Review

Treatment of Class II Molar Furcation Involvement: Meta-Analyses of Reentry Results

Bassam Michael Kinaia,*† Jacob Steiger,†§ Anthony L. Neely,† Maanas Shah,* and Monish Bhola†

Background: Predictable regeneration of lost periodontal tissues in furcations is difficult to achieve. This paper investigates the efficacy of different treatment modalities for Class II molar furcations.

Methods: Publications in English were searched using PubMed, Medline, and Cochrane Library databases combined with hand searching from January 1, 1966 to October 1, 2007. The search included randomized controlled human trials in molar Class II furcations with over 6 months of surgical reentry follow-up. Changes in vertical probing depths, vertical attachment levels, and vertical and horizontal bone levels were compared.

Results: The search identified 801 articles of which 34 of 108 randomized clinical trials met the criteria. Thirteen trials had test and control arms allowing three meta-analyses: 1) five comparing non-resorbable versus resorbable membranes, 2) five comparing non-resorbable membranes versus open flap debridement and 3) three comparing resorbable membranes versus open flap debridement. There was significant improvement for resorbable versus non-resorbable membranes mainly in vertical bone fill (0.77 ± 0.33 mm; [95% CI; 0.13, 1.41]). Non-resorbable membranes showed significant improvement in vertical probing reduction (0.75 ± 0.31 mm; [95% CI; 0.14, 1.35]), attachment gain (1.41 ± 0.46 mm; [95% CI; 0.50, 2.31]), horizontal bone fill (1.16 ± 0.29 mm; [95% CI; 0.59, 1.73]), and vertical bone fill (0.58 ± 0.11 mm; [95% CI; 0.35, 0.80]) over open flap debridement. Resorbable membranes showed significant improvement in vertical probing reduction (0.73 ± 0.16 mm; [95% CI; 0.42, 1.05]), attachment gain (0.88 ± 0.16 mm; [95% CI; 0.55, 1.20]), horizontal bone fill (0.98 ± 0.12 mm; [95% CI; 0.74, 1.21]) and vertical bone fill (0.78 ± 0.19 mm; [95% CI; 0.42, 1.15]) over open flap debridement.

Conclusions: Guided tissue regeneration with the use of resorbable membranes was superior to non-resorbable membranes in vertical bone fill. Both types of membranes were more effective than open flap debridement in reducing vertical probing depths and gaining vertical attachment levels and in gaining vertical and horizontal bone. *J Periodontol 2011;82:413-428.*

KEY WORDS

Barrier; furcation defects; guided tissue regeneration; meta-analysis; molar; review.

* Postgraduate Periodontology Program, Boston University Institute of Dental Research and Education, Dubai, UAE.
† Department of Periodontology, Goldman School of Dental Medicine, Boston, MA.
‡ Department of Periodontology and Dental Hygiene, School of Dentistry, University of Detroit–Mercy, Detroit, MI.
§ Private practice, Farmington Hills, MI.

Molar furcation involvement is one of the most common dento-alveolar sequelae of periodontal disease. The application of a specific treatment method for furcation involvement requires a thorough understanding of tooth anatomy, etiologic factors, and the biologic basis for treatment modalities. Contributing factors to furcation involvement include systemic factors, such as diabetes and smoking,[1-4] and local factors, such as cervical enamel projections,[5,6] furcation entrance width,[7] furcation and root concavities,[8] bifurcational ridges,[6,9] accessory pulpal canals,[10-12] enamel pearls,[13] and furcation restorations.[14] These factors must be assessed thoroughly to ensure a correct diagnosis leading to effective management of furcation involvement.[15]

Historically, various treatment methods have been proposed to treat molar furcation defects. These methods ranged from conservative therapy, such as curettage and open flap debridement, to surgical treatment procedures, such as gingivectomy, root amputation, hemisection, or tunneling. Regardless of the treatment method used, most longitudinal studies have shown that molars are at higher risk for tooth loss than non-molar teeth.[16-18] The introduction of bone grafting methods[19-21] and the concept of tissue regeneration[22-24]

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offered new hope for improved and more predictable treatment of furcation involvement. The combination therapy of a membrane and bone grafting for lower first and second molars has resulted in successful closure of furcations.[25] Although these regenerative procedures are still used today, the advent of biomimetic agents, such as enamel matrix derivatives, platelet-rich plasma, platelet-derived growth factor, and bone morphogenic proteins, has given new promise for improved outcomes.[26] Of the various furcation involvements, Class II furcations have been shown to be the best candidates for regenerative treatment.[27,28]

In assessing the success of these treatment methods, complete closure of the defect is desirable. Therapeutic results can be measured by probing depth (PD) and clinical attachment level (CAL) improvements, bone regeneration, and evidence of histologic periodontal regeneration. Although histologic evaluation is most accurate, surgical closure of the furcation defect and improvements in PD and CAL serve as suitable and practical outcome measures.[29,30]

The objective of this meta-analysis is to investigate the effectiveness of various methods for the treatment of Class II furcation involvement by evaluating clinical improvement and bone regeneration based on reentry results.

MATERIALS AND METHODS

Study Selection and Interventions

To be eligible for inclusion in this literature review and meta-analysis, publications had to 1) be conducted on human molar teeth with Class II furcation involvement; 2) represent randomized controlled clinical trials (RCT) with ≥6 months of follow-up by surgical reentry; and 3) include pretreatment and post-treatment vertical PD (VPD), vertical CAL (VCAL), horizontal bone level (HBL), and vertical bone level (VBL) measurements, or changes in these parameters.

The exclusion criteria included studies that 1) were not RCTs, 2) were conducted on non-humans, 3) were published in languages other than English, 4) involved molar furcation involvements other than Class II, 5) conducted follow up of <6 months, 6) lacked standard deviations or standard error of the mean values, and 7) evaluated results by means other than surgical reentry.

Data Sources and Search

The search included online publications with related data from The National Center for Biotechnology Information PubMed, Medline, and The Cochrane Collaboration Library databases. Publication dates were from January 1, 1966 to October 1, 2007, and were limited to those published in English.

The online search included clinical trials and meta-analyses that seemed to be relevant to the topic. In addition to the online search, a hand search was conducted for related articles and bibliographies of meta-analyses found online and related systematic reviews in the *Annals of Periodontology* (2003) under the topic "Tissue Engineering, Natural teeth." During the search, when a publication was missing relevant data that could be included in the current proposed meta-analyses, the corresponding author of that publication was contacted by e-mail to seek complete ascertainment of the data.

All data were assessed independently by two of the authors (BMK and JS) and disagreements were resolved by discussion. If resolution was not possible, a third author (ALN) was consulted. Online search terminology included "treatment(s) of furcation(s)," "treatment of mandibular molar furcations," "treatment of mandibular furcations," "treatment of maxillary furcations," "treatment of maxillary molar furcations," "treatment of molar furcation," "treatment of molar furcations," "enamel matrix derivatives and molar furcation," "growth factor(s) and molar furcation," "guided tissue regeneration and molar furcation," "regenerative treatment of molar furcation," "bone morphogenic proteins and molar furcation," "platelet-derived growth factor and molar furcation," or "platelet-rich plasma and molar furcation."

Statistical Analyses

The changes of pretreatment and post-treatment VPD, VCAL, HBL, and VBL measurements were the basis for data analysis. The means and standard deviations (or standard error of the mean values) were used and expressed as weighted mean differences and 95% confidence intervals (CI). The figures and tables show CIs for differences between treatments for each of the studies and then the overall combined results of the meta-analysis. The meta-analysis CIs were estimated by using a random effects method, with the use of a statistical software program.‖ The vertical line on the plots represents zero difference between treatments. If the treatments were significantly different at a 5% significance level, then the 95% CI would not include the zero line.

RESULTS

The initial online search identified 801 possible articles for review. Of the 801 publications, 108 were RCTs and seven were meta-analyses, totaling 115 publications. An additional hand search of the *Annals of Periodontology* (2003) and bibliographies of pertinent meta-analyses was performed to seek additional RCTs. A cross-reference hand search was conducted (by BMK and JS) to find relevant articles that were

‖ Number Crunchers Statistical Software Program, NCSS, Kaysville, UT.

not identified by the online search. Title or abstract reviews were completed for these publications, yielding a total of 40 studies from the online search and 14 from the hand search (total of 54 papers). Of the 54 papers, a full-text review concluded that only 34 articles met the specified inclusion criteria for the meta-analyses.[31-64]

A further analysis of these 34 RCT was conducted to identify specific publications that would allow for meta-analyses. Of the 34 publications that satisfied the initial inclusion criteria, 13 exhibited a test and control arm (positive and negative controls), so a meta-analysis could be performed. Of the 13 publications, meta-analysis was conducted for five of them comparing non-resorbable to resorbable membranes, five of them comparing non-resorbable membranes to open flap debridement, and three of them comparing resorbable membranes to open flap debridement (Fig. 1). Results of the three meta-analyses are displayed in Table 1.

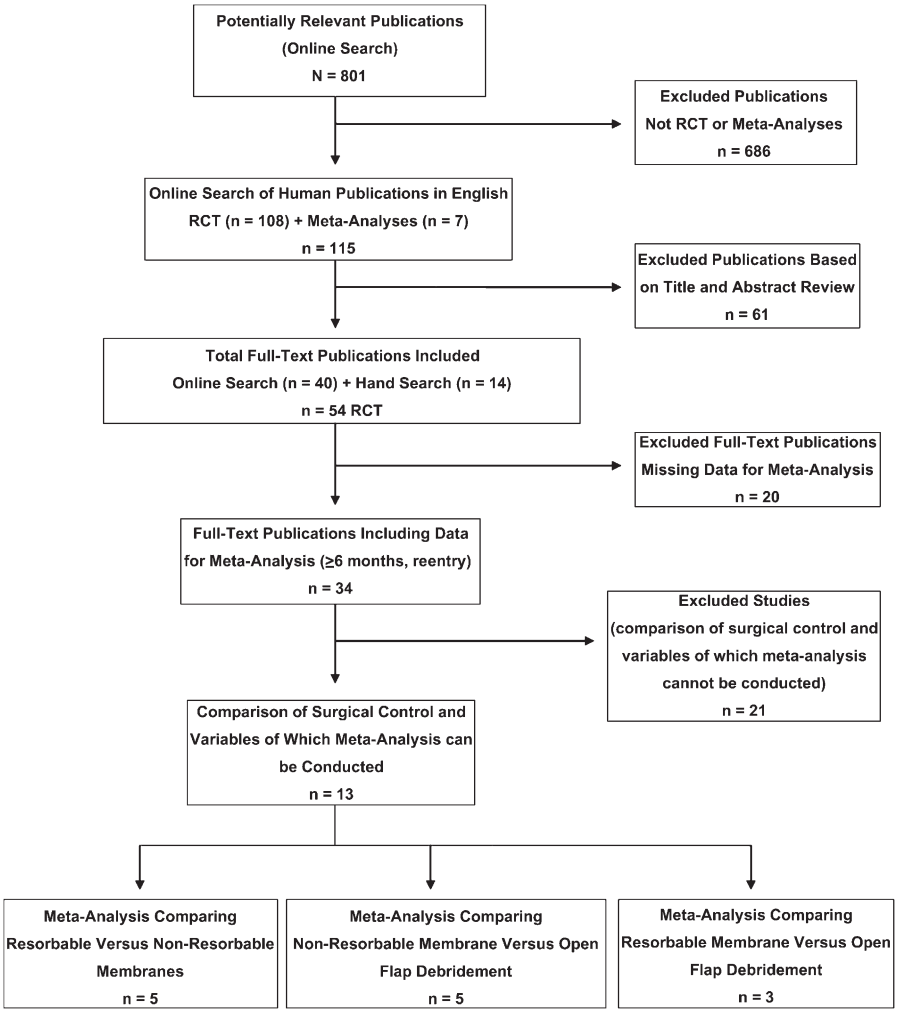

Figure 1.
Flowchart for the identification of publications that matched the initial inclusion criteria and were suitable to conduct the meta-analysis.

Meta-Analysis of Non-Resorbable Versus Resorbable Membranes

Change in VPD. The results demonstrated a non-significant difference in VPD with the use of resorbable and non-resorbable membranes (Fig. 2A).[34,45,57,58] The mean combined difference was 0.25 ± 0.18 mm (95% CI, –0.11 to 0.60). All analyses are expressed as a mean ± standard error of the mean.

Change in VCAL. The results demonstrated a non-significant gain in VCAL with the use of resorbable and non-resorbable membranes (Fig. 2B).[34,43,57,58] The mean combined difference was 0.39 ± 0.26 mm (95% CI, –0.12 to 0.90).

Change in HBL. The results demonstrated a non-significant change in HBL with the use of resorbable membranes and non-resorbable membranes (Fig. 2C).[34,43,45,57,58] The mean combined difference was 0.29 ± 0.21 mm (95% CI, –0.11 to 0.70).

Change in VBL. The results demonstrated a significant difference in the change in VBL with the use of resorbable and non-resorbable membranes (Fig. 2D).[34,43,57,58] The mean combined difference was 0.77 ± 0.33 mm (95% CI, 0.13 to 1.41).

Meta-Analysis of Non-Resorbable Membranes Versus Open Flap Debridement

Change in VPD. Five studies compared non-resorbable membranes to open flap debridement.[31,51,53,60,63] It should be noted that three of these studies evaluated interproximal areas of maxillary furcation defects and showed favorable outcomes.[51,60,63] The results demonstrated significantly greater reduction in VPD with the use of non-resorbable membranes compared to open flap debridement (Fig. 3A). The mean combined difference was 0.75 ± 0.31 mm (95% CI, 0.14 to 1.35).

Change in VCAL. The results demonstrated a significant gain in VCAL with the use of non-resorbable membranes compared to open flap debridement (Fig. 3B). The mean combined difference was 1.41 ± 0.46 mm (95% CI, 0.50 to 2.31).

Table 1.

Characteristics of the 13 Randomized Controlled Trials Included in Meta-Analysis

Reference	Treatment Modality	Randomization Method	Sample Size	Defect Location	Parameters	Evaluation Period
Blumenthal[58] 1993	Resorbable membrane, non-resorbable membrane (periodontal dressing; amoxicillin, 500 mg tid for 7 days; membrane removed at 4 to 6 weeks)	Randomized controlled trial, split mouth for defects (coin toss)	12 patients; 24 furcations (12 R, 12 NR); age range: 31 to 80 years (seven males, five females)	Mandibular, buccal	VPD, VCAL, horizontal bone fill, vertical bone fill	Surgical reentry at 12 months
Dos Anjos et al.[57] 1998	Resorbable membrane, non-resorbable membrane (penicillin V, 312 mg tid for 10 days, followed by doxycycline, 100 mg daily for 20 days; membrane removed at 4 weeks)	Randomized controlled trial, randomization for defects not indicated	15 patients, 30 furcations; age range: 35 to 55 years (11 males, four females)	Mandibular, buccal, and lingual?	VPD, VCAL, horizontal bone fill, vertical bone fill	Surgical reentry at 6 months
Pruthi et al.[34] 2002	Resorbable membrane, non-resorbable membrane (doxycycline, 100 mg daily 14 days; membrane removed at 4 to 6 weeks; coronal flap)	Randomized controlled trial, randomization for defects (method not indicated)	17 patients; 34 furcations (17 R, 17 NR); age range: 35 to 75 years (nine males, eight females)	Mandibular, buccal, and lingual?	VPD, VCAL, horizontal bone fill, vertical bone fill	Surgical reentry at 12 months
Scott et al.[43] 1997	Resorbable membrane, non-resorbable membrane (doxycycline, 100 mg daily 14 days)	Randomized controlled trial, coin toss for defects	12 patients; 24 furcations (12 R, 12 NR); age range: 31 to 61 years (10 males, two females)	Mandibular, buccal	VPD, VCAL, horizontal bone fill, vertical bone fill	Surgical reentry at 6 months
Yukna and Yukna[45] 1996	Resorbable membrane, non-resorbable membrane	Randomized controlled trial, split mouth for defects	32 patients; 64 furcations (32 R, 32 NR); age range: 19 to 72 years (mean 46.8); 14 males, 18 females	Class II furcation defect location unclear	VPD, VCAL, horizontal bone fill, vertical bone fill	Surgical reentry at 6 to 12 months (mean 11.1 months)
Avera et al.[60] 1998	Non-resorbable membrane, OFD (doxycycline, 100 mg bid for 3 weeks; membrane removed at 6 weeks)	Randomized controlled trial, split mouth for defects	Eight patients; 16 furcations (eight NR, eight OFD); mean age: 42 ± 6.5 years (three males, five females)	Maxillary first molar, mesial	VPD, VCAL, horizontal bone fill, vertical bone fill	Surgical reentry at 9 months
Flanary et al.[51] 1991	Non-resorbable membrane, OFD (periodontal dressing; doxycycline, 100 mg bid 3 weeks; membrane removed at 5 to 6 weeks)	Randomized controlled trial, split mouth for defects (coin toss)	19 patients; 38 furcations (19 NR, 19 OFD); age range: 27 to 74 years (12 males, seven females)	15 mandibular + four maxillary; mesial, distal, buccal, and lingual?	VPD, VCAL, horizontal bone fill, vertical bone fill	Surgical reentry at 6 months

Table 1. (continued)

Characteristics of the 13 Randomized Controlled Trials Included in Meta-Analysis

Reference	Treatment Modality	Randomization Method	Sample Size	Defect Location	Parameters	Evaluation Period
Lekovic et al.[53] 1989	Non-resorbable membrane, OFD (periodontal dressing; Pen Vk, 250 mg qid 1 week; membrane removed at 2 months)	Randomized controlled trial, randomization for defects not indicated	12 patients; 24 furcations (12 NR, 12 OFD); age range: 29 to 47 years, mean age 37.2 years (eight males, four females)	Mandibular, buccal, and lingual?	VPD, VCAL, horizontal bone fill, vertical bone fill	Surgical reentry at 6 months
Metzler et al.[63] 1991	Non-resorbable membrane, OFD (periodontal dressing; doxycycline, 100 mg bid for 21 days; membrane removed at 4 to 6 weeks)	Randomized controlled trial, split mouth for defects	17 patients; 34 furcations (17 NR, 17 OFD); age range: 29 to 64 years (13 males, four females)	Maxillary, 12 buccal, 5 mesial/distal	VPD, VCAL, horizontal bone fill, vertical bone fill	Surgical reentry at 12 months
Prathibha et al.[31] 2002	Non-resorbable membrane, OFD (no periodontal dressing; amoxicillin, 250 mg qid 1 week; membrane removed at 6 weeks)	Randomized controlled trial, randomization for defects not indicated	10 patients; 20 furcations (10 NR, 10 OFD); age range: 20 to 50 years	Mandibular, buccal	VPD, VCAL, horizontal bone fill, vertical bone fill	Surgical reentry at 6 months
Paul et al.[64] 1992	Resorbable membrane, OFD	Randomized controlled trial, split mouth for defects	Seven patients, 28 furcations (14 R, 14 OFD); age range: 42 to 65 years, mean age 51.7 years (six males, one female)	Mandibular, buccal, and lingual?	VPD, VCAL, horizontal bone fill, vertical bone fill	Surgical reentry at 6 months
Wang et al.[46] 1994	Resorbable membrane, OFD	Randomized controlled trial, coin toss for defects	12 patients; 24 furcations (12 R, 12 OFD); age range: 32 to 68 years (six males, six females)	Mandibular, buccal, and lingual?	VPD, VCAL, horizontal bone fill, vertical bone fill	Surgical reentry at 12 months
Yukna and Yukna[45] 1996	Resorbable membrane, OFD	Randomized controlled trial, split mouth for defects	27 patients; 54 furcations (27 R, 27 OFD); age range: 19 to 72 years (mean 46.8); 15 males and 12 females	Class II furcation defect location unclear	VPD, VCAL, horizontal bone fill, vertical bone fill	Surgical reentry at 6 to 12 months (mean: 11.1 months)

R = resorbable membrane; NR = non-resorbable membrane; OFD = open flap debridement; ? = study did not clarify whether furcation defect was buccal or lingual.

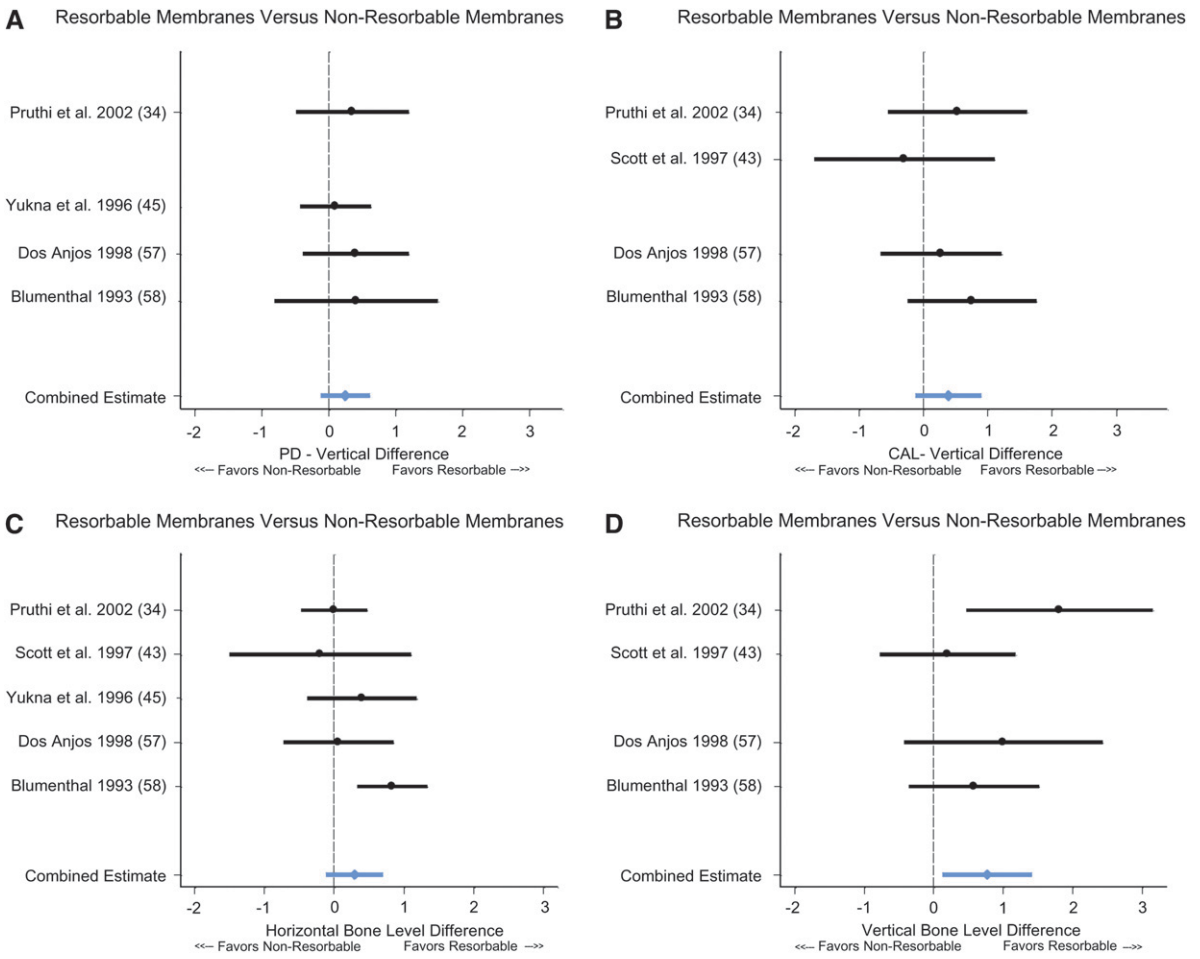

Figure 2.
Forest plot for randomized controlled trials based on surgical reentry for Class II molar furcations. Mean combined difference (in millimeters at 95% confidence interval) between resorbable and non-resorbable membranes. ***A)*** *Change in vertical probing depth.* ***B)*** *Change in vertical attachment level.* ***C)*** *Change in horizontal bone level.* ***D)*** *Change in vertical bone level.*

Change in HBL. The results demonstrated significantly greater HBL increase with the use of non-resorbable membranes compared to open flap debridement (Fig. 3C). The mean combined difference was 1.16 ± 0.29 mm (95% CI, 0.59 to 1.73).

Change in VBL. The results demonstrated significantly greater VBL increase with the use of non-resorbable membranes compared to open flap debridement (Fig. 3D). The mean combined difference was 0.58 ± 0.11 mm (95% CI, 0.35 to 0.80).

Meta-Analysis of Resorbable Membranes Versus Open Flap Debridement

Change in VPD. The results demonstrated significantly greater reduction in VPD with the use of resorbable membranes compared to open flap debridement (Fig. 4A).[45,46,64] The mean combined difference was 0.73 ± 0.16 mm (95% CI, 0.42 to 1.05).

Change in VCAL. The results demonstrated significantly greater gain in VCAL with the use of resorbable membranes compared to open flap debridement (Fig. 4B). The mean combined difference was 0.88 ± 0.16 mm (95% CI, 0.55 to 1.20).

Change in HBL. The results demonstrated significantly greater increase in HBL with the use of resorbable membranes compared to open flap debridement (Fig. 4C). The mean combined difference was 0.98 ± 0.12 mm (95% CI, 0.74 to 1.21).

Change in VBL. The results demonstrated significantly greater increase in VBL with the use of resorbable membranes compared to open flap debridement (Fig. 4D). The mean combined difference was 0.78 ± 0.19 mm (95% CI, 0.42 to 1.15).

Combined Estimate Measurements

Aside from the meta-analyses mentioned previously, no additional meta-analyses were conducted for the remaining publications because of great heterogeneity in the study designs. Instead, the results of each treatment modality were estimated independently to

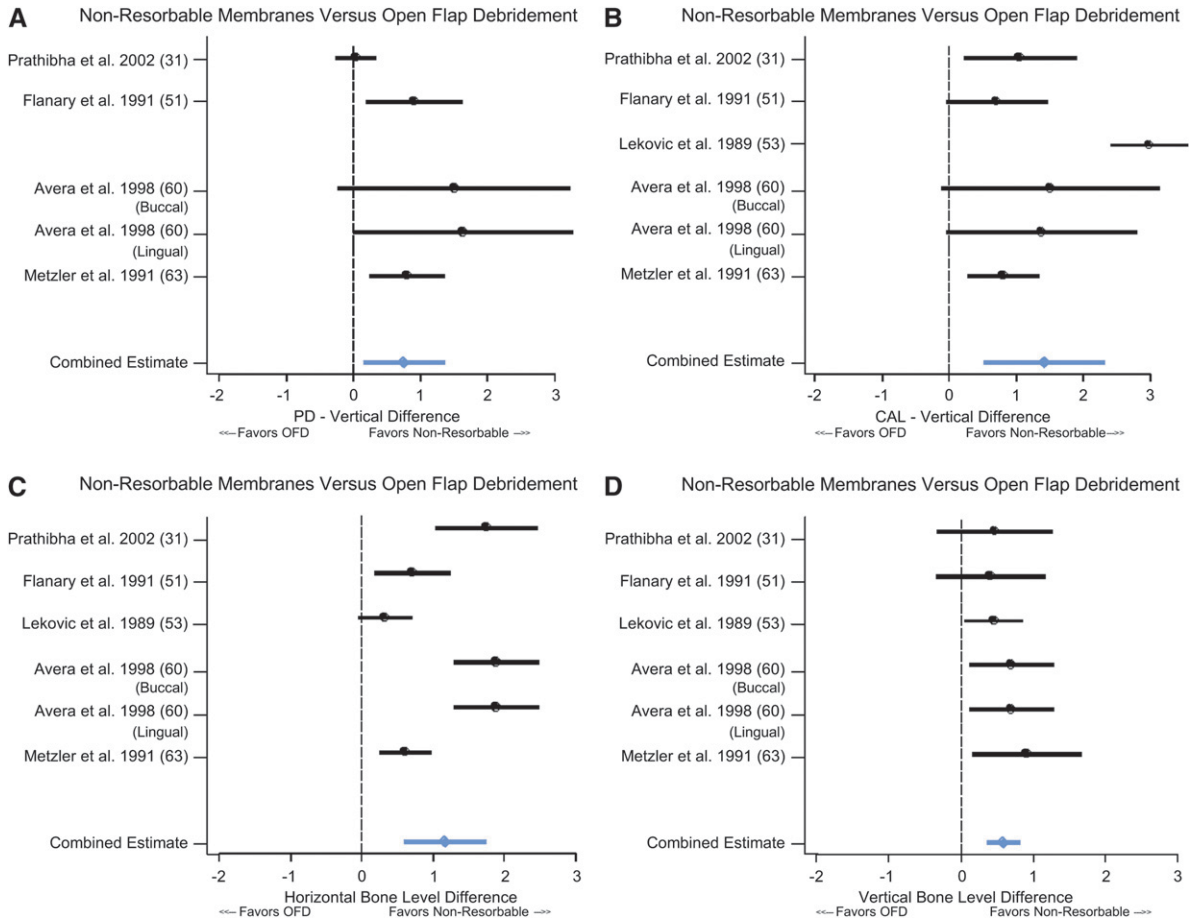

Figure 3.
Forest plot for randomized controlled trials based on surgical reentry for Class II molar furcations. Mean combined difference (in millimeters at 95% confidence interval) between non-resorbable membranes and open flap debridement. ***A)*** *Change in vertical probing depth.* ***B)*** *Change in vertical attachment level.* ***C)*** *Change in horizontal bone level.* ***D)*** *Change in vertical bone level.*

determine a combined estimate that compared one treatment to the other treatment modalities individually. Studies included in the combined estimate measurements are displayed in Table 2.

Combined estimate for non-resorbable membranes. The mean combined estimate that compared the non-resorbable group to other surgical procedures showed significant improvements in outcomes for all four parameters (VPD, VCAL, HBL, and VBL; open flap debridement,[31,51,53,60,63] resorbable membranes,[34,43,45,57,58] antibiotics with non-resorbable membrane,[39] alloplast,[41] xenograft with non-resorbable membrane,[42] connective tissue graft,[49] or alloplast with non-resorbable membrane[61]). The mean combined estimate showed a reduction in VPD of 1.77 ± 0.26 mm (95% CI, 1.26 to 2.27); gain in CAL of 1.35 ± 0.18 mm (95% CI, 1.00 to 1.69); HBL increase of 1.54 ± 0.27 mm (95% CI, 1.02 to 2.06); and VBL increase of 0.75 ± 0.16 mm (95% CI, 0.45 to 1.06).

Combined estimate for resorbable membranes. The mean combined estimate that compared the resorbable group against all other surgical procedures identified statistically significant improvements in outcomes for all four parameters (open flap debridement,[45,46,63] non-resorbable membranes,[34,43,45,57,58] or allograft with resorbable membrane[36]). The mean combined estimate showed a significant reduction in VPD of 2.07 ± 0.29 mm (95% CI, 1.50 to 2.64) and significant gain in CAL of 1.39 ± 0.18 mm (95% CI, 1.03 to 1.75). Significant increases in HBL of 1.85 ± 0.32 mm (95% CI, 1.22 to 2.49) and VBL of 1.49 ± 0.30 mm (95% CI, 0.91 to 2.08) were noted.

Combined estimate for open flap debridement. The mean combined estimate that compared the open flap debridement group to all other surgical procedures indicated less improvement in outcomes for all four parameters (resorbable membranes,[45,46,64] non-resorbable membranes,[31,51,53,60,63] allograft with resorbable membrane,[37] or xenograft with resorbable membrane ± platelet-rich plasma,[32,35] alloplast ± antibiotic,[52,56] or connective tissue graft[50]). The mean combined estimate showed a reduction in VPD of

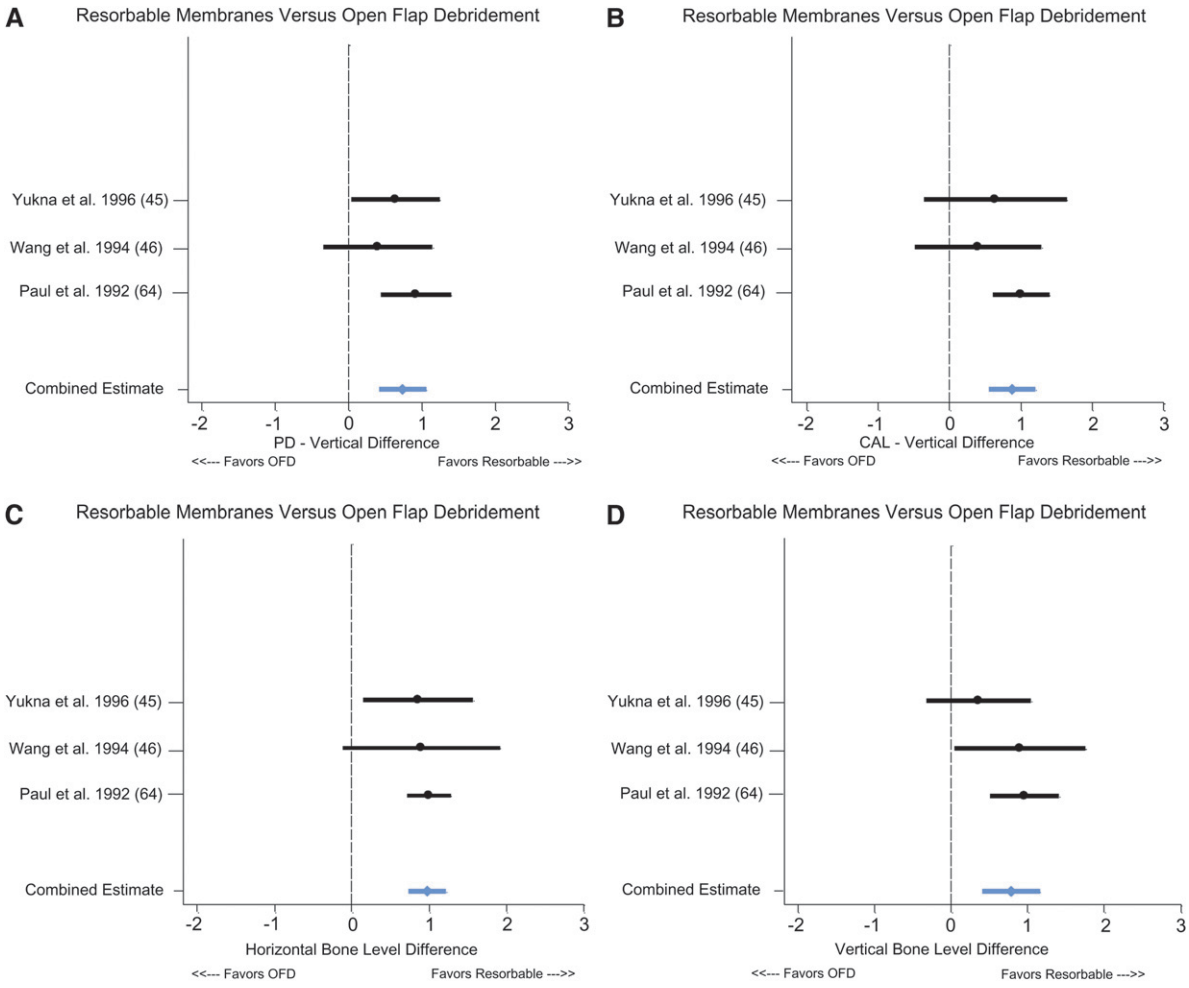

Figure 4.
Forest plot for randomized controlled trials based on surgical reentry for Class II molar furcations. Mean combined difference (in millimeters at 95% confidence interval) between resorbable membranes and open flap debridement. ***A)*** *Change in vertical probing depth.* ***B)*** *Change in vertical attachment level.* ***C)*** *Change in horizontal bone level.* ***D)*** *Change in vertical bone level.*

1.08 ± 0.29 mm (95% CI, 0.51 to 1.66); gain in CAL of 0.45 ± 0.14 mm (95% CI, 0.18 to 0.71); and bone fills of 0.27 ± 0.16 mm (95% CI, –0.04 to 0.58) and 0.13 ± 0.15 mm (95% CI, –0.17 to 0.43) for HBL and VBL, respectively.

Combined estimate for non-resorbable membranes with allograft. The mean combined estimate comparing the non-resorbable with allograft group and all other surgical procedures showed statistically significant improvements in outcomes for all four parameters (resorbable membranes with allograft[40] and non-porous non-resorbable membrane with allograft[65]). The mean combined estimate showed a reduction in VPD of 1.57 ± 0.60 mm (95% CI, 0.40 to 2.73); gain in CAL of 1.38 ± 0.62 mm (95% CI, 0.17 to 2.59); and bone fill of 2.55 ± 0.15 mm (95% CI, 2.26 to 2.84) and 1.15 ± 0.66 mm (95% CI, –0.15 to 2.45) for HBL and VBL, respectively.

Combined estimate for resorbable membranes with allograft/xenograft. The mean combined estimate that compared the resorbable with allograft and all other surgical procedures showed statistical improvements in outcomes of all four parameters (open flap debridement,[37] allograft against resorbable membranes with allograft ± antibiotic[40,44]). The mean combined estimate showed a reduction in VPD of 0.81 ± 0.51 mm (95% CI, –0.20 to 1.81). There was a gain in CAL of 0.76 ± 0.18 mm (95% CI, 0.4 to 1.12). Bone fill of 1.89 ± 0.41 mm (95% CI, 1.09 to 2.69) and 0.79 ± 0.33 mm (95% CI, 0.14 to 1.43) was noted for HBL and VBL, respectively. The addition of xenograft with a resorbable membrane ± platelet-rich plasma[32,35] showed statistically significant improvements. The mean combined estimate showed a reduction in VPD of 3.05 ± 1.03 mm (95% CI, 1.02 to 5.08). There was a gain in CAL of 2.55 ± 0.74 mm

Table 2.

Characteristics of the Studies Used for Combined Estimate Measurements

Reference	Combined Estimates and Interventions		Treatment Modality	Sample Size and Randomization	Defect Location	Parameters	Evaluation Period
Avera et al.[60] 1998	Data used for combined estimates of non-resorbable membranes	Data used for combined estimates of OFD	Non-resorbable membrane, OFD (doxycycline, 100 mg bid for 3 weeks; membrane removed at 6 weeks)	Eight patients, 16 furcations (eight NR, eight OFD); mean age: 42 ± 6.5 years (three males, five females); randomization: for sites/split mouth design	Maxillary, 16 mesial	VPD, VCAL, horizontal bone fill, vertical bone fill	Surgical reentry at 9 months
Blumenthal[58] 1993	Data used for combined estimates of non-resorbable membranes	Data used for combined estimates of resorbable membranes	Non-resorbable membrane, resorbable membrane (periodontal dressing; amoxicillin, 500 mg tid for 7 days; membrane removed at 4 to 6 weeks)	12 patients, 24 furcations (12 NR, 12 R); age range: 31 to 80 years (seven males, five females); randomization for defects with coin toss	Mandibular, 24 buccal	VPD, VCAL, horizontal bone fill, vertical bone fill	Surgical reentry at 12 months
Bouchard et al.[49] 1993	Data used for combined estimates of non-resorbable membranes		Non-resorbable membrane, connective tissue graft	12 patients, 24 furcations (12 NR, 12 CTG); age range: 34 to 56 years (seven males, five females); randomization for defects (contralateral)	Mandibular, 24 buccal	VPD, VCAL, horizontal bone fill, vertical bone fill	Surgical reentry at 12 months
Dos Anjos et al.[57] 1998	Data used for combined estimates of non-resorbable membranes	Data used for combined estimates of resorbable membranes	Non-resorbable membrane, resorbable membrane (penicillin V, 312 mg tid for 10 days, followed by doxycycline, 100 mg daily for 20 days; membrane removed at 4 weeks)	15 patients, 30 furcations; age range: 35 to 55 years (11 males, four females); randomization for defects	Mandibular, buccal, and lingual?	VPD, VCAL, horizontal bone fill, vertical bone fill	Surgical reentry at 6 months
Flanary et al.[51] 1991	Data used for combined estimates of non-resorbable membranes	Data used for combined estimates of open flap debridement	Non-resorbable membrane, open flap debridement (periodontal dressing; doxycycline, 100 mg bid 3 weeks; membrane removed at 5 to 6 weeks)	19 patients, 38 furcations (19 NR, 19 OFD); age range: 27 to 74 years (12 males, seven females); randomization for defects with coin toss	30 mandibular, buccal; eight maxillary, buccal	VPD, VCAL, horizontal bone fill, vertical bone fill	Surgical reentry at 6 months
Lekovic et al.[53] 1989	Data used for combined estimates of non-resorbable membranes	Data used for combined estimates of open flap debridement	Non-resorbable membrane, open flap debridement (periodontal dressing; penicillin VK, 250 mg qid 1 week; membrane removed at 2 months)	12 patients, 24 furcations (12 NR, 12 OFD), age range: 29 to 47 years (eight males, four females); randomization for defects with dice roll	Mandibular, buccal, and lingual?	VPD, VCAL, horizontal bone fill, vertical bone fill	Surgical reentry at 6 months

Table 2. (continued)

Characteristics of the Studies Used for Combined Estimate Measurements

Reference	Combined Estimates and Interventions		Treatment Modality	Sample Size and Randomization	Defect Location	Parameters	Evaluation Period
Lekovic et al.[61] 1990	Data used for combined estimates of non-resorbable membranes	Data used for combined estimates of OFD	Non-resorbable membrane, non-resorbable membrane + alloplast-graft (periodontal dressing; penicillin, 250 mg qid for 7 days; membrane removed at 2 months)	15 patients, 30 furcations (15 NR, 15 NRAp); mean age: 39.4 years (seven males, eight females); randomization: for sites/split mouth design	Mandibular, 30 buccal	VPD, VCAL, horizontal bone fill, vertical bone fill	Surgical reentry at 6 months
Machtei et al.[39] 2003	Data used for combined estimates of non-resorbable membranes		Non-resorbable membrane, non-resorbable membrane + antibiotic (doxycycline, 100 mg daily 7 days; membrane removed at 6 to 8 weeks)	38 patients, 38 furcations; randomization by patients/ double masked	Mandibular, buccal and lingual?	VPD, VCAL, horizontal bone fill, vertical bone fill	Surgical reentry at 12 months
Metzler et al.[63] 1991	Data used for combined estimates of non-resorbable membranes	Data used for combined estimates of OFD	Non-resorbable membrane, OFD (periodontal dressing; doxycycline, 100 mg bid for 21 days; membrane removed at 4 to 6 weeks)	17 patients, 34 furcations (17 NR, 17 OFD); age range: 29 to 64 years (13 males, four females); randomization for defects/split mouth design	Maxillary, 12 buccal, five mesial and distal	VPD, VCAL, horizontal bone fill, vertical bone fill	Surgical reentry at 12 months
Prathibha et al.[31] 2002	Data used for combined estimates of non-resorbable membranes	Data used for combined estimates of OFD	Non-resorbable membrane, OFD (no periodontal dressing; amoxicillin, 250 mg qid 1 week; membrane removed at 6 weeks)	10 patients, 20 furcations (10 NR, 10 OFD); age range: 20 to 50 years; randomization for defects	Mandibular, 20 buccal	VPD, VCAL, horizontal bone fill, vertical bone fill	Surgical reentry at 6 months
Pruthi et al.[34] 2002	Data used for combined estimates of non-resorbable membranes	Data used for combined estimates of resorbable membranes	Non-resorbable membrane, resorbable membrane (doxycycline, 100 mg daily 14 days; membrane removed at 4 to 6 weeks; coronal flap)	17 patients, 34 furcations (17 NR, 17 R); age range: 35 to 75 years (nine males, eight females); randomization for defects	Mandibular, 27 buccal and seven lingual	VPD, VCAL, horizontal bone fill, vertical bone fill	Surgical reentry at 12 months
Scott et al.[43] 1997	Data used for combined estimates of non-resorbable membranes	Data used for combined estimates of resorbable membranes	Non-resorbable membrane, resorbable membrane (doxycycline, 100 mg daily 14 days; membrane removed at 6 weeks)	12 patients, 24 furcations (12 NR, 12 R); age range: 31 to 61 years (10 males, two females); randomization for defects with coin toss	Mandibular, 24 buccal	VPD, VCAL, horizontal bone fill, vertical bone fill	Surgical reentry at 6 months
Simonpietri-C. et al.[42] 2000	Data used for combined estimates of non-resorbable membranes		Non-resorbable membrane, non-resorbable membrane + xenograft	14 patients, 30 furcations (15 NR, 15 NRX); age range: 33 to 62 years (five males, nine females); randomization for defects	Mandibular, buccal and lingual?	VPD, VCAL, horizontal bone fill, vertical bone fill	Surgical reentry at 6 months

Table 2. (continued)

Characteristics of the Studies Used for Combined Estimate Measurements

Reference	Combined Estimates and Interventions		Treatment Modality	Sample Size and Randomization	Defect Location	Parameters	Evaluation Period
Yukna and Yukna[45] 1996	Data used for combined estimates of non-resorbable membranes	Data used for combined estimates of resorbable membranes	Non-resorbable membrane, resorbable membrane	32 patients, 64 furcations (32 NR, 32 R); age range: 19 to 72 years (mean: 46.8), almost equal number of males and females; randomization for defects	Class II furcation defect; location unclear	VPD, VCAL, horizontal bone fill, vertical bone fill	Surgical reentry at 6 to 12 months (mean: 11.1 months)
Yukna et al.[41] 2001	Data used for combined estimates of non-resorbable membranes		Non-resorbable membrane, alloplast-graft	27 patients, 54 furcations (27 NR, 27 AP); age: ≥25 years; randomization for defects with dice roll	Mandibular, 54 buccal	VPD, VCAL, horizontal bone fill, vertical bone fill	Surgical reentry at 6 months
Luepke et al.[36] 1997	Data used for combined estimates of resorbable membranes		Resorbable membrane, resorbable membrane + allograft	14 patients, 30 furcations; age range: 36 to 74 years (eight males, six females); randomization for defects with coin toss	Mandibular, 23 buccal and seven lingual	VPD, VCAL, horizontal bone fill, vertical bone fill	Surgical reentry at 6 months
Paul et al.[64] 1992	Data used for combined estimates of resorbable membranes	Data used for combined estimates of OFD	Resorbable membrane, OFD	Seven patients, 28 furcations (14 R, 14 OFD); age range: 42 to 65 years (six males, one female); randomization for defects/split mouth design	Mandibular, buccal and lingual?	VPD, VCAL, horizontal bone fill, vertical bone fill	Surgical reentry at 6 months
Wang et al.[46] 1994	Data used for combined estimates of resorbable membranes	Data used for combined estimates of OFD	Resorbable membrane, OFD	12 patients, 24 furcations (12 R, 12 OFD); age range: 32 to 68 years (six males, six females); randomization for defects with coin toss	Mandibular, buccal and lingual	VPD, VCAL, horizontal bone fill, vertical bone fill	Surgical reentry at 12 months
Yukna and Yukna[45] 1996	Data used for combined estimates of resorbable membranes	Data used for combined estimates of OFD	Resorbable membrane, OFD	32 patients, 64 furcations (32 R, 32 NR); age range: 19 to 72 years (mean: 46.8), almost equal number of males and females; randomization for defects	Class II furcation defect location unclear	VPD, VCAL, horizontal bone fill, vertical bone fill	Surgical reentry at 6 to 12 months (mean: 11.1 months)
Houser et al.[32] 2001	Data used for combined estimates of OFD	Data used for combined estimates of resorbable membrane + allograft/xenograft	OFD, resorbable membrane + xenograft (100 mg doxycycline daily 10 days)	21 patients, 31 furcations (13 OFD, 18 RX); mean age: 46 years (13 males, eight females); randomization for defects/split mouth design (coin toss)	Mandibular, buccal and lingual?	VPD, VCAL, horizontal bone fill, vertical bone fill	Surgical reentry at 6 months
Kenney et al.[56] 1988	Data used for combined estimates of OFD		OFD, alloplast-graft	23 patients, 46 furcations (23 OFD, 23 AP); age range: 29 to 47 years (eight males, four females); randomization for defects	Mandibular, buccal and lingual?	VPD, VCAL, horizontal bone fill, vertical bone fill	Surgical reentry at 6 months
Lekovic et al.[35] 2003	Data used for combined estimates of OFD	Data used for combined estimates of resorbable membrane + allograft/xenograft	OFD, resorbable membrane + xenograft + platelet-rich plasma (periodontal dressing)	26 patients, 52 furcations (26 OFD, 26 RXP); mean age: 38 ± 11 years (12 males, 14 females); randomization for defects/split mouth design (coin toss)	Mandibular, 52 buccal	VPD, VCAL, horizontal bone fill, vertical bone fill	Surgical reentry at 6 months

Table 2. (continued)

Characteristics of the Studies Used for Combined Estimate Measurements

Reference	Combined Estimates and Interventions		Treatment Modality	Sample Size and Randomization	Defect Location	Parameters	Evaluation Period
Pepelassi et al.[52] 1991	Data used for combined estimates of OFD		OFD, APA (100 mg doxycycline dissolved in 25 ml sterile water and mixed with graft)	15 patients, 26 furcations (13 OFD, 13 APA); age range: 32 to 64 years (seven males, eight females); randomization for defects/split mouth design	Mandibular, buccal and lingual?	VPD, VCAL, horizontal bone fill, vertical bone fill	Surgical reentry at 6 months
Tsao et al.[37] 2006	Data used for combined estimates of OFD	Data used for combined estimates of resorbable membrane + allograft/xenograft	OFD, resorbable membrane + allograft	27 patients, 27 furcations (Nine OFD, nine RA, nine A); mean age: 54.4 ± 9.8 (15 males, 12 females); randomization for patients (drew paper from bags)	Mandibular, buccal and lingual	VPD, VCAL, horizontal bone fill, vertical bone fill	Surgical reentry at 6 months
Couri et al.[40] 2002	Data used for combined estimates of non-resorbable membrane + allograft	Data used for combined estimates of resorbable membrane + allograft/xenograft	Non-resorbable membrane + allograft, resorbable membrane + allograft	13 patients, 26 furcations (13 NRAI, 13 RAI); age range: 36 to 73 years (four males, nine females); randomization for defects/split mouth design (coin toss)	Mandibular, buccal and lingual?	VPD, VCAL, horizontal bone fill, vertical bone fill	Surgical reentry + clinical evaluation at 12 months
Lamb III et al.[65] 2001	Data used for combined estimates of non-resorbable membrane + allograft		Non-resorbable membrane + allograft (polytetrafluoroethylene)	24 patients, 24 furcations; age range: 38 to 75 years (13 males, 11 female); randomization for defects with coin toss	Two maxillary; mandibular, 19 buccal, three lingual	VPD, VCAL, horizontal bone fill, vertical bone fill	Surgical reentry at 9 months
Vest et al.[44] 1999	Data used for combined estimates of resorbable membrane + allograft		Resorbable membrane + allograft, resorbable membrane + allograft + antibiotic (metronidazole, 250 mg tid + ciprofloxacin, 250 mg bid for 7 days, followed by doxycycline, 50 mg for 7 days)	24 patients, 24 furcations (12 RAI, 12 NRAIa); randomization for patients with coin toss	Mandibular, buccal, and lingual; maxillary, buccal	VPD, VCAL, horizontal bone fill, vertical bone fill	Surgical reentry at 9 months

R = resorbable membrane; NR = non-resorbable membrane; OFD = open flap debridement; RAI = resorbable membrane + allograft; NRX = non-resorbable membrane + xenograft; NRAI = non-resorbable membrane + allograft; CTG = connective tissue graft; NRAp = non-resorbable membrane + alloplast-graft; NRA = non-resorbable membrane + antibiotic; AP = alloplast-graft; RAL = resorbable membrane + allograft; RX = resorbable membrane + xenograft; RXP = resorbable membrane + xenograft + platelet-rich plasma; APA = alloplast-graft + antibiotic; NRAL = non-resorbable membrane + allograft; NRAIa = resorbable membrane + allograft + antibiotic; ? = study did not clarify whether furcation defect was buccal or lingual.

(95% CI, 1.09 to 4.01). Bone fill of 2.58 ± 0.35 mm (95% CI, 1.88 to 3.27) and 2.25 ± 0.28 mm (95% CI, 1.70 to 2.79) was noted for HBL and VBL, respectively.

DISCUSSION

The objective of this study is to investigate the efficacy of different treatment modalities used in Class II molar furcations. The efficacy was evaluated by measuring clinical changes, and also by measuring hard tissue changes after surgical reentry. The search parameters included vertical and horizontal bone increase, clinical PDs, and attachment level measurements. Of the original 801 articles, 34 met the initial inclusion criteria and 13 qualified to conduct the final meta-analyses.

The first meta-analysis that compared non-resorbable to resorbable membranes indicated an advantage for resorbable membranes with improvements in VPD reduction of 0.25 mm, CAL gain of 0.39 mm, horizontal bone increase of 0.29 mm, and vertical bone increase of 0.77 mm. Because these differences were modest, it should be noted that the use of a non-resorbable membrane can still be considered a viable treatment. The combined estimate effect identified reduction in VPD of 2.07 mm and 1.77 mm, CAL gain of 1.39 mm and 1.35 mm, horizontal bone increase of 1.85 mm and 1.54 mm, and vertical bone increase of 1.49 mm and 0.75 mm for resorbable and non-resorbable membranes, respectively. Although these results indicated significantly better results for resorbable membranes in the treatment of Class II furcation defects, the clinical differences were modest. Evaluation of these results with the second and third meta-analyses indicated that both resorbable and non-resorbable membranes yielded significantly better outcomes compared to open flap debridement. This result is in agreement with the systematic review by Murphy and Gunsolley.[28]

With regard to the combination of resorbable or non-resorbable membranes with a bone graft for the regeneration of Class II defects, a meta-analysis was not conducted because only two studies compared these treatment methods. The combined estimate effect, however, indicated favorable results for resorbable membrane with allograft/xenograft[32,35,37,40,44] compared to non-resorbable membrane with allograft[40,65] (PD vertical reduction [3.05 versus 1.57 mm], CAL vertical gain [2.55 versus 1.38 mm], horizontal bone fill [2.58 versus 2.55 mm], vertical bone fill [2.25 versus 1.15 mm], respectively). The findings of the present study differ from other systematic reviews that showed vertical probing attachment–level enhancement only, by using expanded polytetrafluoroethylene and polymeric barriers.[28]

When an allograft with a non-resorbable membrane[40,65] was compared to a non-resorbable membrane alone,[31,34,39,41-43,45,49,51,53,57,58,60,61,63] the results demonstrated that the addition of an allograft was of minimal clinical value when evaluating soft tissue measurements. For hard tissue measurements, however, the addition of an allograft to the non-resorbable membrane improved the horizontal and vertical bone increase more than did non-resorbable membrane alone. This finding is clinically significant (horizontal bone gain [2.55 versus 1.54 mm] and vertical bone gain [1.15 versus 0.75 mm]). These results are in agreement with other studies confirming that the combination therapy of a particulate bone graft under non-resorbable membranes resulted in favorable outcomes.[25,28]

The addition of allograft/xenograft to resorbable membranes[32,35,37,40,44] resulted in more improvement in all parameters compared to resorbable membranes alone[34,36,43,45,46,57,58,64] (PD vertical reduction [3.05 versus 2.07 mm]; CAL vertical gain [2.55 versus 1.39 mm]; horizontal bone gain [2.58 versus 1.85 mm]; and vertical bone gain [2.25 versus 1.49 mm]). These results differ from other systematic reviews that did not report significant enhancement by combining graft material and resorbable membranes.[27,28]

These results are important in determining the most effective method to treat Class II molar furcations. Local and systemic factors can influence the outcome of these treatments. Most of the studies reviewed in this paper address the effects of all local factors, when present. These factors included removal of cervical enamel projections, restoration overhangs, bifurcational ridges, and enamel pearls before beginning treatment. The removal of these local factors is essential in improving the predictability of regeneration in furcation defects. In addition to these local factors, location of the Class II furcation defect is also important. Generally, the literature has demonstrated more predictable and consistent results for regeneration in mandibular furcation defects compared to maxillary defects.[63] Most of the studies included in this analysis examine treatment of mandibular or combination of mandibular and maxillary facial furcation defects. However, a meta-analysis was not feasible to assess the influence of defect location on the outcomes of treatment. This is because of the high variability and lack of homogeneity among study designs.

When evaluating patient factors, the studies included in the current analysis discuss oral hygiene and smoking status. Generally, the studies had a plaque score (O'Leary plaque index or its modification)[66,67] of 25% or less before performing the surgical treatment. Therefore, good plaque control is recommended before initiating surgical treatment. With regard to the effects of smoking on treatment outcome, a study by Luepke et al.[36] evaluated

a resorbable membrane group compared to a resorbable membrane with allograft group in smokers and non-smokers. They observed favorable results for both groups, with the non-smoker group being slightly better than the smoker group as follows: PD vertical reduction (1.86 ± 0.69 versus 0.94 ± 0.98 mm) and CAL vertical gain (1.57 ± 0.79 versus 1.19 ± 0.88 mm) in favor of the non-smokers compared with smokers in the resorbable membrane group; PD vertical reduction (2.71 ± 0.49 versus 1.31 ± 0.70 mm) and CAL gain (2.00 ± 1.73 versus 1.69 ± 1.03 mm) in favor of the non-smokers in the resorbable membranes with allograft group.[36] Nonetheless, it is noteworthy that although these studies show less improvement in smokers compared with non-smokers, the overall outcomes are still favorable for regenerative treatments.[68,69] These results are in agreement with other regeneration studies of intrabony defects.[70,71]

The current study is limited to a small number of studies and thus more uniform or consistent criteria are needed for future RCTs so their data can be included.

CONCLUSIONS

In evaluating primary parameters (VPD, VCAL, HBL, and VBL) in the treatment of Class II furcation defects judged by surgical reentry at ≥6 months, the following conclusions were drawn: 1) the use of resorbable membranes was significantly better compared to non-resorbable membranes; 2) guided tissue regeneration by using resorbable or non-resorbable membranes produced better results compared to open flap debridement for all four parameters; 3) the addition of allograft/xenograft to a resorbable membrane enhanced VPD reduction, attachment level gain, and HBL increase compared to resorbable membranes alone; 4) guided tissue regeneration by using a non-resorbable membrane and an allograft resulted in improved bone level gains compared to a non-resorbable membrane alone; 5) tooth and patient factors influenced the outcome of regeneration and these factors should be addressed presurgically; and 6) there was a high variability and lack of heterogeneity among the studies that limited this study to three meta-analyses.

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Correspondence: Dr. Bassam Michael Kinaia, Department of Periodontology, Boston University Institute of Dental Research and Education, Dubai, United Arab Emirates. E-mail: abkinaiadds@yahoo.com.

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