

Unanswered Questions

Can Bone Lost from Furcations Be Regenerated?



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KEYWORDS

- Furcation defects • Alveolar bone • Animal models • Histology
- Human clinical trials

KEY POINTS

- Histologic demonstration of new bone growth in furcations is the gold standard.
- There is histologic evidence of new bone growth in experimental furcation defects in animal models and in a few reports of furcation defects in humans.
- There are several reported human clinical trials that include surgical reentry and open measurement of furcation defects, but the nature of the hard tissue in the furcation needs to be determined by histology.
- There is a need for more histologic analysis in human clinical studies to confirm the presence and to determine the extent of new bone growth in human furcation defects.

INTRODUCTION

Furcation involvements pose one of the most difficult challenges in periodontal therapy and explain the greater likelihood of molar teeth being lost during the course of chronic periodontitis compared with single-rooted teeth.¹ The architecture of furcation defects plays a major role in disease progression and resistance to therapy.

The architecture of periodontal osseous defects is, by contrast, much simpler than furcation defects. The number of bony walls—1, 2, 3, or a combination—defines periodontal osseous defects. When considering the inferior osseous border is always present, periodontal osseous defects are actually 2-, 3-, or 4-walled defects. Regenerative periodontal therapy typically involves surgical débridement and placement of an autograft, allograft, xenograft, or alloplast into the defects followed by a barrier membrane to obstruct the migration of epithelial cells from the mucoperiosteal flap into the healing site. Over the next several weeks, fibroblasts migrate from the periodontal ligament (PDL) and osteoblasts migrate from the defect osseous walls to

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colonize the graft scaffold. The migration of host cells into the healing site is sometimes stimulated by biologic agents, such as bone morphogenic or enamel matrix proteins. Over time, osteoblasts may replace the graft material with new bone contiguous with the existing alveolar bone.²

Furcation defects present unique challenges. Furcation defects, like osseous defects, are bordered by alveolar bone. In addition, furcation defects are bordered by root surfaces usually covered by cementum but sometimes covered with dentin or even enamel in cases of cervical enamel projections. As periodontal disease progresses, the roots become exposed to the oral environment. They are colonized by oral bacteria and contaminated by bacterial toxins. The furcation fornix may be so narrow that patient oral hygiene is impossible and even professional débridement is difficult. Similar to periodontal osseous defects, cortical bone lines periodontal furcation defects. The procedure for osseous grafts frequently includes cortical (intramarrow) penetration. This causes bleeding from subcortical cancellous bone, clot formation, and migration of osteoblasts into the defect. Intramarrow penetration has been shown to increase clinical bone gain in infrabony defects treated by open flap débridement.³

There is a great deal of data on periodontal regeneration in furcation defects. These data are summarized in several excellent reviews (discussed later). This article does not address the entire area of periodontal regeneration. Rather, it focuses on a single but unique and important aspect of periodontal regeneration, that of new bone growth in furcation defects. This article addresses the unanswered question, Can bone lost from furcations be regenerated?

DIAGNOSIS AND CLASSIFICATION OF FURCATION DEFECTS

The diagnosis of furcation defects in dental practice is based primarily on periodontal probing and dental radiographs. Furcation probes (pigtailed explorer and Nabers probe) are used both to detect furcation defects and quantitate the extent of the defect.

Three types of furcation defects were described by Hamp and colleagues⁴ based on clinical probing measurements: degree I = horizontal loss of periodontal tissue in the furcation less than 3 mm; degree II = horizontal loss of support in the furcation exceeding 3 mm but not encompassing the total width of the furcation area; and, degree III = horizontal through-and-through loss of the tissue in the furcation. There are several other classification systems (Ramfjord,⁵ Tarnow and Fletcher,⁶ and Hou and colleagues⁷), some of which provide subcategories to the Hamp classification based on the severity of the furcation defect measured in a vertical direction from the fornix, or roof, of the furcation to the base, or floor, of the defect. The system described by Hamp and colleagues,⁴ however, remains widely used in both clinical practice and clinical research.

Standard periapical, bitewing, and panoramic radiographs are used to diagnose furcation defects in dental practice. Like the detection of alveolar bone loss in chronic periodontitis, a significant amount of alveolar bone loss must occur before a furcation defect can be seen on a radiograph. Initial class I furcation defects are only detectable by probing. More severe class II and class III defects maybe evident on radiographs but even then the defects may be hidden by superimposition of roots. Furcation defects might be evident as slight alterations in trabecular radiodensity or they might demonstrate gross radiolucencies. Consequently, the sensitivity of standard radiographs in detecting furcation defects is low but the specificity is high.^{8,9}

Besides periodontal probing and radiographs, additional measurements are used to characterize the size of the furcation defects, particularly in clinical studies. These

parameters include closed measurements, such as vertical probing depth and horizontal probing depth; vertical attachment level and horizontal attachment level; gingival recession; and open measurements made at the time of surgery or surgical reentry. These vertical and horizontal defect measurements are used to calculate initial defect volume, post-treatment vertical defect fill, and horizontal defect fill as well as overall change in defect volume.

TREATMENT OF FURCATION DEFECTS

Prior to the advent of periodontal regeneration, furcations defects were usually treated by resective surgery, such as tunneling, root resection/amputation, and bicuspidization. These treatments have supplemented by therapies directed toward the regeneration of periodontal tissues. The origin of periodontal regeneration can be traced to studies of new attachment using filters and Teflon membranes.^{10,11} This was followed by guided tissue regeneration using nonresorbable and then resorbable barrier membranes followed by combinations of osseous grafts and barrier membranes and, more recently, the use of biologic agents, such as bone morphogenetic proteins and enamel matrix proteins. The field of periodontal regeneration is, therefore, a translational science applying the results of basic laboratory research to clinical practice. For example, peptide-enhanced anorganic bone matrix particulate grafts contain the synthetic biomimetic of the 15 amino acid cell-binding domain of type I collagen bound to bovine hydroxyl apatite. This product is the result of laboratory research that determined the amino acid sequence of type I collagen, pinpointed the cell binding part of the collagen molecule, synthesized the terminal peptide, and linked it to bovine hydroxyl apatite.

THE PROBLEM WITH PROBING

Periodontal probing is the standard method of detecting periodontal furcation defects. With class I defects, there may only be a slight depression indicating the divergence of the roots, whereas the probe may enter the defect to greater depths with class II and III defects. Entry of the probe depends, however, on the absence of obstructing soft tissues, and the depth of penetration depends on the width of the osseous defects and the divergence of the roots. Recent studies using cone-beam CT (CBCT) call into question the accuracy of periodontal probing in the detection of furcation defects.

CBCT enables visualization of slices of the maxilla and mandible in sagittal and horizontal planes. Consequently, furcations that might not be probeable because the defects are too narrow or tortuous are visible on CBCT. Furcations that might be categorized into one class of defect by probing might be categorized into another class of defect by CBCT.

Two recent studies have examined the relationship between clinical probing and CBCT for the detection and classification of furcation defects. Both studies indicate that the clinical diagnosis of furcation defects by periodontal probing can result in significant underestimates and overestimates of the extent of a furcation defect. In one study by Walter and colleagues,¹² CBCT was used to assess 22 maxillary molars in 12 generalized chronic periodontitis patients with clinical furcation defects. There was agreement between clinical probing and CBCT in 27% of the sites, but the clinical diagnoses were overestimated compared with CBCT in 29% of the sites and the clinical diagnoses were underestimated compared with CBCT in of the 44% sites. All the clinically detectable class III furcations were also detected by CBCT but clinical class II and class II to III furcation defects were underestimated by as much as 75%. In a study by Laky and colleagues,¹³ 582 molars were clinically examined for class II and class III

furcation defects and compared with CT scans. There was agreement between clinical diagnosis and CT in 57% of the sites but the clinical diagnosis was overestimated in 20% of the sites and the clinical diagnosis was underestimated in 23% of the sites. The best correlation between clinical diagnosis and CT was in sites that were the easiest to probe—mandibular and maxillary buccal furcations (correlation coefficients = 0.52 and 0.38, respectively). The worst correlation between clinical diagnosis and diagnosis by CT was in sites that were the hardest to probe—maxillary distal furcations.

The data from these and other studies indicate that furcation defects may be misclassified using standard methods. Zappa and colleagues¹⁴ compared probing with surgical exposure of furcation defects and found that 7% of degree 1 and 24% of degree 2 (Hamp index) were overestimations whereas 27% of degree 3 involvements were not recognized. Pistorius and colleagues¹⁵ compared clinical probing with CT and found a correlation in 69% of defects and an underestimate in 31% of the defects. Accordingly, studies that rely on clinical criteria to classify furcations may have an inherent methodologic error. Misclassification of furcation defects may affect the clinical outcome of treatment studies. For example, a cohort of patients with class II maxillary furcation defects selected on the basis of probing also likely includes some teeth with class III furcation defects. There is known to be significant variability in treatment outcomes for furcation defects. Some of this variability is attributable to patient compliance and some is attributable to unknown factors.¹⁶ Misclassification of periodontal furcation defects may be an as-yet underappreciated source of variability in studies of furcation defects.

POUCHES WITHIN FURCATIONS

In addition to the factors normally associated with the progressing periodontitis—pathogenic plaque bacteria; inadequate oral hygiene; systemic factors, such as diabetes mellitus; habits, such as smoking; local factors, such as open contacts; and overhanging restorations—furcation defects have their own unique factors. These include root morphology, root trunk length, accessory canals, enamel pearls, cemental caries, and pulpal disease manifesting as periodontal-endo-dontic lesions. The anatomy of the furcation often hinders oral hygiene because it may be too narrow for access by toothbrush bristles or even scalers or curettes during professional treatment. Bower,¹⁷ for example, reported that the width of the furcation entrance in molars is narrower than the width of most curettes.

Another important factor in the etiology of furcation defects is cervical enamel projections—the triangular-shaped extension of enamel from the cemento-enamel junction into the furcation. The presence of enamel projections—reported in 15% to 24% of mandibular molars and 9% to 25% of maxillary molars¹⁸—provides an area devoid of connective tissue attachment and predisposes to the development of furcation defects. Correlations between cervical enamel projections and the presence and severity of furcation defects have been reported by several investigators.^{19–21}

Recent electron microscopic studies show that there is even greater complexity to cervical enamel projections than previously thought.²² Pouchlike openings (Fig. 1) have recently been described in association with cervical enamel projections. These anomalies can hide oral biofilms resistant to even the most stringent oral hygiene efforts, thus contributing to the progression of furcation defects.

TYPES OF EVIDENCE FOR NEW BONE GROWTH IN FURCATION DEFECTS

What constitutes evidence for new bone growth in furcation defects? The gold standard for ascertaining the presence and amount of new bone in a furcation defect is

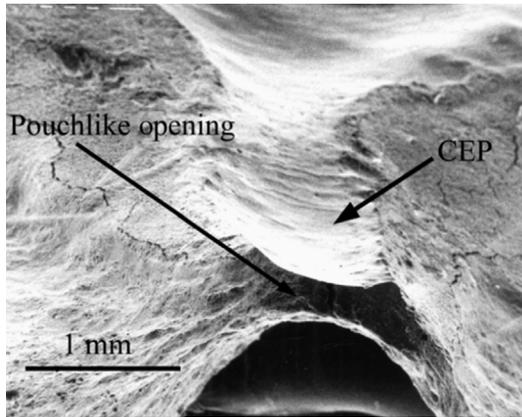


Fig. 1. Electron microscopic view of a furcation. This shows a pouchlike opening apical to the cervical enamel projection that can harbor oral biofilms and lead to progression of furcation defects. CEP, cervical enamel projection. (From Blanchard SB, Derderian GM, Averitt TR, et al. Cervical enamel projections and associated pouch-like opening in mandibular furcations. *J Periodontol* 2012;83(2):198–203; with permission.)

histology—the microscopic identification of bone matrix, osteocytes, osteoblasts, osteoclasts, and haversian canals. The exact nature of the tissue present in a furcation can only be determined by histology. As described by Garrett,¹⁶ “Histological evaluation remains the only reliable method of determining the nature of the attachment apparatus resulting from therapeutic attempts to regenerate the periodontium.” Similarly, Eickholz and Hausmann²³ wrote, “the type of tissue recolonizing a periodontal defect after surgical therapy can only be precisely evaluated by histology.” Several investigators have recently reaffirmed this view. Nevins and colleagues²⁴ wrote, “Without histology it would not be possible to evaluate the biological potential of the surgical procedure.” Avila-Ortiz and colleagues²⁵ summarized a systematic review of periodontal regeneration in furcation defects: “These future studies should also have long-term follow-ups, ideally greater than 5 years after baseline, and should place more emphasis on histologic and patient-reported outcomes.”

The reason for the dearth of human histologic data on treated furcation defects is self-evident. Material appropriate for histologic examination necessitates surgical exposure and block extraction to preserve tissues relationships. Not many patients or human subject review committees approve block extractions or even extraction of individual teeth that might otherwise be maintained. Hopeless teeth are the exception. Hopeless teeth can be treated with the understanding that they will be subsequently extracted and processed for histologic examination.

The vast majority of histologic and histomorphometric data available in the literature is derived from animal studies. Furcation defects in animal models can be histologically examined to assess periodontal regeneration, including new bone growth, but there are differences between animal and human furcation defects. First, animal teeth have different anatomy. Second, furcation defects in animal models are created surgically rather than the result of chronic periodontitis. There are differences between furcation defects in animal models and humans in types of microorganisms infecting the sites and bacterial toxins on the root surfaces. Also, surgically created furcation defects in animal models are lined by cancellous bone rather than by cortical bone in human furcation defects resulting from chronic periodontitis.

As a consequence of the ethical issues associated with the procurement of human tissue samples for histologic examination, surrogate measures are frequently used to study human furcation defects. These surrogate measures include closed measurements, open measurements made at the time of surgery, and radiographic assessments, including subtraction radiography and micro-CT. The acceptability of surrogate measures in assessing periodontal regeneration in furcation defects can be traced back to the 1996 World Workshop in Periodontics. It was recommended that acceptable proof of periodontal regeneration could include histologic analysis of tissue samples from animal models together with human controlled clinical trials.²⁶

Although open measurements made during surgery or surgical reentry provide more evidence for new bone formation in a furcation defect than do closed measurements, it can be difficult to differentiate new bone in a surgically exposed furcation from other tissues, such as cartilage or fibrous connective tissue that may be present in a treated furcation. Consequently, open measurements at surgical reentry may overestimate the amount of bone in a defect. Also, as opposed to histologic analysis in which new bone is measured from a notch placed in the root marking the apical extent of the defect, surgical reentry evaluates changes in probing measurements without actually being able to see the starting point of the furcation defect.

Difficulties in clinically differentiating the type of tissue present in a healing furcation have been reported in several studies. Becker and colleagues²⁷ reported 3 cases of guided tissue regeneration with surgical reentry at 3 or 6 months. They reported that there were gains in defect fill that they termed, *open probing new attachment*, but that the material “did not have the consistency of bone.” Lekovic and colleagues²⁸ performed intraoperative and reentry measurements of mandibular class II furcation defects. They reported that changes in probing measurements were not due to the growth of new bone in the furcation defect but to new connective tissue attachment. They concluded, “Histologic evaluation of successfully treated Class II furcations in humans will be necessary in the future to verify the possibilities of complete periodontal regeneration with the various techniques.”

In their study, Houser and colleagues²⁹ reported that the “...6-month reentry reveals a bonelike substance that is resistant to probing in the furcation.” Clinical reports often refer to hard tissue measurements or hard tissues seen at the time of surgical reentry. These terms are, however, often used interchangeably with *bone*, although there is no histologic basis for this categorization.^{30,31}

HISTOLOGIC EVIDENCE FOR NEW BONE GROWTH IN FURCATION DEFECTS IN ANIMAL MODELS

Histologic examination of block sections from animal models provides definitive evidence of bone growth in furcation defects. **Table 1** lists studies of class II and class III furcation defects in animal models—mainly dogs but also baboons and minipigs—treated with a variety of periodontal regenerative agents. The treatments include recombinant human transforming growth factor β 3,³² platelet pellet,³³ poly(lactide-co-glycolide acid/calcium phosphate bilayered biomaterial,³⁴ human osteogenic protein-1 and human transforming growth factor- β 3,³⁵ cultured PDL cells,³⁶ collagen hydrogel/sponge scaffold,³⁷ enamel matrix derivative with a biphasic calcium phosphate,³⁸ and bioactive glass/platelet rich plasma.³⁹

All these animal studies with histology reported new bone growth in furcation defects. The amount of new bone growth varied. Keles and colleagues³³ reported “limited coronal new bone growth.” Suiad and colleagues³⁹ reported 5.45 mm of new bone in test sites compared with 1.89 mm in control sites. Kosen and

Table 1
Histologic evidence for new bone growth in furcation defects in animal models

Study	Animal Model	Furcation Classification	Treatment	Results
Teare et al, ³² 2008	Baboon	Class II	Surgically created class II furcation defects in maxillary and mandibular molars of 4 adult baboons were treated with heterotopic ossicles and recombinant human transforming growth factor- β 3.	After 60 d, recombinant human transforming growth factor- β 3, delivered by Matrigel as carrier, was found to induce alveolar bone.
Keles et al, ³³ 2009	Dogs	Class II	Surgically created mandibular class II lesions were treated with platelet pellet or platelet pellet and GTR or scaling and root planning.	12 wk postsurgery, there was limited coronal new bone growth in all groups not significantly different from each other.
Carlo Reis et al, ³⁴ 2011	Dogs	Class II	Treated experimental class II furcation defects were treated with semirigid poly(lactide-co-glycolide) acid/calcium phosphate bilayered biomaterial.	Control defects were filled mainly with dense connective tissue. New alveolar bone was evident from the apical limit to the most coronal part of the defect and from lingual to buccal.
Teare et al, ³⁵ 2012	Baboon	Class II	Surgically created class II furcation defects of the first and second mandibular molars of 3 adult baboons	Application of human osteogenic protein-1 and human transforming growth factor- β 3 resulted in new bone against the root surfaces.
Suaid et al, ³⁶ 2012	Dogs	Class III	Surgically created class III furcation defects were treated with cultured PDL cells.	After 3 mo, larger area of new bone compared with controls $5.45 \pm 1.58 \text{ mm}^2$ vs $1.89 \pm 0.95 \text{ mm}^2$ untreated control
Kosen et al, ³⁷ 2012	Dogs	Class II	Surgically created mandibular class II lesions in beagle dogs were treated with collagen hydrogel/sponge scaffold vs untreated control group and evaluated 2 and 4 wk.	Volume of new bone was significantly greater in the test group vs control group—% new bone 51.4 ± 6.4 vs 36.4 ± 5.3 .
Mardas et al, ³⁸ 2012	Dogs	Class III	Surgically created 17 mandibular class III lesions in 9 dogs were treated with either enamel matrix derivative with a biphasic calcium phosphate or untreated control.	After 5 mo, new bone formation was observed in both groups—mean new bone height was $4.4 \pm 1.3 \text{ mm}$ and $4.3 \pm 1.6 \text{ mm}$ in the control and test groups. There was no significant difference between groups.
Suaid et al, ³⁹ 2012	Dogs	Class II	Surgically created class II lesions were treated with GTR + BG + PRP or with just GTR + BG and B.	There was greater mineralized bone area observed for the GTR + BG + PRP treated defects compared with GTR + BG— 10.73 mm^2 vs 7.63 mm^2 after 90 d.

Abbreviations: BG, bioactive glass; GTR, guided tissue regeneration; PRP, platelet-rich plasma.

Data from Refs.^{32–39}

colleagues³⁷ reported that test sites had 51.4% bone fill by volume compared with 36.4% in control sites (**Fig. 2**). Clearly there are numerous literature reports providing histologic evidence of new bone growth in both treated and control furcation defects in animal models.

HISTOLOGIC EVIDENCE FOR NEW BONE GROWTH IN HUMAN FURCATION DEFECTS

In contrast to animal studies, there are few histologic data demonstrating new bone growth in human furcation defects (**Table 2**). Stoller and colleagues⁴⁰ (**Fig. 3**) presented histologic data on a furcation in a patient treated 25 months previously during a study of guided tissue regeneration using bioabsorbable polylactic acid–based barrier membranes. The study patients all had class II furcation defects with vertical

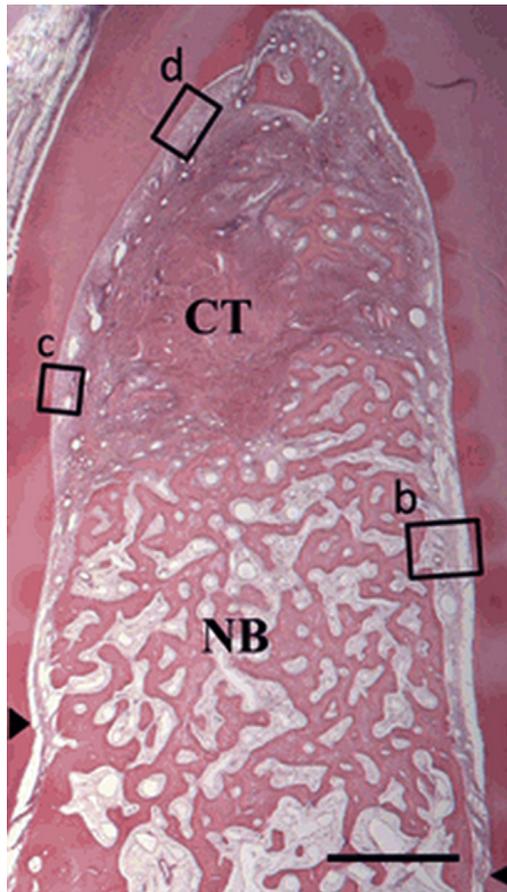


Fig. 2. New bone formation in an experimental dog model 4 weeks after placement of a collagen hydrogel/sponge scaffold. Apical notches marking the apical extent of the original furcation defect are indicated by the arrow heads. New bone fills most of the dimension from the apical notches to the fornix. CT, connective tissue; NB, new bone. (From Kosen Y, Miyaji H, Kato A, et al. Application of collagen hydrogel/sponge scaffold facilitates periodontal wound healing in class II furcation defects in beagle dogs. *J Periodontol Res* 2012;47(5):626–34; with permission.)

Table 2 Histologic evidence for new bone growth in human furcation defects				
Study	Type of Study	Furcation Classification	Treatment	Findings
Stoller et al, ⁴⁰ 2001	Case report	Class II	GTR with bioabsorbable membrane	Bone growth shown in the buccal class II furcation #18, 25 mo after GTR
Mellonig et al, ⁴¹ 2009	Four cases	Class III	PDGF and β -tricalcium phosphate	Class III furcations treated in 4 patients with hopeless periodontal prognosis. Some new bone was noted in 3 of 4 teeth ranging from 0 to 2.04 mm.
Nevins et al, ²⁴ 2013	Single-center prospective clinical study	Class III	LANAP in 12 defects in 8 subjects with advanced periodontitis, including 3 teeth with class III furcations	There was some regeneration, including some new bone.

Abbreviations: GTR, guided tissue regeneration; LANAP, laser-assisted new attachment procedure; PDGF, platelet derived growth factor.

Data from Refs.^{24,40,41}

probing depths of at least 5 mm and horizontal probing depths of at least 3 mm. The patient had cracked the treated tooth, a mandibular left second molar, and did not want additional treatment. The tooth was extracted and examined histologically (see Fig. 3). PDL and bone were apparent in the furcation. New bone growth could

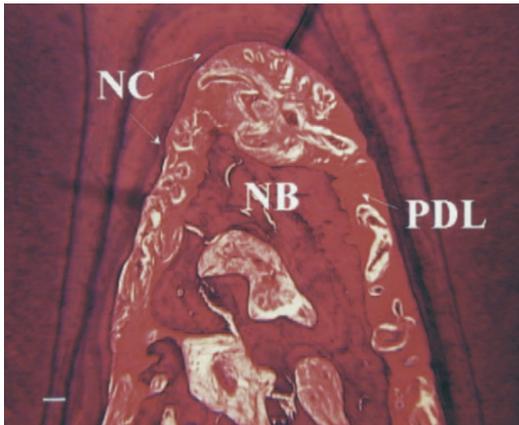


Fig. 3. A histologic section of a buccal furcation in a human mandibular second molar furcation previously by periodontal regenerative surgery. At the time of treatment, the tooth exhibited vertical probing depths of at least 5 mm and horizontal probing depths of at least 3 mm. Twenty-five months after treatment, the tooth cracked. The patient declined treatment. The tooth was extracted and examined histologically. Alveolar bone extends almost to the furcation fornix. NB, new bone; NC, new cementum. (From Stoller NH, Johnson LR, Garrett S. Periodontal regeneration of a class II furcation defect utilizing a bioabsorbable barrier in a human. A case study with histology. *J Periodontol* 2001;72:238-42; with permission.)

be seen coronal to a notch placed in the root at the time of treatment demarcating the apical extent of the furcation defect. The investigators suggest that this particular furcation defect might have been especially favorable to new bone growth because the roots were narrow mesiodistally and there was a 3-wall infrabony defect at the buccal entrance to the furcation.

Mellonig and colleagues⁴¹ examined 4 mandibular first molars with class III furcations and hopeless periodontal and prosthetic prognosis in patients with advanced chronic periodontitis. The furcation defects were treated with a combination of recombinant human platelet-derived growth factor and β -tricalcium phosphate and covered on both facial and lingual surfaces by a collagen membrane. The teeth were extracted after 6 months and evaluated histologically. The investigators found histologic evidence of new bone growth in the furcation: "Foci of new bone were seen almost to the fornix of the furcation."

Nevins and colleagues²⁴ examined laser-assisted new attachment procedures in 12 hopeless teeth in 8 patients, including 3 teeth with class III furcations. Nine months after treatment, the teeth were extracted and examined histologically. They found new bone growth coronal to the root notch, which was confirmed by micro-CT. Overall, these 3 histologic studies suggest that bone growth is possible in human furcation defects.

EVIDENCE FOR NEW BONE GROWTH IN HUMAN FURCATION DEFECTS OBTAINED BY SURGICAL REENTRY

After histology, the next best evidence for bone growth in furcation defects is surgical reentry. **Table 3** lists studies assessing bone growth in human periodontal furcation defects by surgical reentry, after 6 or 12 months. Most reentry studies examine class II furcations because these are considered especially amenable to periodontal regeneration. As discussed previously, surgical reentry evaluated tissues that feel hard by probing and that may be bone or cartilage or dense connective tissue.

As shown in **Table 3**, surgical reentry studies demonstrated gain of hard tissue in both test and control groups with more gain of hard tissue in the test groups. Although the magnitude of gain in the test sites compared with the control sites was often statistically significant, it was often minimal in terms of real tissue and raises questions as to clinical significance. For example, Houser and colleagues²⁹ compared the treatment of mandibular class II furcations with either bovine bone xenograft and collagen membranes or open-flap débridement. Surgical reentry after 6 months showed that the test group had decreased vertical probing of 1.5 mm and decreased horizontal probing of 2.1 mm, indicative of new bone growth. This calculated to an 82.7% reduction in the furcation defect in the test group compared with a 42.5% reduction in the furcation defect in the control group. Taheri and colleagues⁴² compared anorganic bovine bone xenograft plus bioabsorbable collagen membrane (test) with anorganic bovine bone xenograft alone (control) in human mandibular class II furcations defects. Surgical reentry after 6 months showed decreased probing measurements in both the test and the control groups. The difference between the test and the control groups, however, in both horizontal and vertical measurements was less than 1 mm, suggesting that the amount of new hard tissue may not be clinically significant. Palioto and colleagues⁴³ (**Fig. 4**) treated class III furcations using a nonresorbable membrane with or without bovine inorganic bone matrix. Surgical reentry at 6 months showed significant gain in terms of reduced vertical probing depths in the test group. There were mean changes of 0.86 and 1.1 mm in horizontal and vertical open probing measurements in the test group compared with -0.03 and 0.84 mm in the control group.

Table 3
Surgical reentry evidence for new bone growth in human furcation defects

Study	Furcation Classification	Treatment	Findings
Houser et al, ²⁹ 2001	Class II	Compared anorganic bovine bone xenograft with a bioabsorbable collagen barrier to open-flap débridement in human mandibular class II furcation; surgical reentry at 6 mo	The test group showed 2.0 mm of vertical and 3.0 mm of horizontal furcation bone fill and an 82.7% defect resolution compared with 0.5 and 0.9 mm and 42.5% in test group.
Lamb et al, ⁴⁴ 2001	Class II	Compared porous and nonporous Teflon barrier membranes plus demineralized freeze-dried bone allografts in class II buccal/lingual furcation defects; surgical reentry after 9 mo	There was gain of hard tissue (open horizontal probing depth) of 2.33 ± 0.78 mm and $49 \pm 12\%$ fill in the nonporous membrane group and 2.75 ± 0.75 mm and $56 \pm 12\%$ fill in the porous membrane group.
Pruthi et al, ⁴⁵ 2002	Class II	Compared ePTFE and collagen membranes in treating class II furcations in human mandibular molars; surgical reentry at 12 mo	There was loss of vertical fill— 1.00 ± 2.03 mm in the ePTFE group and gain of 0.81 ± 1.80 mm in the collagen group—and gain of 0.41 ± 0.62 , 0.41 ± 0.71 in horizontal fill in the ePTFE and collagen groups, respectively.
Lekovic et al, ⁴⁶ 2003	Class II	Evaluated platelet-rich plasma, bovine porous bone mineral and guided tissue regeneration in class II molar furcation defects; surgical reentry at 6 mo	There was mean vertical bone level gain of 2.56 ± 0.36 mm in the test vs 0.19 ± 0.02 mm in the control and mean horizontal bone level gain of 2.28 ± 0.33 mm vs 0.08 ± 0.02 mm.
Palioto et al, ⁴³ 2003	Class III	Compared nonresorbable membrane with or without bovine inorganic bone matrix in human class III furcations; surgical reentry at 6 mo	There was a mean change of 0.86 and 1.1 mm in horizontal and vertical open probing measurements in the test group compared with -0.03 and 0.84 mm in the control group. There was significant gain over time for vertical probing depths in the test group.
Taheri et al, ⁴² 2009	Class II	Compared anorganic bovine bone xenograft plus bioabsorbable collagen membrane (test) to anorganic bovine bone xenograft alone (control) in human mandibular class II furcations defects; surgical reentry after 6 mo	Both groups showed reductions in furcation probing depths at reentry—mean vertical and horizontal reduction of 1.9 ± 1.3 mm, 2.1 ± 0.7 for test and 2.1 ± 1.0 , 2.4 ± 1.3 for control, respectively.
Jenabian et al, ⁴⁷ 2013	Class II	Compared horse bone grafts with either autogenous connective tissue (case) or resorbable membranes (control); surgical reentry procedure after 6 mo	Both groups showed reductions in furcation probing at reentry—mean vertical and horizontal reduction of 0.38 mm and 1 mm for case and 0.51 mm and 0.34 mm for control.

Abbreviation: ePTFE, expanded polytetrafluoroethylene.

Data from Refs.^{29,42–47}

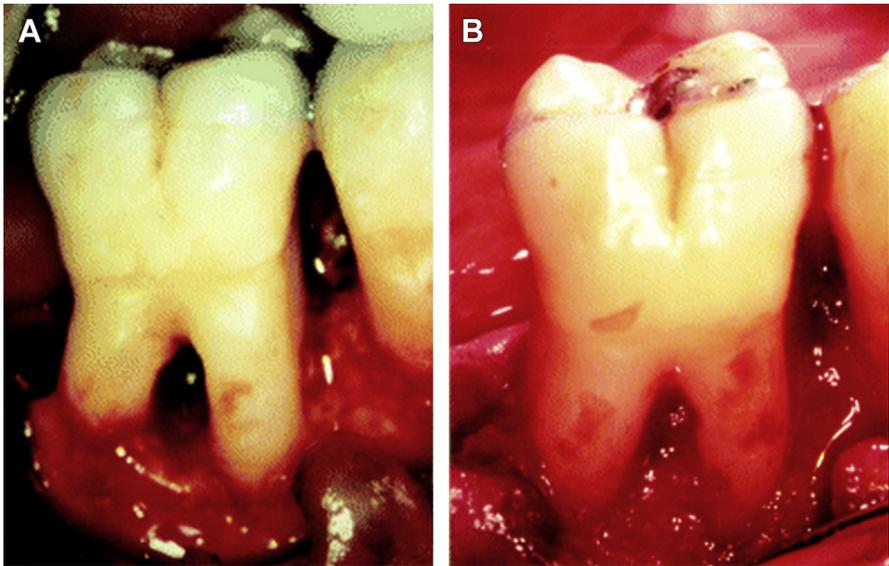


Fig. 4. Periodontal regeneration treatment of a class III mandibular molar furcation. Before (A) and after (B) treatment of a class III furcation using bovine inorganic bone matrix and nonresorbable membrane. (From Palioto DB, Joly JC, deLima AF, et al. Clinical and radiographic treatment evaluation of class III furcation defects using GTR with and without inorganic bone matrix. *J Clin Periodontol* 2003;30:1–8; with permission.)

PERIODONTAL REGENERATION

There are several recent reviews of periodontal regeneration in furcation defects. Again, periodontal regeneration is defined in histologic terms—new cementum and a functionally oriented periodontal ligament as well as new bone—but the determination of periodontal regeneration is made not by histology but by closed or open clinical measurements and sometimes radiography.

Kinaia and colleagues⁴⁸ reviewed randomized controlled human trials for the treatment of class II furcations with surgical reentry at 6 to 12 months. Guided tissue regeneration surgery with resorbable or nonresorbable membranes (13 studies) was better than open flap débridement in reducing vertical probing depth, increasing vertical attachment, and increasing vertical and horizontal bone levels (hard tissues). Horizontal bone increased by 1.85 mm and 1.54 mm whereas vertical bone increased by 1.49 mm and 0.75 mm for resorbable and nonresorbable membranes, respectively. Two studies reported guided tissue regeneration surgery using both graft materials and either resorbable or nonresorbable membranes. Horizontal bone increased by 2.58 and 2.55 mm and vertical bone increased by 2.25 and 1.15 mm for the resorbable and nonresorbable membranes with graft material, respectively.

Chen and colleagues⁴⁹ examined randomized controlled clinical trials comparing open flap débridement, guided tissue regeneration, and guided tissue regeneration with osseous grafting in the treatment of class II furcation defects. Meta-analysis of studies with at least 6 months' follow-up showed that guided tissue regeneration and guided tissue regeneration with osseous grafting were both better than open flap débridement in the treatment of mandibular molars in terms of furcation closure rate, vertical and horizontal bone fill, and vertical and horizontal attachment level

Table 4
Efficacy of periodontal regeneration in the treatment of furcation defects

Category	Conclusions
Class I defects Maxillary and mandibular molars	Most defects successfully treated with periodontal nonregenerative surgical therapy; regenerative therapy beneficial in certain cases
Class II defects Maxillary and mandibular molars	Regenerative treatment predictable; periodontal regeneration demonstrated histologically and clinically
Class III defects Mandibular molars	One case report demonstrates periodontal regeneration histologically
Class III defects Maxillary molars	Regenerative therapy not predictable; shown only in clinical case reports

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gain. Guided tissue regeneration with osseous grafting was better than guided tissue regeneration without osseous grafting. In maxillary molars, guided tissue regeneration resulted in greater vertical/horizontal bone fill and vertical attachment level gain than the open flap débridement.

In a recent systematic review, Avila-Ortiz and colleagues²⁵ examined 150 articles with clinical, radiographic, histologic, microbiologic, and patient-reported outcomes in regenerative therapy for different severities of furcation defects in different teeth. As summarized in [Table 4](#), the investigators found that most class I mandibular and maxillary molar defects can be treated using standard nonsurgical periodontal therapy. Periodontal regeneration may be useful in specific class I defects. Mandibular and maxillary molar class II defects can be successfully treated by periodontal regeneration. Mandibular and maxillary molar class III furcation defects or maxillary premolar class II and III furcation defects are not predictably treated by periodontal regeneration.

SUMMARY

There is histologic evidence of new bone growth in experimental furcation defects in animal models. There are few reports demonstrating histologic evidence of new bone growth in furcation defects in human. There are also several reports of controlled human clinical trials of hard tissue fill, possibly bone, in furcation defects as determined by surgical reentry. Together the existing data point to the clear need for more histologic analysis for both the presence and the extent of new bone growth in human furcation defects.

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