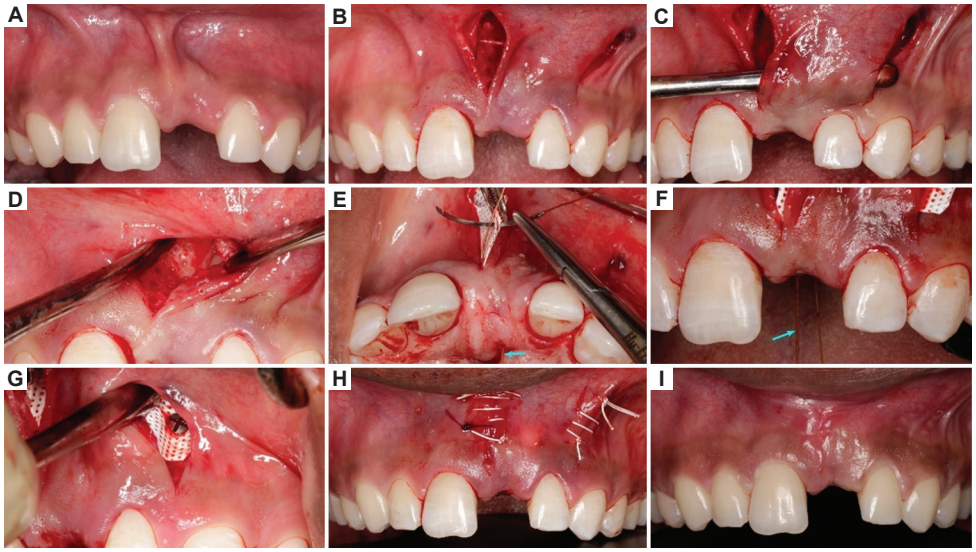

Figure 6. Tunnel access for guided bone regeneration (GBR). (A) Baseline appearance of maxillary anterior teeth. At the left central incisor position, a substantial undercut in the alveolar bone could be palpated and appreciated visually. A cone-beam computed tomography scan confirmed inadequate bone volume for implant placement. (B) Vertical vestibular incisions were placed in the midline frenum and between the left canine and lateral incisor. The incisions extended from the depth of the vestibule 2–3 mm into the attached gingiva. A subperiosteal tunnel was established between the two vestibular incisions. The full-thickness reflection extended palatally over the alveolar crest. A periosteal releasing incision was placed at the apical aspect of the tunnel. (D) Intramarrow penetrations were established through the vertical incisions. (E) A dense polytetrafluoroethylene (PTFE) membrane was trimmed to the dimensions of the site and inserted into the tunnel. A 4-0 chromic gut suture (arrow) needle was passed from the palatal aspect of the tunnel through the midline vertical incision. The suture engaged the portion of the membrane designed to extend over the alveolar crest. (F) The needle was then passed through the midline vertical incision, exiting the palatal mucosa adjacent to the original needle entry point (arrow). The membrane was then drawn into place by exerting tension on both ends of the suture. (G) After implanting autogenous bone shavings and a freeze-dried bone allograft, the membrane was stabilized with two fixation screws and an absorbable 5-0 polyglycolic acid mattress suture. (H) The vestibular incisions were closed with simple continuous 4-0 dense PTFE sutures. (I) Appearance of the site 6 months following GBR.

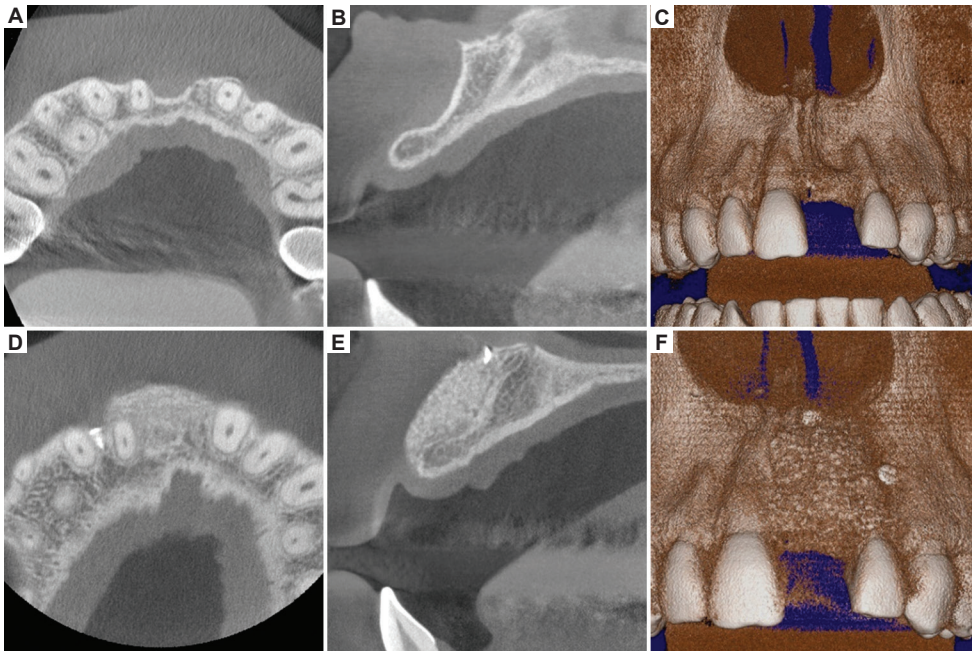

Figure 7. Comparison of baseline and follow-up cone-beam computed tomography volumes. (A) Baseline axial slice. (B) Baseline cross-sectional slice. (C) Baseline volume rendering. (D) Axial slice 6 months following the procedure. (D) Cross-sectional slice 6 months following the procedure. (E) Volume rendering 6 months following the procedure.

In 2020, Karmon *et al.*[18] introduced a tunneling technique for horizontal ARA using a subperiosteal bag. The technique involved folding, suturing, and perforating a collagen membrane containing a deproteinized bovine bone derivative. A vertical vestibular incision was placed adjacent to the alveolar ridge deficiency, through which a subperiosteal tunnel was reflected. The bag containing a particulate xenograft was then implanted in the tunnel with the perforated side facing the alveolar bone. Three patients received ARA using this technique. Each procedure resulted in sufficient alveolar ridge volume for implant placement, and all patients reported minimal discomfort.

4. Tunnel flaps in regenerative periodontal therapy

In regenerative periodontal surgery, a clear trajectory from conventional flap techniques toward minimally invasive methods has emerged over the last half-century. From the late 1960s to the late 1980s, reports were published confirming histologic periodontal regeneration—formation of new bone, cementum, and periodontal ligament—at intrabony periodontal defect sites treated with autogenous bone implants, bone derivatives, and guided tissue regeneration.[34-37] In subsequent years, skilled clinician–researchers carefully identified patient-, tooth-, defect-, procedure-, and operator-related factors relevant to the establishment of periodontal regeneration.[38] Wound closure, space maintenance, and clot stability were recognized as surgical prerequisites.[39,40] In the 1990s, variations of conventional mucoperiosteal flaps were developed to maximize wound closure for primary intention healing over barrier membranes and biomaterials implanted at IBD sites.[41,42]

Later, Dr. Cortellini and Tonetti[43,44] advocated for increasingly less invasive surgical methods, introducing first the MIST,[43] then the M-MIST.[44] Compared with conventional flap techniques, these procedures limited access to the root surface for debridement but emphasized wound closure and clot stability.[43,44] The M-MIST represented a refinement of the original technique to reduce patient morbidity further, minimize collapse of the interproximal gingiva, maximize space maintenance, and enhance wound/clot stability.[44] It involved reflection of only a buccal/facial papillary flap. The oral papilla remained intact, and the granulation tissue was sharply dissected from the lingual soft tissue and bone using a microblade and removed using a mini-curette. Favorable periodontal stability after 10 years of follow-up has been observed at IBDs treated with the M-MIST alone, M-MIST + EMD, and M-MIST + EMD + bone derivative.[3]

The M-MIST evolved further with the advent of the entire papilla preservation technique (EPPT).[19,45-47] The EPPT completely avoided reflection of any portion of the IBD-associated papilla.[19,45] Instead, a vertical incision was shifted to an adjoining tooth.[19] A small full-thickness flap was reflected between the vertical incision and the IBD, and the defect-associated papilla was approached in a "tunnel-like" fashion. Microsurgical scissors and mini-curettes were used to remove the interproximal granulation tissue.

Two additional tunneling techniques have been devised to access deep IBDs without incision of the defect-associated papilla. Moreno Rodríguez and Caffesse[20] developed the non-incised papilla surgical approach (NIPSA). In this procedure, one apical horizontal or oblique incision was made within the alveolar mucosa. Through this access, the granulation tissue was removed, the root surfaces were debrided, and biomaterials/EMD were implanted.[20,48] In a comparative analysis including NIPSA and MIST procedures, the two techniques produced similar clinical results.[20] However, NIPSA resulted in lower recession and superior soft-tissue preservation.[20,48] Meanwhile, Pohl and Buljan[21] introduced the VISTA technique for regenerative treatment of IBDs. The technique combined VISTA access with application of a bone allograft, EMD, and an SCTG. Favorable clinical outcomes and PROMs were observed.

5. New tunneling applications in periodontics

5.1. Circumferential tunneling in periodontal plastic surgery

Gingival recession caused by mechanical factors, such as tooth brushing, is typically restricted to the facial surfaces of teeth, whereas recession caused by periodontitis can occur in a circumferential pattern and may be irreversible.[49,50] Nevertheless, clinicians occasionally encounter teeth exhibiting both oral and facial gingival recession defects that are not attributable to periodontitis. Although the vertical height of the interproximal alveolar crest may be normal, dehiscence defects at oral and facial surfaces may be present, and the interproximal bone may be thin and delicate. In such situations, circumferential tunneling is a potential treatment option for achieving root coverage at both facial and palatal/lingual surfaces (Figure 8). Controlled clinical research is needed to establish the predictability of this method.

5.2. Multi-surface tunnel preparation in the treatment of periodontitis

Incorporating gingival augmentation into regenerative periodontal therapy at periodontal defect sites that demonstrate soft tissue deficiency has been recommended.[51] Dr. Zucchelli *et al.*[52,53] proposed the use of the connective tissue graft wall technique to replace a deficient or missing

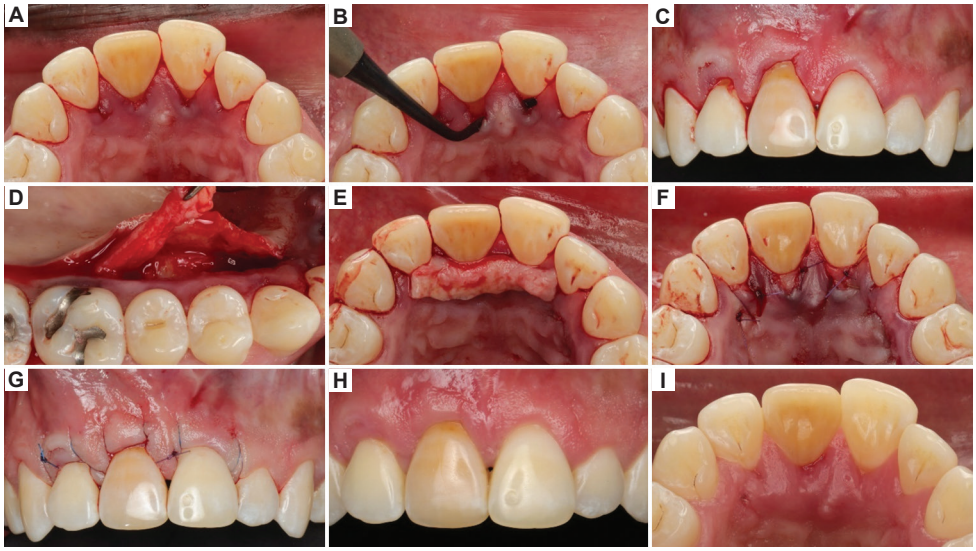

Figure 8. Circumferential tunneling for root coverage. (A) Subperiosteal tunnel established at the maxillary central incisor palatal recession sites. (B) Tunneling instrument demonstrating a patent tunnel between the central incisors. (C) A facial tunnel was established to address gingival recession at the right lateral and central incisors. (D) Subepithelial connective tissue graft (SCTG) harvested. (E) The SCTG was trimmed to the dimensions of the palatal tunnel. (F) The SCTG was stabilized with interrupted 7-0 polyglycolic acid sling sutures. (G) A subpapillary continuous sling suture was used to coronally advance the facial tunnel without the addition of a second SCTG. (H) Facial view of maxillary incisors 3 months following the procedure. (I) Palatal view of maxillary incisors 3 months following the procedure.

IBD wall, enhance space maintenance for periodontal regeneration, and minimize facial and interproximal recession. The procedure has been shown to result in significant reduction in probing depth and gain in clinical attachment, while also producing root coverage and improved papilla fill. Rather than reflecting a conventional flap, an SCTG wall can be accomplished through multi-surface tunneling. Figure 9 demonstrates the establishment of an SCTG wall through a lingual tunnel, without the need for conventional flap reflection. Extending the tunnel interproximally and facially permitted access for complete debridement of the IBD, proper instrumentation of root surfaces, and coronal advancement of the interproximal gingiva, with stability achieved using a bone allograft.

6. Discussion

The purpose of this report is to review the evolution of tunnel-based surgical techniques in periodontics and to suggest new tunneling applications within the field. Multiple minimally invasive techniques have become increasingly utilized in periodontics due to documented long-term stability of results and high patient acceptance.[3,23,26,54,55] In periodontal plastic surgery, clinicians have long acknowledged that tunnel-based root coverage procedures often lead to superior patient-oriented outcomes, characterized by reduced discomfort and swelling, faster return to daily activities, and favorable early esthetic results.[10-13,28-32,54,55]

Nevertheless, mixed results appear in the literature when comparing clinical outcomes of tunnel-based root coverage procedures versus those attained through conventional flap techniques.[23,56-59] Stabilizing the flap margin in a coronal position beyond the CEJ is a procedure-related factor that has been associated with CRC.[60] Accomplishing this degree of advancement may be more difficult when a tunnel flap is utilized. For example, the described post-surgical position of the PAT flap margin was the CEJ.[12] Likewise, the MiTT involved positioning the graft—not the flap—1 mm coronal to the CEJ.[13] Zabalegui *et al.*[6] did not attempt to coronally advance the tunnel flap, intentionally leaving portions of the implanted SCTG exposed during healing. However, the magnitude of flap advancement after suturing is known to influence the treatment outcome—the more coronal the flap margin at the completion of surgery, the greater the likelihood of CRC.[60]

Tunneling techniques that include external incisions may offer clinically relevant advantages. Both the PAT and VISTA techniques enhance access for tunnel flap preparation, graft or biomaterial placement, and flap release for coronal advancement. These techniques may also reduce surgical trauma to the marginal gingiva and decrease operating time. Indeed, in a systematic review and meta-analysis, outcomes following VISTA + ADM or SCTG surpassed results obtained through tunneling without external incisions.[30]

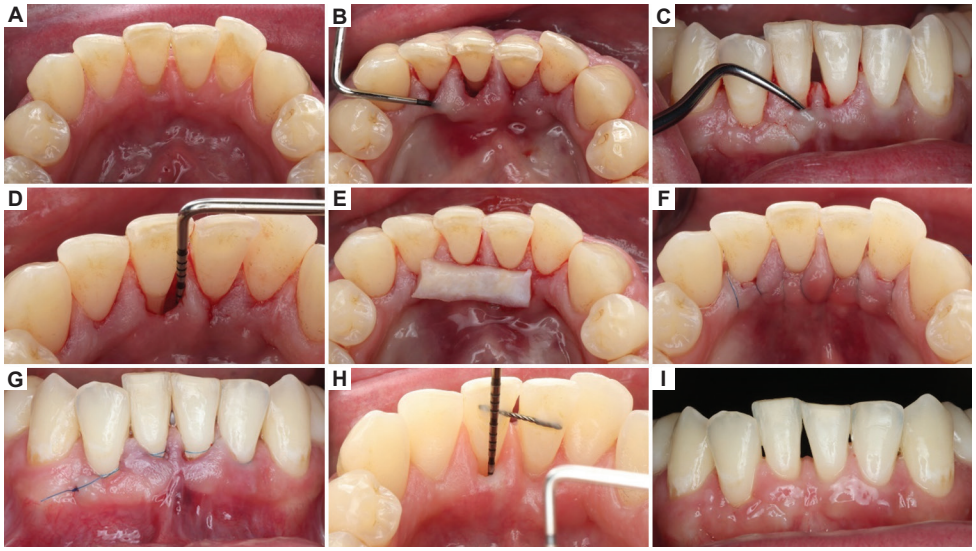

Figure 9. Multi-surface tunnel preparation for the connective tissue graft wall technique. (A) Lingual recession at mandibular central incisors. The left central incisor exhibited 9-mm probing depths at the mesiolingual and direct lingual aspects. (B) Intrasulcular incisions were made with ophthalmic microblades, and a lingual subperiosteal tunnel was established to facilitate debridement of the defect, thorough root planing, and positioning of a de-epithelialized gingival graft (DGG). (C) The tunnel preparation extended to the interproximal and facial surfaces to permit complete instrumentation of the affected root surfaces and coronal advancement of the midline papilla. (D) Appearance of the root surface after debridement. (E) The DGG was harvested from the palate, de-epithelialized extraorally, and tailored to the dimensions of the site. (F) A demineralized freeze-dried bone allograft (DFDBA) was applied through the facial tunnel access against the lingual connective tissue graft wall. The DFDBA helped maintain the midline papilla in a coronal position. The DGG and lingual tunnel flap were stabilized using a subpapillary continuous sling suture (7-0 polyglycolic acid). (G) Immediate post-operative appearance, facial view. The two mandibular central incisors were splinted, and occlusion was adjusted to avoid excessive force on the affected tooth. (H) 3 months following the procedure, all probing depths were ≤3 mm. (I) Facial view of mandibular anterior teeth 3 months following the procedure.

Evidence supporting tunnel-based ARA procedures is limited to case reports/series.[14-18] However, positive results documented in initial reports suggest that controlled clinical studies are warranted. The most common post-operative complication of GBR is wound dehiscence and membrane exposure at the incision line.[33] It is possible that accomplishing GBR without the need for a horizontal incision at the alveolar crest may reduce the occurrence of wound dehiscence. Achieving ARA using a subperiosteal tunnel may also simplify closure, reduce the procedure duration, and limit patient morbidity.

Tunnel applications in regenerative periodontal surgery represent iterations of prior minimally invasive procedures that have been validated through long-term clinical investigation.[3,41,42] All these procedures balance two critical concerns—clot stability and access to the root surface for addressing the etiology. Additional controlled clinical research and comparative analyses are needed to define the relative efficacy of emerging techniques. In principle, however, the conditions for periodontal regeneration that clinicians must establish intraoperatively have not changed.[37,38] Tunneling is merely a means of establishing these conditions.

Integrating tunnel-based techniques into graduate dental education presents a dilemma for educators. Despite generally consistent reports that tunneling can favorably influence PROMs, available evidence does not imply that tunnel procedures should completely replace more established methods. Thus, students must become proficient in using both conventional and tunnel flap designs. However, tunnel-based procedures may be more technique-sensitive and thus challenging for inexperienced operators. A reasonable approach may be to start new residents using conventional flaps and introduce tunneling after the students have gained additional surgical experience and confidence.

Multiple tunnel-based procedures have utilized specialized surgical instruments. For example, in the modified microsurgical tunnel technique, Zuhr *et al.*[7] utilized special tunneling knives during tunnel preparation. Meanwhile, Chao[11] and Chao *et al.*[31] utilized a specialized transmucosal papilla elevator to accomplish the pinhole procedure for root coverage. Both the MiTT and the MCAT relied upon specifically designed tunneling instruments.[9,13,24] Certainly, it is possible to establish a tunnel preparation without the benefit of specialized instrumentation. Nevertheless, such instruments may augment the operator's ability to achieve adequate flap reflection and release without causing undue trauma to the delicate marginal gingiva.

7. Conclusion

Tunneling procedures represent a subset of the minimally invasive surgeries that have emerged in contemporary periodontics. Virtually all tunneling procedures aim to limit patient morbidity, enhance wound stability, and avoid exposure of implanted membranes, grafts, and biomaterials. The procedures often represent refinements of techniques that involve reflection of crestal or papillary gingival tissue. Tunnel flaps for root coverage derive from one of the simplest procedures used to treat isolated gingival recession defects—the Raetzke pouch. Subsequent authors have expanded tunneling to sites exhibiting multiple adjacent recession defects and enhanced the procedures using external incisions, specialized instruments, distinct surgical protocols for addressing the interproximal gingiva, advanced suturing techniques, and implantation of various grafts and biologics. In periodontal regeneration, tunneling techniques represent the natural extension of highly successful and well-validated M-MIST. Tunnel-based ARA procedures are intriguing; however, supporting evidence is limited to case reports. This narrative review recounts the evolution of tunneling within periodontics and suggests opportunities for further derivations of the technique. Multi-surface and circumferential tunneling may be applicable in specific clinical circumstances.

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Conflict of interest

The authors declare that they have no competing interests.

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Ethics approval and consent to participate

Each patient completed an informed consent process involving verbal and written components. The consent process included completion of a standardized photographic release form for training, education, research, and publication. All consent forms are maintained in the appropriate patient electronic health records.

Consent for publication

Patients consented to the publication of their data.

Availability of data

Not applicable.

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