

Rationale for the Application of the GTR Principle Using a Barrier Membrane in Endodontic Surgery: A Proposal of Classification and Literature Review



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Periradicular surgery has become an established treatment option in endodontic surgery. The major objective of this surgery is to obtain periradicular tissue regeneration, including the formation of a new attachment apparatus, by exclusion of any potentially noxious agent within the physical confines of the affected root. However, in a substantial number of cases, the endodontic lesion has a concomitant marginal periodontal lesion that may complicate the healing success. In periodontology, the guided tissue regeneration (GTR) principle using a barrier membrane has been extensively studied and successfully used, and thus may become an adjunct in endodontic surgery. This article presents a classification system of endodontic and periodontal lesions with respect to the application of the membrane technique and reviews the pertinent literature based upon this classification system. (Int J Periodontics Restorative Dent 2001;21:127-139.)

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The use of the membrane technique in guided tissue regeneration (GTR) and guided bone regeneration (GBR) has become a standard of care in periodontology and implant dentistry.¹⁻⁴ Recent case reports have demonstrated that this technique can also be successfully applied in endodontic surgery. However, only a few controlled clinical and experimental studies have evaluated the membrane technique in endodontic surgery.

The use of a membrane for regeneration of tooth-supporting structure was first reported in 1982 by Nyman et al.⁵ A subsequent experimental study in monkeys⁶ confirmed that placement of a membrane would result in considerable and predictable formation of new attachment by preventing gingival connective tissue and gingival epithelium from contacting the root surface. Although other investigators had described much earlier the need of physically sealing off an anatomic site for bone healing, the principle of guided bone formation was systematically evaluated in the late 1980s.⁷⁻⁹

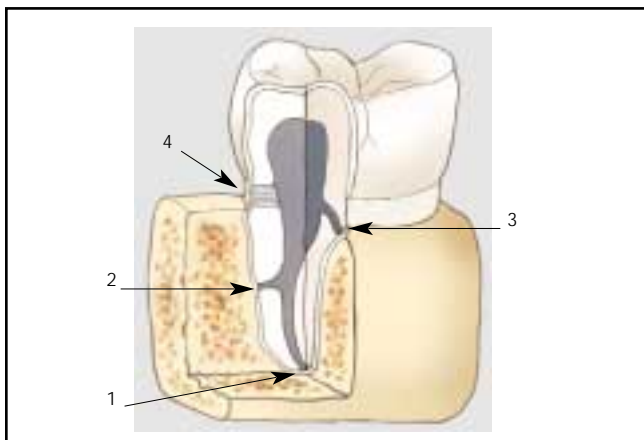


Fig 1 Possible pathways of communication between the pulp and the periodontium: 1 = apical foramen with delta; 2 = lateral accessory canal; 3 = furcation accessory canal; 4 = dentinal tubules.

Class I:	Periapical bone defect without marginal lesion
Ia	Lingual/palatal cortex not eroded
Ib	Lingual/palatal cortex eroded (with a buccal surgical approach, this will result in a transosseous or through-and-through bone defect)
Class II:	Periapical lesion (with or without lingual erosion) and concomitant marginal lesion
IIa	No communication between the separate lesions
IIb	The two lesions are fused = communicating apicomarginal or endodontic-periodontal lesion
Class III:	Lateral or furcational lesion (with or without marginal lesion)
IIIa	No communication to alveolar crest/marginal periodontium
IIIb	Communication to alveolar crest/marginal periodontium

Fig 2 Classification of membrane application in endodontic surgery.

Based on the clinical success of GTR and GBR, it became obvious to use the same principle in endodontic surgery, where the ultimate goal is also regeneration of periradicular tissues including cementum, periodontal ligament, and alveolar bone.¹⁰ However, a new aspect, ie, endodontic factors, must be taken into account when employing this treatment modality in endodontic surgery. There is an important interrelationship between periodontal and pulpal tissues. A number of articles have demonstrated similarities of the microflora found in infected root canals and in advanced periodontitis.^{11–13} In addition, the composition of the cellular infiltrate of long-standing periapical lesions following pulpal infection has many features in common with that of advanced inflammatory lesions of the marginal periodontium.¹⁴

It has also been shown that an endodontic infection influences the progression of marginal bone loss in periodontitis.^{15,16} Teeth with periapical radiolucencies have approximately 2 mm less radiographic attachment in comparison to teeth without periapical radiolucencies.¹⁷ An approximate threefold amplification of the rate of marginal radiographic bone loss (0.19 mm/year vs 0.06 mm/year) was found for teeth in periodontitis-prone patients with an endodontic infection compared to teeth without an infection or with a subsiding endodontic infection.¹⁸ Additional clinical studies showed that a persisting endodontic infection may be regarded as a contributing risk factor for aggravating marginal attachment loss.^{15,19–22}

The propagation of endodontic pathogens into the periodontium was demonstrated in experimental

animal studies.^{18,23} An endodontic infection significantly stimulated the epithelial downgrowth along denuded dentin surfaces with marginal communication.¹⁸ Exposed dentin surfaces also showed significantly larger areas of resorption in infected roots compared to noninfected roots. No such difference was seen for cementum-covered dentin surfaces.²³ The authors concluded that the endodontic pathogens or their products were not able to penetrate the cementum barrier. In the case of patent dentinal tubules, however, they may propagate into the periodontium.

The possible anatomic pathways of communication between the pulp and the periodontium are depicted in Fig 1. The apical foramen is the main pathway between these two tissues. However, in a number of cases accessory canals are present

either to the lateral aspect or, in multirrooted teeth, to the furcational aspect of the root. However, a large discrepancy of 0% to 76% for the incidence of accessory canals in the furcal area of human molars is reported in the literature.²⁴ A third pathway of communication is the dentinal tubules. Normally covered by the protective cementum barrier, the tubules become patent following damage to the cementum after trauma or following cementum removal after root scaling and planing. Also, the cementum may be congenitally missing. In addition, a communication may arise following accidental perforation of the root canal or because of pathologic internal/external root resorption.

The objectives of membrane application in endodontic surgery resemble those in periodontology and implantology: (1) facilitate tissue regeneration by creating an optimum environment (stable and protected wound); and (2) exclude undesired fast-proliferating cells that interfere with desired tissue regeneration. However, the presence of a nonvital tooth may complicate tissue regeneration and may not lead to the same outcome observed for GTR in periodontology or for GBR in implantology. Therefore, a number of issues must be addressed prior to GTR application in endodontic surgery:

- Appropriate patient and case selection
- Basic periodontal and endodontic treatment prior to surgery
- Selection of type of endodontic surgery

- Use of basic surgical principles (tissue handling, wound closure)
- Reduction of bacterial numbers within the periradicular lesion (a clean-contaminated wound)
- Application of approved regeneration materials (barrier membrane, bone substitute)

One objective of the present article is to propose a new classification of periradicular lesions prone to undergo GTR. The other objective is to give an updated literature review as of September 1999 with regard to membrane therapy in endodontic surgery. Although the term guided tissue regeneration does not necessarily imply the use of a barrier membrane, this article will only review papers using a membrane technique in endodontic surgery. The proposed classification will be used to structure the literature review.

Classification of membrane application in endodontic surgery

The following proposed classification is based on typical periradicular lesions, which are distinguished by their location, extension, or pathway of infection (Fig 2).

Class I

Lesions in class I comprise bony defects located at the apex (Fig 3). The defect may erode the buccal and/or lingual cortex (Fig 4). The periapical lesion cannot be probed

through the sulcus of the affected tooth. In this class, the main objective of membrane application is the regeneration of periapical tissues, including the reestablishment of an apical attachment apparatus.

Class II

Lesions in class II comprise apical lesions with concomitant marginal lesions (Fig 5). These lesions are commonly called combined endodontic-periodontal lesions. If no attachment is separating the marginal and the apical lesion, a so-called apicomarginal communication is present (Fig 6). Usually, probing reveals deep periodontal pocket formation. In this class, the membrane approach is employed to regenerate periapical and marginal tissues at the same time.

Class III

Lesions in class III include juxta-radicular lateral or furcational lesions originating from accessory canals or after iatrogenic perforation (Fig 7). The affected tooth may have a concomitant marginal lesion with or without communication (Fig 8). In this class, the membrane technique is used for periradicular tissue regeneration with or without marginal tissue regeneration.

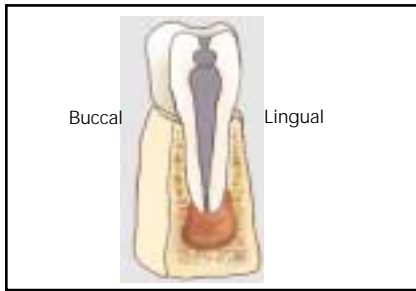


Fig 3 Class Ia lesion (bone defect confined to periapical region).

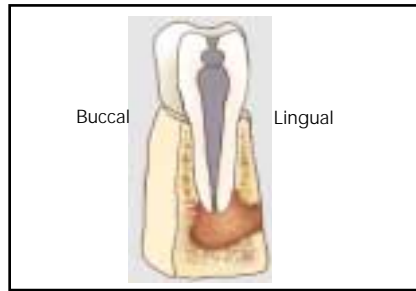


Fig 4 Class Ib lesion (periapical bone defect with erosion of lingual cortical plate).

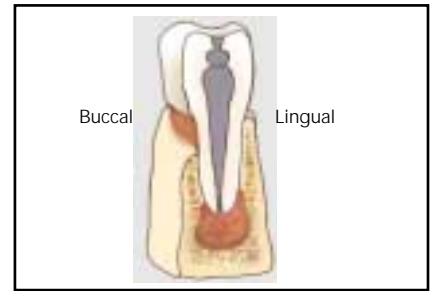


Fig 5 Class IIa lesion (periapical and concomitant marginal lesion without communication).

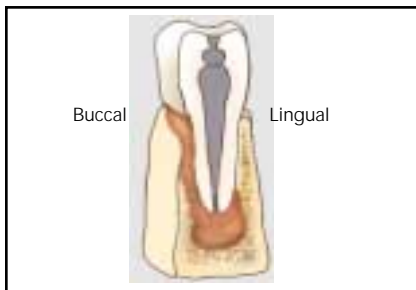


Fig 6 Class IIb lesion (periapical and concomitant marginal lesion with communication).

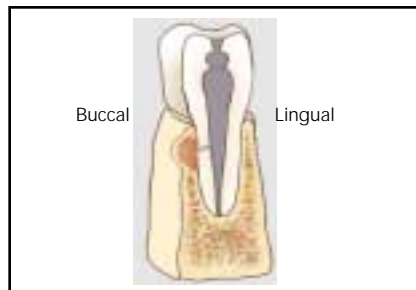


Fig 7 Class IIIa lesion (lateral juxtardicular lesion).

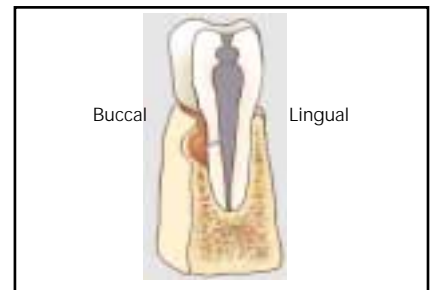


Fig 8 Class IIIb lesion (lateral juxtardicular lesion with communication to marginal lesion).

Literature review

Membrane application in class I lesions

The application of a membrane technique in class I lesions has been investigated to date in only two experimental studies. The first

experimental study addressing membrane application in endodontic surgery was performed in monkeys.⁹ Acute transosseous defects (class Ib) were created periapically at both maxillary lateral incisors, which had been preexperimentally sealed with gutta percha. Test sites received expanded polytetrafluoroethylene

(e-PTFE) membranes buccally and palatally, thus completely sealing the created bony defects. No membranes were placed in control sites. After a healing period of 3 months, all test sites histologically showed almost complete closure by newly formed bone. However, control defects were mainly filled with

fibrous tissue. One may comment that the noninfected and acutely created bone lesions are very different from the situation in humans in which usually infected and chronic-type periapical lesions are present.

The other experimental study evaluated the effects of resorbable membrane placement or human osteogenic protein-1 (hOP-1) application on hard tissue healing after periradicular surgery in cats.²⁵ Periapical lesions (class 1a) were induced by exposing the root canals of maxillary canines to the oral flora. Three weeks later, endodontic treatment with canal obturation was performed. Root ends were resected, and 3-mm-deep retrograde cavities were filled with mineral trioxide aggregate. Three different treatment conditions were analyzed: (1) defects were covered with a resorbable polylactide membrane on the buccal aspect; (2) defects were filled with hOP-1 on a collagen carrier without membrane placement; and (3) control sites received no further treatment. After a healing period of 3 months, histomorphometry revealed a poor osseous fill ranging from 14% to 18% for the three groups, without a significant difference across treatment conditions. These results differ considerably from those obtained in the study described above.⁹ The differences found might be explained by the study design (chronic inflammatory lesions vs acutely created noninfected lesions, monocortical defect vs transosseous bicortical defect), the type of membrane (resorbable polylactide vs nonresorbable e-PTFE), and the species

(cat vs monkey). The polylactide membrane used in the second study may have maintained its barrier function for too short a period compared to the nonresorbable e-PTFE membrane. In addition, other factors (membrane degradation?) may have contributed to the more noticeable inflammatory reaction in membrane-treated versus control sites in the second study.

A search of the English-language literature produced only two controlled clinical studies evaluating the GTR principle in endodontic surgery for class I indications. One study evaluated placement of an e-PTFE membrane versus no membrane treatment following apicoectomy and root-end filling.²⁶ Periapical radiolucency reduction percentage for test sites after 9 months was 85%, compared to 78% for control sites. Although the conclusion was made that healing with a membrane is better than without a membrane, the study failed to show a significant benefit of membrane treatment. With many of the following studies or case reports, the authors referred to the quality of the regenerated tissues based only on clinical and radiographic assessment, without histologic evaluation.

The second clinical study evaluated GBR of bone defects (class Ia) following enucleation of radicular cysts.²⁷ Three different treatment conditions were randomly assigned: (1) placement of an e-PTFE membrane; (2) placement of a polylactide membrane; and (3) no membrane treatment. Affected teeth were either removed or surgically

treated (apicoectomy). Evaluation by computed tomographic (CT) scans after 6 months failed to show any beneficial effect of membrane application for defect healing or density of newly formed bone following enucleation of radicular cysts.

Only a few case reports have described membrane treatment of class I lesions.²⁸⁻³⁰ Details of these case presentations are given in Table 1. Considering the large number of apicoectomies performed, this is surprisingly little information for the dental community. Several issues may relate to this paucity of published studies. Clinicians might hesitate to apply the GTR principle in endodontic surgery because of good long-term results obtained with surgical approaches that do not include membrane application. In addition, higher costs, a more complex operative technique, possibly new healing complications, and lack of research with regard to predictability and long-term outcome may have discouraged surgeons from employing this surgical technique for treatment of class I periapical lesions.

Indeed, the results of one experimental²⁵ and of both clinical studies^{26,27} suggest a similar outcome for periapical tissue regeneration in class Ia lesions following endodontic surgery whether a membrane is applied or not. The marked difference between the benefit of membrane placement in ridge augmentation procedures⁴¹ versus membrane placement in class I lesions might be explained by unknown "endodontic" factors that

Table 1 Review of case presentations using GTR with the membrane technique in endodontic surgery

Study	n	Tooth	Class of lesion	GTR	Surgical endodontics	Antimicrobial medication	Membrane removal	Reentry comment	Total follow-up	Evaluation Outcome
Brugnami and Melloni 1999 ³¹	1	Maxillary central incisor	Ilb	Titanium-reinforced e-PTFE membrane + DFDBA	Apicoectomy, retrofill (amalgam)	Doxycycline (1 × 100 mg/d) for 2 wk	6 mo	Labial cortical plate and apical area completely regenerated	1 y	Reentry, histology, clinical, radiograph
Mastromihalis et al 1999 ³²	1	Maxillary lateral incisor	Ilb	Poly lactide membrane + anorganic bovine bone graft	Apicoectomy, retrofill (amalgam)	Amoxicillin (4 × 500 mg/d) for 7 d	None	—	6 mo	Clinical, radiograph
Milano and Melsen 1997 ³³	6	N/A (all treated same way)	Ilb	Collagen membrane + xenograft (bovine type I collagen)	Nonsurgical root canal	Amoxicillin-clavulanic acid (2 × 1 g/d) for 10 d; CHX 0.2% for 4 w	None	(Reentry after 1 y to check healing) new supporting tissue	1 y	Reentry, clinical, radiograph
Pompa 1997 ³⁴	1	Mandibular central incisor	Ilb	e-PTFE membrane + perforation of marrow space	Apicoectomy, retrofill (material N/A)	Antibiotics 1 wk; CHX 1 wk	6 mo	Complete osseous regeneration, minimal membrane exposure	5 y	Reentry, clinical, radiograph
	1	Maxillary lateral incisor	Ilb	e-PTFE membrane + perforation of marrow space	Apicoectomy, retrofill (material N/A)	Antibiotics 1 wk; CHX 1 wk	6 mo	Complete regeneration of alveolus	N/A	Reentry
	1	Mandibular second premolar	Ilb	e-PTFE membrane + perforation of marrow space	Apicoectomy, retrofill (material N/A)	Antibiotics 1 wk; CHX 1 wk	6 mo	Complete regeneration	5 y	Reentry, radiograph
Uchin 1996 ³⁵	1	Maxillary second molar	Ilb	Poly lactide membrane	Apicoectomy, EBA retrofill	No antibiotics, CHX 2×/d for 6 mo	None	—	6 mo	Clinical, radiograph
	1	Mandibular second molar	Ilb	Poly lactide membrane	None	No antibiotics, CHX 2×/d for 6 mo	None	—	6 mo	Clinical, radiograph
Tseng et al 1996 ³⁶	1	Maxillary first premolar*	Ilb	e-PTFE membrane + DFDBA + tetracycline	None	N/A	1 mo	Large amount of new tissue growth	18 mo	Reentry, clinical, radiograph
Rankow and Krasner 1996 ³⁰	1	All mandibular incisors	la	e-PTFE membrane	Apicoectomy, retrofill (material N/A)	N/A	6 mo	Solid, dense bone	N/A	Reentry
	1	Mandibular central incisor*	Ilb	e-PTFE membrane + DFDBA	Apicoectomy, SuperEBA retrofill	N/A	4 mo	Solid bone barrier	N/A	Reentry, radiograph

Table 1 (Continued)

Study	n	Tooth lesion	Class of lesion	GTR	Surgical endodontics	Antimicrobial medication	Membrane removal	Reentry comment	Total follow-up	Evaluation Outcome
Rankow and Krasner 1996 ³⁰	1	Maxillary first molar*	IIb	e-PTFE membrane + DFDBA	Retrofill of perforation w/SuperEBA	N/A	1 mo	N/A	12 mo	Clinical, radiograph +++
Pinto et al 1995 ²⁸	1	Maxillary lateral incisor	IIb	e-PTFE membrane + DFDBA	Apicoectomy (no retrofill?)	Amoxicillin (2 × 1 g/d) for 10 d; CHX 2 × /d for 7 d	7 mo	Complete osseous healing of labial and palatal cortical plates	7 mo	Reentry, histology, clinical +++
Tseng et al 1995 ²⁹	1	Mandibular central incisor [†]	Ia	e-PTFE membrane + DFDBA + tetracycline	Apicoectomy, amalgam retrofill	No antibiotics, CHX for 7 d	6 mo	Hard, bone-like tissue beneath membrane	12 mo	Reentry, clinical, radiograph +++
Abramowitz et al 1994 ³⁷	1	Maxillary lateral incisor	IIb	e-PTFE membrane + DFDBA	Apicoectomy, amalgam retrofill + varnish	Penicillin V (2 × 500 mg/d) for 7 d; CHX swabs 2 × /d	1 mo	Defect completely filled w/granulation tissue	6 mo	Reentry, clinical, radiograph ++
	1	Maxillary lateral incisor	IIb	e-PTFE membrane + DFDBA + tetracycline	Apicoectomy, amalgam retrofill + varnish	N/A	3 mo	Defect completely filled w/hard, dense tissue	12 mo	Reentry, clinical +++
Duggins et al 1994 ³⁸	1	Maxillary first molar	IIIa	e-PTFE membrane + DFDBA	Apicoectomy, IRM for retro-fill and fill of perforation	Doxycycline (1 × 100 mg/d) for 10 d; CHX 2 × /d	7 mo	Hard tissue resistant to probing	15 mo	Clinical, radiograph +++
Kellert et al 1994 ³⁹	1	Maxillary first premolar	IIb	e-PTFE membrane + FDBA	Apicoectomy, SuperEBA retrofill	N/A	6 wk	Healthy granulation tissue	N/A	Reentry +
	1	Mandibular first molar	IIb	e-PTFE membrane + FDBA	Apicoectomy, SuperEBA retrofill	N/A	6 wk?	Healthy granulation tissue	N/A	Reentry +
Duff 1993 ⁴⁰	1	Mandibular second molar	IIb	e-PTFE	None	Doxycycline (1 × 100 mg/d) for 2 wk; CHX 2 × /d for 2 wk	6 wk	Complete osseous regeneration (2 y)	2 y	Reentry, clinical, radiograph +++

*Plus sinus tract.

[†]Plus mucosal fenestration.

+++ = complete healing of bone defect; ++ = good healing of bone defect; + = uncertain healing of bone defect; - = no healing of bone defect; CHX = chlorhexidine digluconate; IRM = intermediate restorative material.

may influence regeneration of periapical tissues adjacent to nonvital teeth.

In addition, the size of a periapical lesion may surpass the critical defect size for complete osseous regeneration even when the wound is enclosed within bone. This is supported by a large study evaluating 572 periapical surgeries in which a correlation was shown between healing and size of the periapical lesion.⁴² A success rate of only 40% was found for lesions exceeding 15 mm in diameter, whereas small lesions of 5 mm had a success rate of 62%.

Compared to the class Ia indication for membrane therapy, the GTR principle might contribute more favorably in the treatment of transosseous (through-and-through) lesions (class Ib). In the large study by Hirsch et al⁴² evaluating periapical surgery, a correlation was shown between the healing and the type of cortical destruction of a periapical lesion. Lesions with buccal and lingual breakthrough showed complete healing in only 25% of lesions. This compares to success rates of 36% for eroded lingual but intact buccal cortex and 42% for eroded buccal but intact lingual cortex. Finally, 50% of the cases healed when both cortical plates were intact. A similar discrepancy for periapical healing between lesions with perforation of the lingual and buccal cortex (complete healing in 47%) and lesions without perforation (complete healing in 81%) was reported elsewhere.⁴³

Class Ib lesions are of special concern for follow-up evaluation. It

has been shown that pathologic or surgical defects eroding both labial and palatal cortical plates normally do not show complete osseous healing, but rather fill with scar tissue. Radiographically, this results in a partially healed or persistent periapical lesion.⁴⁴ Others have confirmed the occurrence of incomplete healing with scarred but inflammation-free tissue following endodontic surgery in class Ib lesions.⁴⁵⁻⁴⁸ The use of membrane therapy in class Ib periapical lesions might help to avoid situations in which the clinician is likely to reenter unnecessarily a former transosseous periapical defect, only to find no recurrence of periapical infection.

Membrane application in class II lesions

The application of the GTR principle in class II lesions, particularly in communicating endodontic-periodontal lesions, has been recognized as one of the more challenging treatment modalities in endodontic surgery.⁴⁹ There have always been discussions about whether to try to salvage a periapically diseased tooth with advanced marginal bone loss or to extract it. A retrospective study addressing this problem was published in 1985 by Skoglund and Persson.⁵⁰ Although this study did not evaluate the GTR principle, it has become frequently quoted with regard to membrane therapy of combined endodontic-periodontal lesions. The authors assessed the outcome following apicoectomy of

27 teeth that showed total buccal bone loss at the time of surgery. After a mean observation period of 3 years, only 37% of the cases were deemed successful. The authors noted that for apicoectomies of teeth without marginal periodontal destruction, much higher success rates of up to 90% were normally reported in the literature. The negative influence of buccal bone loss on periapical surgery had also been reported elsewhere.⁴² Only 27.3% of teeth with total buccal bone loss showed healing, whereas the success rate of teeth with an intact buccal bone plate was 49.5%.

Surprisingly, no controlled clinical or experimental study has been published to date addressing the application of the membrane technique for treatment of class II endodontic-periodontal lesions. However, a thesis that evaluated barrier membrane treatment of class IIb lesions was found.⁵¹ In nine dogs, root canal treatment with obturation was performed on the mandibular third and fourth premolars. Subsequently, the root ends were resected, and the bone was completely removed from the crest to the apex over the facial root aspect. The resected root ends and exposed buccal root surfaces were burnished with 10% citric acid–3% ferric chloride solution. One tooth per side received at random a bioabsorbable membrane (polylactide–citric acid ester) covering the communicating endodontic-periodontal lesions (class IIb), while the other tooth served as the control. No defect filler was used. At sacrifice after 27 weeks, a beneficial effect of

the membrane was demonstrated in terms of periapical bone fill (89% vs 67% in control sites). However, no attempts were made to quantify the regenerated bone width or volume on the buccal aspect. In fact, the regenerated bone never reached its former marginal level. One can speculate that the bioabsorbable membrane collapsed toward the buccal root surface because no filler was applied. However, the membrane sites revealed a significantly better connective tissue attachment (4.1 vs 1.8 mm) that seemed unrelated to the presence or absence of alveolar buccal bone. These findings are consistent with other experimental studies that have shown that new connective tissue attachment and regeneration of bone may progress independently.^{52–54} While that study did not attempt to simulate the more chronic and infected types of alveolar bone lesions found in humans (class IIb bone lesions were created acutely), it is the only experimental study reviewed that evaluated communicating apicomarginal lesions.

In contrast to the lack of controlled studies, a larger number of case presentations and case series^{30–37,39,40} have been published reporting membrane application in class II lesions (all of them were communicating endodontic-periodontal class IIb lesions). The majority of these reports demonstrated good to excellent tissue regeneration following membrane application for treatment of combined endodontic-periodontal defects. So-called terminal cases with hopeless teeth were salvaged by employing the GTR

principle with a membrane with or without a graft following degranulation and endodontic surgery. Radiographically and upon reentry, most case reports demonstrated healing with dense and hard tissue. However, without histology, it would be difficult to confirm true osseous healing.

The application of a membrane technique for class II lesions is probably the most challenging in endodontic surgery. Advanced marginal periodontal destruction with a concomitant periapical lesion or communicating endodontic-periodontal lesions is a problematic situation for the patient and the clinician alike. This is aggravated by the fact that the true extent of bone loss can often only be determined intraoperatively after flap reflection. Therefore, the surgeon must carefully plan the surgery to be prepared for management of an extended combined lesion.

For treatment of communicating apicomarginal defects, a barrier technique might become an important aid to regenerate tooth-supportive structure, ie, to create new attachment. In periodontology, a large number of articles have shown that periodontal tissues lost through disease or trauma can be regenerated by membrane application.^{55,56} Periodontal defects that predictably benefit from GTR therapy are intrabony lesions, furcation Class II lesions, and gingival recession defects.⁴ One would assume that this technique also has the potential for treatment of combined endodontic-periodontal lesions. However, this literature review found only one

controlled experimental study that evaluated this particular application of the membrane technique.⁵¹ Therefore, without further controlled studies, this surgical approach must still be considered an experimental option for treatment of class II lesions.

Membrane application in class III lesions

For this class of lesions, the least number of articles was found in the literature. Only a single experimental study evaluated the membrane technique for treatment of class IIIa lesions.⁵⁷ The study was performed in six dogs that underwent root canal therapy on mandibular fourth premolars and first molars and had perforations created halfway between the furcation and the apex. After 1 week, the perforations were surgically accessed and were prepared with an ultrasonic instrument and either filled or not filled. The exposed roots were demineralized employing tetracycline-HCl. Sites were randomly assigned to one of the following treatments: (1) the bony defect was filled with human demineralized freeze-dried bone (DFDB; a xenograft to the dog) and covered with an e-PTFE membrane; (2) no bone graft was placed, but the area was covered with an e-PTFE membrane; and (3) neither a graft nor a membrane was applied. The dogs were sacrificed at 6, 12, and 24 weeks, and decalcified sections were analyzed. Sites with membrane placement demonstrated excellent

bone formation. The inclusion of DFDB, however, had no effect on the osseous healing observed. Sites without membrane application showed some bone formation, but to a lesser degree. Interestingly, no histologic evidence was found of regeneration of the periodontal attachment apparatus in the area of retrofilled perforations and membrane application. All teeth without retrograde obturation of the perforation showed very poor bone formation irrespective of membrane placement. Although a root canal treatment with obturation and closure of the coronal access had been performed 1 week earlier, one explanation was that there was still some microbial leakage affecting bone formation in teeth without retrofilling the perforations. Still, this study showed that large access openings necessary for repairing root canal perforations heal better using a membrane.

Only two case reports have addressed a GTR approach with a membrane for treatment of class III lesions.^{30,38} Both case presentations reported a successful membrane treatment of an endodontic furcation perforation (for details, see Table 1). Given the added benefit of GTR in the periodontal treatment of mandibular degree II furcations, and to a lesser degree in maxillary degree II furcations, membrane therapy might be particularly indicated for treatment of endodontic furcation lesions that communicate with the marginal periodontium.

The future of GTR in endodontic surgery

To date, only limited information and data are available with regard to GTR therapy using membranes in endodontic surgery. There is an apparent lack of controlled clinical and experimental studies evaluating this issue. Although a substantial number of case reports have addressed the membrane approach in endodontic surgery, it should be noted that without a control lesion of similar size to evaluate healing in the absence of a membrane and/or graft material, conclusions in case presentations can only be made tentatively.

With respect to the proposed classification system, the most information and data are available for class I lesions. For periapically confined lesions without lingual erosion (class Ia), there have been a large number of studies evaluating clinical and radiographic healing, all of them without using a membrane. This has been the traditional way of treating periapical lesions. With the advent of GTR using membrane barriers, a new treatment modality has surfaced, which has not been shown to date, however, to be superior to the conventional technique of just repositioning the mucoperiosteal flap over the buccally exposed defect.

In contrast, periapical lesions with erosion of the lingual cortex (class Ib) usually demonstrate a reduced healing capacity and may benefit from membrane application. The potential of enhancing periapical healing by sealing off such a

defect with membranes should be investigated further.

In the near future, the most attractive indication for GTR with membranes and/or grafts in endodontic surgery is the treatment of combined endodontic-periodontal lesions (class II). Root exposure from periodontal infection concomitant with a periapical lesion poses a real challenge to the clinician. Several treatment aspects of GTR using membranes and/or grafts regarding this indication are of interest:

- Does periapical regeneration influence periodontal regeneration? And vice versa?
- What type of membrane yields the most predictable results?
- Is a space filler placed between the exposed root and the membrane of additional benefit or even a prerequisite? If yes, what is the preferred filler?
- Is root conditioning required for periodontal regeneration in combined endodontic-periodontal lesions?
- What is the rate of external root resorption or ankylosis following GTR treatment with membranes and/or grafts?

Parallel to GTR and GBR, a tendency of using bioabsorbable instead of nonresorbable membranes has been noted in endodontic surgery. However, a considerably longer period of intact barrier function with structural membrane rigidity might be required for combined endodontic-periodontal lesions compared to periodontal lesions

alone. Historically, nonresorbable membranes applied for periodontal indications are usually removed after 4 to 6 weeks. However, studies on the sequential healing of bone defects using the GBR principle have shown that a longer time frame of at least 6 months is needed for larger bony lesions.³¹ The optimum healing period is unclear when using membranes in endodontic surgery. It would appear, based upon the literature evaluated for this review, that the longer healing time would favor more enhanced tissue healing.

The other major question regarding GTR with membranes in endodontic surgery remains the issue of using a membrane with or without a graft or bone substitute. Of all reviewed controlled experimental and clinical studies, only one study addressed this question, but it did not find any beneficial effect of adding a bone graft. Because no other data are available, no final conclusion can be drawn with respect to using a graft or bone substitute simultaneously with a membrane in endodontic surgery.

Endodontic surgery might also benefit from new and continually developing biologic therapies, including the application of tissue substitutes or biologic mediators.⁵⁸ However, the primary goal of dentistry should remain the preservation and/or regeneration of as many of the natural tooth components as possible, be it the tooth itself or its supporting structures. One of the highest achievements in combining endodontic and periodontal (surgical) procedures is to salvage a tooth

on a long-term basis that has been defined as hopeless at the initiation of treatment.

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