Orthodontic tooth movement in relation to angular bony defects

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Objectives: This review provides a comprehensive assessment of the benefits of adjunctive orthodontic treatment with or without periodontal regenerative surgery in the treatment of angular bony defects, defect volume, and periodontal tissue conditions in adult patients.

Methods: An electronic keyword search was conducted in the literature database PubMed as well as in Google Scholar. Originally, studies describing all types of orthodontic tooth movement (tipping, bodily movement, intrusion, extrusion) in relation to bone defects such as periodontal, furcation and extraction site defects were reviewed. Only those articles depicting tooth movement after periodontal therapy and the control of inflammation were included.

Results: Evidence indicates that orthodontic tooth movement can result in the reduction or elimination of periodontal bony defect dimensions, a reduction in probing pocket depth and a gain in clinical attachment level. Furthermore, the published data show that orthodontic tooth movement before or after regenerative surgery can provide therapeutic benefits in the recovery of angular bony defects.

Conclusions: This review supports the premise that adjunctive orthodontic treatment in adults with reduced but healthy periodontal tissues is a solution for the modification of bony defect contours with or without periodontal regenerative therapy.

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Introduction

Worldwide studies have shown that the prevalence of gingival inflammation in adults is high (50 to 90%), with 30% of the population advancing to periodontal disease.[1,2] The most visible clinical sign of advanced periodontitis is pathological tooth migration as a result of the destruction of tooth supporting structures. This presents a major aesthetic and functional concern for patients. The frequency of periodontal disease increases with age,[3] and so an increasing number of adults who suffer from periodontal disease and subsequent tooth migration are seeking orthodontic treatment. Adult orthodontic therapy requires a different approach to address the reduction or elimination of angular bony defects, solve occlusal and aesthetic problems and facilitate the management of several restorative challenges associated with tipped abutment teeth, excess spacing, inadequate pontic space, hyper-erupted incisors and diastema.[4,5] Orthodontics is a requirement in the interdisciplinary approach to help adult individuals suffering from periodontal disease to maintain a natural dentition with a stable occlusion, acceptable masticatory function and pleasant aesthetics. The aim of this paper is to present a comprehensive literature review to highlight the benefits of adjunctive orthodontic treatment alone or in combination with periodontal regenerative therapy, and to provide evidence that an interdisciplinary approach offers alternative options in the management of angular bony defects, as a result of periodontal, furcation and extraction events.

Considerations of orthodontic treatment in adult patients

There are a number of factors to consider during orthodontic treatment in adults. Conditions that are natural outcomes of aging are reduced vascularity of the periodontal ligament (PDL), a decrease in the number of fibroblasts and an insufficient source of pre-osteoblasts. Together, these conditions reduce bone reactivity to mechanical forces.[6] As a result, the duration of orthodontic treatment in adults may be longer compared with young individuals;[6,7] moreover, retention should be prolonged in order to allow desired bone remodelling.[6,8] An additional factor of importance in adults is that cortical bone becomes denser while the cancellous bone reduces, which, in combination with a reduced capacity of the PDL to respond, may increase the risk of root resorption during orthodontic tooth movement (OTM).[6,8] Furthermore, patients suffering from periodontal tissue breakdown have a reduced tissue surface and an alteration in the applied biological and biomechanical conditions. Tissue hyalinisation occurs more easily in adults[9] and the centre of resistance (CR) of periodontally-compromised teeth is often displaced more apically.[10,11] This increases the likelihood of tipping movements leading to the creation of greater moments during force application.[6,9] Although bodily tooth movement is frequently a clinical aim, small elements of tipping, rotation, torque, intrusion or extrusion can also be produced.[12] Nevertheless, the literature recommends the application of light forces in adults, in order to avoid tissue overloading and hyalinization, which may lead to adverse effects and further tissue breakdown.[13-15] A longitudinal study,[16] comparing tissue alterations during orthodontic treatment in adults with reduced or normal periodontal tissues to those of adolescents, showed that there is no significant difference in loss of connective tissue attachment between the two groups. Therefore, with proper biomechanical design, adults with normal periodontal tissues as well as those with reduced but healthy periodontal support can undergo orthodontic therapy without experiencing an increased risk of periodontal tissue breakdown or tooth loss.

The effect of orthodontic force application on the periodontal tissues

The effect of different types of tooth movement on inflamed and non-inflamed as well as on reduced and normal periodontal tissues has been examined in multiple experimental,[14,17-24] clinical,[16,25-32] and systematic review studies.[9,33]

Experimental studies

Animal studies have shown that in the absence of inflammation, even in cases in which periodontal support is reduced, orthodontic bodily forces are not capable of inducing gingivitis.[17,18] Moreover, in the presence of inflammation, applied forces will not convert gingivitis into destructive periodontitis. However, bodily movement of teeth in relation to inflamed infrabony defects may increase pocket depth and lead to a loss of connective tissue attachment, especially when the tooth is moved into the defect.[19] Infrabony defects are common in adults and may form as a result of destructive periodontal disease.[34] Intruding and tipping movements of teeth harbouring plaque were also found capable of creating infrabony pockets,[21] although the loss of clinical attachment level (CAL) might have been overestimated due to deeper probe penetration in the presence of inflammation.[35] Alternatively, studies in monkeys have concluded that the intrusion of teeth with a normal periodontium does not lead to a loss of connective tissue attachment,[23] or to a decrease of marginal bone level.[24] The same has been reported for extrusive movements.[22]

Clinical studies and systematic reviews

Clinical and systematic review studies have shown that, if periodontal health and proper oral hygiene standards are maintained during active orthodontic therapy, there is minimal risk of clinically significant injury occurring to the supporting tissue,[9,25,27,29] even in cases in which periodontal support is severely reduced.[16,29] Moreover, in a long-term study that evaluated the periodontal status after orthodontic therapy, it was apparent that orthodontic treatment during adolescence had no noticeable effect on periodontal health in later life.[32] However, if oral hygiene is neglected during orthodontic treatment, there is an increased risk of adverse periodontal effects.[25] Contrary clinical studies have shown that orthodontic treatment may result in a small but statistically significant worsening of the periodontal status after treatment.[26,28,30,33] However, the reported differences might have been due to biased results, host-specific factors (alteration of oral hygiene habits

during orthodontic therapy), or site-specific changes (such as molar bands or extractions) rather than as a direct adverse consequence of orthodontic forces.[33]

The results from the above studies indicate the importance of periodontal therapy prior to the commencement of and during orthodontic treatment. In the absence of inflammation, OTM may take place without clinically significant injuries to the periodontium. It has been reported that the new periodontal architecture after tooth realignment may facilitate better oral hygiene as well as provide support to reduced, but otherwise healthy, tissues.[36,37]

Material and methods

In order to examine the effect of OTM in relation to angular bony defects on the periodontal tissues and its impact on defect volume, an electronic keyword search in the literature database PubMed was conducted using the phrases: 'orthodontic tooth movement (bodily movement/intrusion/extrusion/tipping) in relation to or of teeth with angular bony defects (periodontal/infrabony/intrabony or alveolar defects)', 'orthodontic resolve of periodontal defects' and 'orthodontics-periodontal regeneration/healing'. The search revealed 276 articles, from which 33 were included for critical review. Moreover, from an electronic keyword search in Google Scholar ('orthodontic tooth movement in relation to infrabony defects') nine additional papers were included from 412 identified. The reference lists of the identified papers related to the topic were also reviewed for completeness and this process resulted in the inclusion of six additional studies. Articles containing all types of OTM in relation to angular, furcation as well as extraction defects were included. Studies with a title or abstract irrelevant to the subject were excluded. Furthermore, since the deleterious effect of force application on inflamed tissues is widely recognised, only studies in which OTM occurred after appropriate periodontal therapy and a control of inflammation were selected. As a result, two additional studies[19,38] were excluded. Therefore, from the search, 48 articles were included in the present study (Figure 1) and were divided into two major topics: OTM in relation to angular bony defects treated with non-regenerative periodontal therapy (Table I) and OTM in relation to angular bony defects treated with regenerative surgery (Table II). Each group was subsequently subdivided into animal, clinical and systematic reviews.

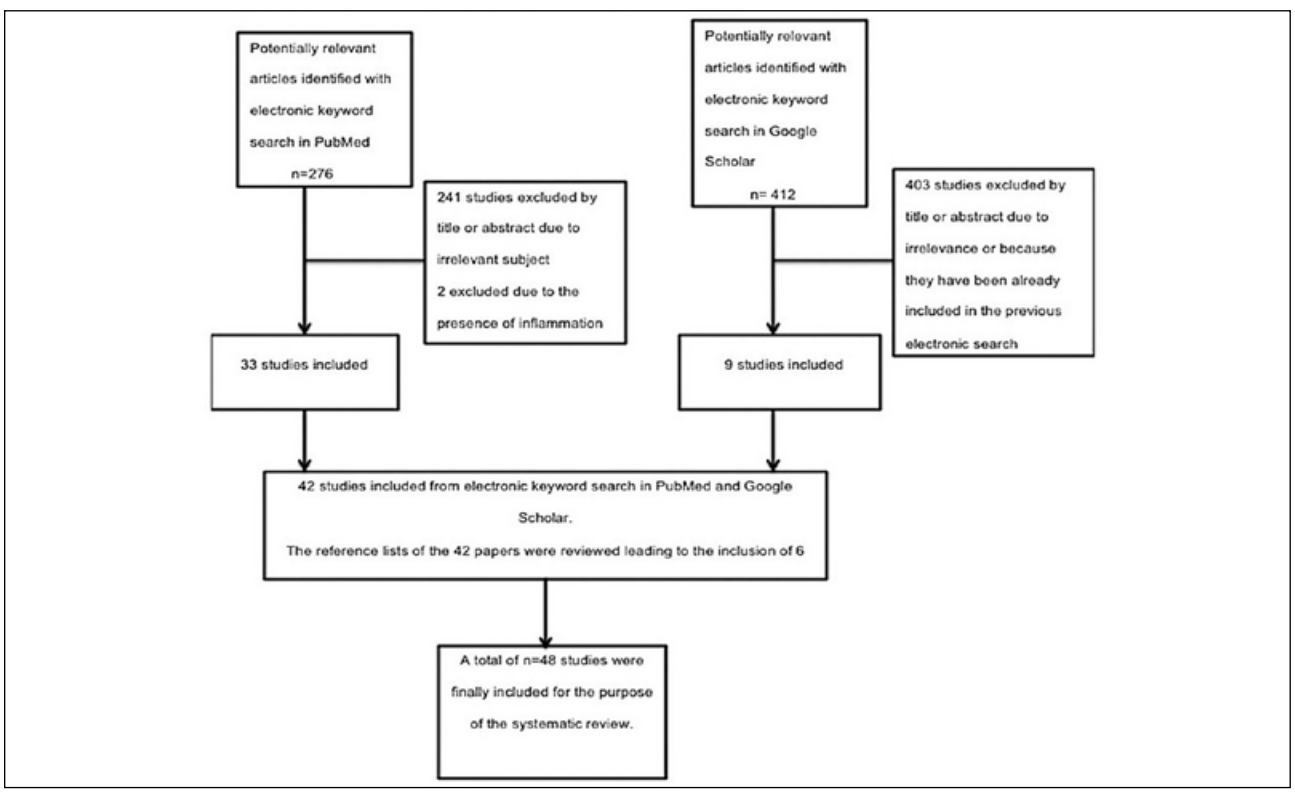

Figure 1. The flow diagram demonstrates the strategy used for the selection of studies for this review.

Table Ia. Orthodontic tooth movement in relation to angular bony defects treated with non-regenerative periodontal therapy: Experimental studies subgroup.

Results I: The effects on clinical periodontal parameters. Results II: The effects on angular bony defect fill and connective tissue attachment level.

Authors	Type of study	Subjects	Type of movement	Results I	Results II
Polson et al. 1984[39]	Experimental study	4 rhesus monkeys (4 test and 4 control teeth).	Bodily tooth movement into and through infrabony pockets.		Elimination of the defect. No effect on connective tissue attachment.
Geraci et al. 1990[40]	Experimental study	2 adult rhesus monkeys (4 3-wall defects, 4 2-wall defects, 4 control).	Tipping or bodily movement of teeth with 2- and 3- wall infrabony defects.		New connective tissue attachment to a root surface that previously bordered an inflammatory lesion.
Berglundh et al. 1991[41]	Experimental study	5 beagle dogs.	Extrusion without fiberotomy.	The periodontium followed the extrusive tooth movement, probing depth remained unchanged, gingival margin receded at distance of 0.5 mm.	The height of supracrestal attachment remained stable. Elimination of infrabony pocket.
Vardimon et al. 2001[42]	Experimental study	52 Wistar rats.	Mesial tipping and displacement movements of maxillary first molars with alveolar defects on their mesial aspect, no OTM[a] in control teeth.		6.5-fold larger bone apposition in treated than in the control group.
Cirelli et al. 2003[43]	Experimental study	4 mongrel dogs.	Tipping of teeth after periodontal surgery towards 1-walled intraosseous defects.		No interference with the healing process of 1-wall intraosseous defects as far as connective tissue level, apical extent of epithelial migration and new cementum formation but a smaller extent of linear bone apposition was observed.
Nemcovsy et al. 2004[44]	Experimental study	33 adult male Wistar rats.	Tipping of teeth into periodontal (group 2, N = 19) and alveolar bony defects (group 1, N = 14).		Enhanced bone healing of defects with no connective tissue attachment gain. Bone apposition was greater in periodontal defects, where PDL[b] and root damage was included, than in alveolar bony defects.
Nemcovsy et al. 2007[45]	Experimental study	Group 1: 16 male Wistar rats with a bony defect that did not include the attachment apparatus. Group 2: 15 rats with a bony defect that included the periodontal ligament.	Tipping of right first molar teeth mesially towards infrabony defects. The contralateral molars were not moved and served as controls.	OTM has no negative effects on diminished but not inflamed periodontal tissues.	OTM may lead in the elimination or reduction of angular infrabony defects. OTM can enhance connective tissue healing and restrict junctional epithelium apical down-growth. No attachment gain but healing with LJE[c].
da Silva et al. 2008[46]	Experimental study	7 mongrel dogs where Class III furcations were created in third and fourth lower premolars (28 teeth, divided into 4 groups of 7 teeth).	Group I: furcation defects treated with open flap debridement (OFD). Group II: OFD plus intrusion (I) with mini implant anchorage 30 days after surgery. Group III: GTR[d] associated to bone autograft (BA). Group IV: GTR/BA and I.	All Class III furcations were clinically closed or reduced to Class II or I in the intrusion groups, while 50% of the lesions in non-moved teeth remained unchanged. Clinical attachment was maintained or improved by intrusion.	Improved bone filling occurred with intrusion in the defect area treated with OFD.

[a]Orthodontic Tooth Movement, [b]Periodontal Ligament, [c]Long Junctional Epithelium, [d]Guided Tissue Regeneration

Table Ib. Orthodontic tooth movement in relation to angular bony defects treated with non-regenerative periodontal therapy: Clinical studies subgroup.

Results I: The effects on clinical periodontal parameters. Results II: The effects on angular bony defect fill and connective tissue attachment level.

Authors	Type of study	Subjects	Type of movement	Results I	Results II
Brown 1973[47]	Descriptive case series	5 subjects (4 experimental and 1 control).	Uprighting and extrusion of molars in relation to periodontal defects.	Mean 1 mm reduction in bone height after OTM[a].	Reduction of infrabony defect dimensions (mean reduction 3.5 mm).
Ingber 1974[48]	Case report	50-year-old female with isolated 1-wall osseous defect on mandibular second premolar.	Forced eruption.	PPD[b] reduction.	Extrusion can be used for the correction of 1- and 2-wall infrabony defects.
Wagenberg et al. 1980[49]	Case series	5 cases.	Forced eruption and uprighting of mesially tipped teeth.	No CAL[c] loss.	Reduction or elimination of infrabony defects.
Miyajima 1985[50]	Case report	42-year-old female.	Bodily tooth movement and extrusion for root realignment of furcation-involved maxillary first molar with mesial infrabony defect.		Decrease or elimination of the infrabony defects.
Nevins and Wise 1990[51]	Case report	2 adults with vertical defects.	Tipping and bodily movement of teeth towards 1- (case I) and 2-wall infrabony pockets (case II).		Elimination of the defects.
Salama, Salama 1993[52]	Clinical review	Several cases presented in order to provide a systematic approach in the management of extraction defect environment.	Extrusion of 'hopeless teeth' in local alveolar bony defect environment for implant site development.		Extrusion can be used for the management of extraction site defects and increase the dimensions of the alveolus for implant placement.
Mathews, Kokich 1997[53]	Clinical review	Information presented for the orthodontic treatment of patients with underlying periodontal problems (diagnosis, management, need for and timing of pre-orthodontic periodontal surgery).	Orthodontic movement of teeth with underlying periodontal problems, such as, soft tissue and hard tissue problems (osseous craters, 3-wall infrabony defects, hemiseptal defects and furcation defects).		Osseous craters will not improve with orthodontic therapy therefore pre-orthodontic osseous surgery might be indicated in order to maintain these areas during appliance wear. 3-wall defects are best treated with regenerative surgery prior to OTM. Hemiseptal defects can often be eliminated with appropriate orthodontic treatment. Furcation lesions are the most difficult to maintain and may worsen during OTM.
Cardaropoli et al. 2001[36]	Case series	10 adult patients with severe periodontal disease (8 women, 2 men, 33-53 years old).	Intrusion 7 to 10 days after periodontal surgery of migrated maxillary central incisors with infrabony defects.	Achievement of periodontal health, PPD reduction, no remarkable root resorption.	Significant closure of the angular infrabony defect dimensions.
Re et al. 2002[54]	Case report	Adult patient with advanced periodontitis, extrusion and migration of maxillary central incisor with a large infrabony defect on the mesial aspect (PD[d] 9mm).	Intrusive movement, also leading in closure of the diastema after surgical periodontal therapy.	PPD reduction.	Reduction of defect volume.
Corrente et al. 2003[55]	Descriptive case series	10 patients with advanced periodontal disease and an elongated maxillary central incisor.	Intrusion of upper central incisors with 1-,2- and 3-wall infrabony defects 7–10 days after periodontal surgery.	PPD reduction (mean 4.35 mm) and CAL gain (mean 5.5 mm).	Radiologic bone fill of defects.

Re et al. 2004[56]	Descriptive case series	28 adult patients suffering from severe chronic periodontitis.	Periodontal surgery and subsequent intrusion of elongated upper central incisors with infrabony defects.	PPD reduction, reduction of gingival recession.	
Cirelli et al. 2006[57]	Case report	36-year-old woman with severe periodontal disease, pathologic tooth migration of maxillary central incisors with a vertical bone loss at their mesial aspect, midline diastema, overjet and deep overbite.	OTM to close the diastema, upright the anterior teeth and reduce overjet after basic periodontal therapy.	PPD reduction, CAL gain.	Radiographically there was a slight reduction of the infrabony defect.
Iino et al. 2008[58]	Case report	50-year-old woman with 1- and 2-wall infrabony defects at two incisors and a canine.	Extrusion after periodontal therapy.		Improvement of 1- and 2-wall isolated vertical infrabony defects.
Mihram, Murphy 2008[59]	Clinical review (presentation of several case studies)	Patient with a vertical osseous defect on the mesial aspect of the maxillary lateral incisor.	Extrusion combined with repeated fiberotomies on the distal side of a maxillary lateral incisor with a vertical infrabony defect on the mesial aspect.		Extrusion led in the elimination of the infrabony defect mesially, while fiberotomies distally prevented the incisal movement of the intact periodontium on the distal aspect of the tooth.
Modoni et al. 2009[60]	Case report	47-year-old female.	Intrusion for the treatment of an isolated vertical infrabony defect.	PPD reduction, CAL gain.	
Khurana, Soni 2010[61]	Clinical review	Orthodontic intervention to resolve periodontal problems (uneven gingival margins, missing papillae, mucogingival defects and periodontal bone defects).	OTM in relation to soft and hard tissue defects (interproximal craters, 1-, 2-wall defects, 3-wall defects, furcation defects and horizontal bone loss).		OTM cannot improve interproximal craters. 1- and 2-wall bony defects are treated more efficiently by orthodontics. 3-wall defects are not resolvable with orthodontics and if the patient cannot maintain these areas during orthodontic therapy, they must be resolved prior to bracket placement (with regenerative therapy). Usually Class II and III furcation defects are not maintainable by patients during OTM and must be resolved prior to orthodontic treatment.
Pinho et al. 2012[4]	Case report	43-year-old woman with multiple missing teeth, mild chronic periodontitis and a malocclusion with a cant of the occlusal plane.	Intrusion (with the help of a miniscrew implant) of left anterior teeth in order to level the occlusal plane as part of a multidisciplinary treatment plan.		This case report is in agreement with the possibility of bone apposition in infrabony defects after OTM.

[a]Orthodontic Tooth Movement, [b]Probing Pocket Depth, [c]Clinical Attachment Level, [d]Pocket Depth

Table Ic. Orthodontic tooth movement in relation to angular bony defects treated with non-regenerative periodontal therapy: Systematic review studies subgroup.

Results I: The effects on clinical periodontal parameters. Results II: The effects on angular bony defect fill and connective tissue attachment level.

Authors	Type of study	Subjects	Type of movement	Results I	Results II
Gkantidis et al. 2010[9]	Systematic review	Human studies: 88 articles included from 2076 articles screened. Animal studies: 17 articles included from 552 articles screened.	Bodily tooth movement/ intrusion after periodontal surgical therapy.	Clinical attachment level gain.	Radiographic bone fill.
Rotundo et al. 2011[62]	Systematic review	29 articles included from 197 articles screened.	Extrusion and bodily tooth movement.	Clinically positive results.	Radiologic positive results concerning the correction of periodontal defects.

Results

OTM in relation to angular bony defects treated with non-regenerative periodontal therapy

Table I (a,b,c) summarises the data from experimental,[39-46] clinical[4,36,47-61] and systematic review studies[9,62] addressing the effect(s) of OTM in relation to angular bony defects on clinical periodontal parameters (Results I) and on angular bony defect fill and connective tissue attachment level (Results II).

Table Ia displays data from animal studies on tipping movement,[40,42-45] intrusion,[46] extrusion,[41] as well as bodily tooth movement[39,40] towards infrabony defects (one-, two- and three-wall),[39-41,43-45] furcation defects[46] or alveolar bone defects[42,44] after surgical or non-surgical periodontal therapy. Histologic analysis in most of these studies revealed that, although the dimensions of the defect were reduced after OTM, there was no gain in connective tissue attachment level.[39,41,43-45] Therefore, healing occurred with long junctional epithelium (LJE).[45] However, one experimental study reported that defect fill occurred with new attachment formation on a root surface previously bordered by an inflammatory lesion.[40] Studies also indicated that OTM is a stimulating factor for bone apposition[42] and that this process is significantly greater in periodontal defects in which PDL and root damage are involved than in alveolar bone defects with no PDL involvement (representing defects in extraction sites).[44] Tipping movement towards infrabony defects was reported to have no negative effects on diminished non-inflamed periodontal tissues.[45] The intrusion of teeth with Class III furcation defects following open flap debridement (OFD) led to their clinical reduction to Class II or I.[46] An alternative study,[41] in which extrusion occurred without repeated fiberotomies in a defect area, concluded that the periodontium followed the extrusive movement of the tooth with no increase in probing pocket depth (PPD), but with some (0.5 mm) gingival margin recession.

Based on the data from the clinical studies shown in Table Ib, it was concluded that orthodontic intrusion, with or without previous periodontal surgery directed at infrabony defects, may lead to PPD reduction and CAL gain.[36,54-56,60] Extrusion and uprighting of tipped teeth did not to lead to CAL loss.[49] A PPD reduction was reported in one study after extrusion[48] but a contrary study described a mean 1 mm reduction in bone height.[47] Extrusive,[47-50,52,58,59] intrusive,[4,36,54-56,60] bodily and tipping[51,57] movements with or without pre-orthodontic periodontal surgery were all reported capable of reducing clinical or radiographic infrabony,[4,36,47-51,54-60] alveolar,[52] and furcation[50] defect dimensions. Moreover, in a clinical review,[52] it was noted that extrusive movements could be used for the management of extraction site defects and for increasing the dimensions of the alveolus, thus facilitating subsequent implant placement. In two clinical reviews[53,61] it was suggested that OTM alone is more efficient in resolving one- and two-wall infrabony defects. However, the treatment of interproximal craters and three-wall infrabony defects required pre-orthodontic osseous or regenerative surgery. It was also reported that furcation lesions were the most difficult to maintain and may worsen during OTM. The systematic review studies shown in Table Ic also support the concept that bodily tooth movement with intrusion after periodontal surgery,[9] or with extrusion[62] of teeth in defect areas, leads to positive clinical results and radiographic bone fill of the defects.

OTM in relation to angular bony defects treated with regenerative periodontal surgery

Table II shows the results from the experimental[46,63-67] (Table IIa), clinical[4,68-83] (Table IIb) and systematic review[9] (Table IIc) studies focusing on defects treated with a combined orthodontic-regenerative approach. Most animal[63-67] and clinical studies[4,68-74,76-82] indicated that OTM after periodontal regenerative surgery is beneficial and leads to successful treatment of infrabony or extraction defects without damaging the augmentation biomaterials. However, one reviewed study reported a reduction of bone regeneration on the pressure side after OTM,[64] whereas in two experimental studies[63,66] and one clinical re-entry case report[70] it was stated that, following OTM, the augmentation biomaterials were replaced by bone-like hard tissue. Most studies[46,64,65,77] reported either no or minor additional beneficial effects on the regenerated tissues by OTM. However, in a randomised clinical trial (RCT), Ogihara and Wang[79] noted that limited orthodontic movement (rapid extrusion) four weeks after regenerative surgery might provide additional benefit to two-wall defects treated with enamel matrix derivative and demineralised freeze-dried bone allograft (EMD/DFDBA). In a case report study, Ogihara and Marks[74] also suggested that orthodontic

Table IIa. Orthodontic tooth movement in relation to angular bony defects treated with periodontal regenerative therapy: Experimental studies subgroup.

Authors	Type of study	Subjects	Type of movement	Results
Araújo et al. 2001[63]	Experimental study	5 beagle dogs, the 1st, 2nd and 4th mandibular premolars were removed in each side.	The defect at the left 4th premolar site was filled with a biomaterial (Bio-Oss) while the corresponding defect in the right side was left for spontaneous healing. 3 months later, distal bodily movement of 3rd premolars occurred into the extraction defects.	OTM[a] was possible into the graft material (Bio-Oss was degraded and eliminated from the part of the alveolar ridge that was utilized for the experiment).
Diedrich et al. 2003[64]	Experimental study	4 foxhounds, 64 3-wall defects created mesially and distally of 1st and 2nd premolars. 8 second premolars were intruded, 8 were bodily distalized, both away from (tension side) and through (pressure side) the bony defect, the others served as control.	Intrusion and bodily tooth movement into the defect (pressure side) and away from the defect (tension side) 1 month after GTR[b] (Emdogain at tension side and membrane at the pressure side).	Periodontal regenerative procedures appear to enhance conditions for subsequent OTM of teeth with attachment loss. Bone regeneration was high in control, intrusion and tension side groups but reduced on the pressure side. OTM does not enhance healing of Emdogain.
da Silva et al. 2006[65]	Experimental study	4 mongrel dogs where Class II furcation lesions were created in maxillary second premolars.	Treatment with bovine bone mineral matrix and GTR with absorbable membrane. 2 months later, orthodontic bodily movement of maxillary second premolars was performed in the mesial direction for 3 months (test teeth), whereas unmoved premolars served as control.	There were no statistically significant differences between the two groups in total bone and biomaterial areas or linear extension of periodontal regeneration on the radicular surfaces.
Oltramari et al. 2007[66]	Experimental study	6 minipigs, 4 defects created in each animal at the mesial aspects of the maxillary and mandibular first permanent molars.	Right side (test): defects were filled with xenograft. Left side (control): defects were filled with blood clot. Mesial bodily movement of first permanent molars 3 months later halfway into the defect spaces.	Teeth can be moved into areas of bone defects previously filled with xenograft (the biomaterial was almost totally replaced by new bone and no significant root damage was observed).
da Silva et al. 2008[46]	Experimental study	7 mongrel dogs with Class III furcation defects created in third and fourth lower premolars (28 teeth, divided into 4 groups of 7 teeth).	Group I: furcation defects treated with open flap debridement (OFD). Group II: OFD plus intrusion (I) with mini implant anchorage 30 days after surgery. Group III: GTR associated to bone autograft (BA). Group IV: GTR/BA and I.	Intrusion 1 month after the regenerative periodontal treatment with membrane and BA did not improve bone formation in the defect area, suggesting that interaction between orthodontic movement and biomaterial degradation must be analyzed in future research.
Attia et al. 2012[67]	Experimental study	18 male guinea pigs. Bony defects were created in the alveolar process midway between the central incisor and mandibular first molar.	Treatment of the defects with bioactive glass particles and collagen membrane in combination with OTM immediately after surgery (Group I), 2 weeks after surgery (Group II) and no OTM (Group III).	Combined therapy enhanced bone formation. The defects treated with immediate application of OTM showed a statistically significant increase in trabecular count and total area of newly formed bone compared to the other groups.

[a]Orthodontic Tooth Movement, [b]Guided Tissue Regeneration

extrusion might enhance the regenerative potential of guided tissue regeneration (GTR), but the study lacked a control group. Attia et al., in an experimental[67] and controlled clinical trial,[81] indicated that combined ortho-regenerative treatment might offer additional benefits in bone formation and in clinical periodontal parameters, such as PPD reduction and CAL gain, compared with regenerative treatment alone.

Reports have also shown that regenerative procedures prior to OTM may improve the topography and volume of bone, as well as the supporting tissues, thereby providing a favourable environment for subsequent tooth movement into bone deficient areas.[64,71,80] Additional clinical studies[71,80] reported that in the case of orthodontic space closure in extraction sites, previous treatment with regenerative

techniques offers favourable conditions for successful tooth movement (no resulting inflammation or root resorption), while at the same time preventing gingival invaginations. In addition, OTM prior to regenerative procedures may increase the success rate of subsequent regenerative therapy.[75,83] For example, in a case report[75] it was shown that the deepening of a periodontal defect around the mandibular central incisor, due to the reduction of its horizontal width caused by OTM, increased blood circulation and improved the success rate of the subsequent GTR.

There has been a discussion initiated by experimental and clinical studies, related to the timing of OTM after tissue regenerative procedures. An experimental[67] study performed in animals and a human clinical study[81] reported beneficial results if OTM was applied immediately after regenerative surgery compared with a delayed application (two weeks in the animal study, or two months later in the clinical study) or no OTM. In turn, a clinical study[82] reported that early orthodontic movement, even if it took place in immature bone during the healing time, did not affect the maturation process of the periodontal apparatus. However, a systematic review[9] indicated that there was no clear sign of the timing of GTR in patients requiring orthodontic intrusion.

Discussion

Periodontal defects are commonly encountered in adults presenting for orthodontic therapy. Accepted methods of treatment of the defects include osseous resection, grafting procedures or even extraction when the defect jeopardises adjacent teeth, but these methods pose limitations.[48] The present review is the first to thoroughly evaluate the benefits and concerns of adjunctive orthodontic treatment with or without regenerative therapy in the reduction or the elimination of angular bony defects (infrabony, furcation and alveolar defects).

Adjunctive orthodontic treatment in periodontal defects treated without regenerative surgery

One-, two-, three-wall infrabony defects and interproximal craters

Infrabony pockets are angular defects with inflamed connective tissue and with the gingival epithelium located apical to the crest of the alveolar bone.[34] Their classification is schematically illustrated in Figure 2.[84] From a review of the limited clinical studies, the present paper concludes that OTM can be successfully utilised as an alternative adjunctive procedure in the management of one- and two-walled periodontal defects. This is of paramount importance in cases in which excessive osseous resection is contraindicated. Specifically, conventional periodontal therapy or curettage followed by orthodontic forced eruption with occlusal equilibration has been shown as capable of levelling periodontal defects and leading to the reduction or elimination of their volume.[48,58] It could be hypothesised that bone formation is stimulated by the tension created within the PDL. Nonetheless, this approach might require subsequent endodontic and prosthodontic therapy. In addition, in periodontally compromised patients, orthodontic uprighting of mesially tipped molars, with periodontal defects on their mesial aspect, may produce favourable effects in PPD reduction after proper inflammation control.[47]

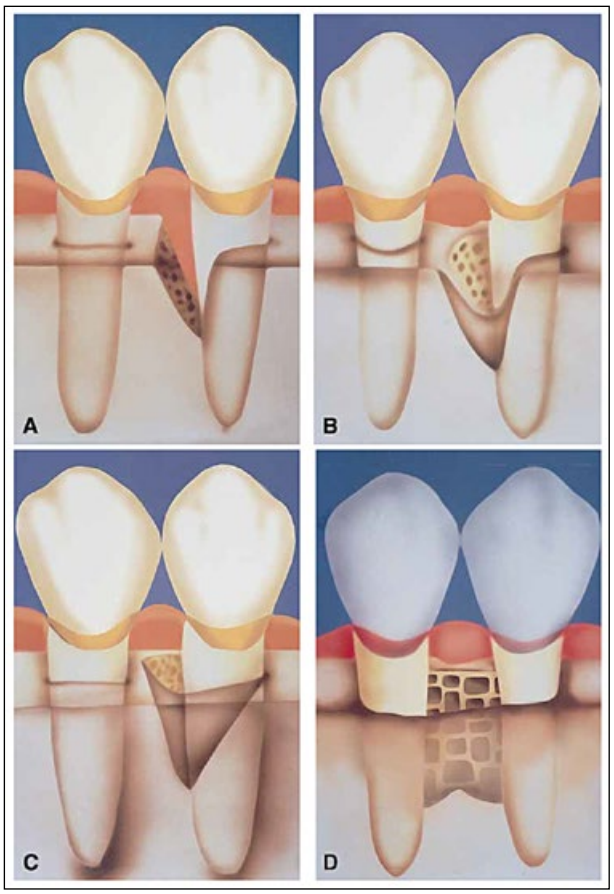

Figure 2. Infrabony defects. A. One-wall infrabony defect. B. Two-wall infrabony defect. C. Three-wall infrabony defect. D. Interproximal crater. Reprinted with permission from Papapanou and Tonetti.[84] Copyright 2003 by John Wiley and Sons.

Table IIb. Orthodontic tooth movement in relation to angular bony defects treated with periodontal regenerative therapy: Clinical studies subgroup.

Authors	Type of study	Subjects	Type of movement	Results
Nemcovsky et al. 1996[68]	Case series	3 patients with advanced adult periodontitis.	OTM[a] subsequent to GTR[b] (with resorbable and nonresorbable membranes, with and without demineralized freeze-dried bone allograft).	CAL[c] gain (mean 3.3 mm) and radiographic bone fill of defects was observed after regenerative surgery. OTM into the regenerated area was reported successful.
Aguirre-Zorzano et al. 1999[69]	Case series	28-year-old woman with advanced early-onset periodontitis (palatal defect at maxillary right central incisor PD[d] > 9 mm). 44-year-old woman with moderate-severe chronic adult periodontitis and a endoperiodontal lesion on mandibular right central incisor.	Case I: nonresorbable membrane (Gore-Tex, WL Gore)/demineralized bone in the defect and initiation of OTM (intrusion and space closure) 6 months after surgery. Case II: regenerative treatment with resorbable membrane and OTM 5 months later.	Clinical stability of the new attachment gained by GTR was achieved after OTM.
Re et al. 2002[70]	Case report	Adult periodontal patient with infrabony defects on the lingual aspects of elongated maxillary central incisors.	The teeth were moved and intruded into the defects 10 days after periodontal regenerative surgery with Bio-Oss and Tissucol.	The teeth were successfully moved into the defects and the augmentation material was replaced by bone-like hard tissue.
Tiefengraber et al. 2002[71]	Clinical trial	3 girls 11-14 years old with indication for extraction of the first premolars.	Sockets unilaterally augmented with an e-PTFE[e] membrane immediately after premolar extraction in a split-mouth technique (contralateral served as control). The membrane was removed 6–8 weeks later and one-week after removal space closure occurred.	Membrane supported healing of extraction sockets offers favourable periodontal conditions for subsequent orthodontic tooth movement with a reduction of gingival clefts.
Ogihara and Marks 2002[72]	Case report	49-year-old male with a bony defect with poor biologic width at right maxillary premolar furcation resulting from extensive subgingival caries.	Combined regenerative therapy (open debridement, bioabsorbable synthetic bone graft, bioabsorbable membrane and minocycline root conditioning) with orthodontic extrusion 8 weeks after surgery.	The furcation defect was successfully treated (as seen in radiographs and re-entry documentation).
Cardaropoli et al. 2006[73]	Descriptive case series	3 adult patients suffering from chronic periodontitis each with an infrabony defect adjacent to a migrated maxillary central incisor.	Bodily tooth movement and intrusion 2 weeks after regenerative surgery with Bio-Oss.	PPD[f] reduction, CAL gain and radiologic defect resolution. No detrimental effects of OTM on augmentation material.
Ogihara and Marks 2006[74]	Case report	45-year-old female with an infrabony pocket in lower second molar.	Extrusion and uprighting 8 weeks after GTR surgery (open debridement with particulate anorganic cancellous bovine-derived bone xenograft (BDX), bioabsorbable membrane, and minocycline root conditioning).	Extrusive force can enhance the regenerative potential of GTR (demonstrated by radiographs and re-entry documentation). Infrabony defect and alveolar ridge were successfully treated.
Passanezi et al. 2007[75]	Case report	17-year-old girl with localized juvenile periodontitis.	Combined perio-ortho therapy: initial non-invasive periodontal surgery followed by levelling, aligning and intruding of incisors and subsequent regenerative surgery (EDTA[g], autogenous bone graft, emdogain, GTR).	Following OTM a decreased pocket depth in the maxillary incisors was observed. In addition, a deepening with reduction of the horizontal width of the defect in the mandibular central incisor caused by OTM increased the success rate of the subsequent GTR.
Maeda et al. 2008[76]	Case report	55-year-old male with a missing maxillary first molar and mesially inclined neighbouring second molar with a severe circumferential bone defect.	Combined ortho-regenerative treatment with bone grafting and subsequent second molar uprighting with extrusion.	These procedures minimized the bone defect and at the same time offered a suitable site for implant placement in the first molar area.
Ghezzi et al. 2008[77]	Descriptive case series	14 patients with severe infrabony defects and pathologic tooth migration.	GTR and subsequent bodily movement and intrusion of teeth into 1-,2- and 3-wall infrabony defects.	OTM 1 year after GTR did not improve the healing of infrabony defects treated with GTR but did not damage the regenerated tissues.

Reichert et al. 2010[78]	Clinical review	37 identified publications (through electronic keyword search in PubMed, manually searched journals and reference lists of identified papers).	OTM in, and tooth eruption through non-autogenous bone graft (used in experimental setups, periodontal defects, cystic lesions and alveolar clefts).	OTM in bone graft as well as tooth eruption through bone graft are not only possible but might provide positive results. The articles presented a low level of evidence and diversity in question therefore more research is warranted in order to avoid risks of orthodontic treatment in such cases.
Ogihara and Wang 2010[79]	Randomized clinical trial	47 subjects mean age of 53 ± 10.7 years. Each patient had a 2- or 3-wall infrabony defect larger or equal to 6 mm deep.	Treatment with: Orthodontics (extrusive forces 4 weeks after surgery)/EMD/DFDBA[h] (N = 24) or EMD/DFDBA (N = 23).	Both treatment modalities were effective in managing 2- or 3-wall infrabony defects but limited orthodontics provided additional benefit to EMD/DFDBA in 2-wall defects (statistically significant open probing attachment level gain in ortho group in 2-wall defects).
Reichert et al. 2011[80]	Clinical trial	3 patients where analogous premolars were extracted for orthodontic reasons.	One extraction socket was filled with a silica matrix-embedded, nanocrystalline hydroxyapatite bone substitute (NanoBone) with the contralateral serving as a control (split-mouth design). Orthodontic space closure was initiated 6 weeks later.	OTM was possible through NanoBone, space closure succeeded without complications (root resorption, inflammation). Gingival invaginations were also prevented in the test group.
Attia et al. 2012[81]	Clinical trial	15 adult patients with at least 3 infrabony defects and malocclusion (45 defects total).	Combined ortho-regenerative therapy. Group I: immediate application of OTM (test group). Group II: delayed (2 months later) application of OTM (test group). Group III: regenerative therapy alone (control group).	Immediate application of OTM had a statistically significant positive difference in clinical and radiographic parameters (PPD reduction, CAL gain, increase in bone density and bone fill).
Pinho et al. 2012[4]	Case report	43-year-old woman with multiple missing teeth, mild chronic periodontitis, and a malocclusion with a cant of the occlusal plane.	Periodontal regenerative therapy (Emdogain/Bio-Oss) in 2-wall infrabony defects in the anterior maxillary region and mesially of the mandibular right canine followed by intrusion 3 months later.	Resolved periodontal defects.
Ghezzi et al. 2013[82]	Prospective case series	10 patients with infrabony defects (PPD greater or equal to 6 mm) and pathologic tooth migration contributing one defect each.	Treatment with EMD/collagen bovine mineral bone in combination with OTM initiating 1 month after surgery.	Early orthodontic movement, even if it took place in immature bone during the healing time, did not adversely affect the maturation process of the periodontal apparatus. The combined treatment offered excellent clinical results.
Panchal et al 2013[83]	Case report	32-year-old female with mobile, palatally drifted upper left central incisor with a 9 mm deep infrabony pocket.	OTM after basic periodontal therapy with a removable appliance containing a 'Z' spring for the alignment of the upper anterior teeth. After the anterior teeth were splinted the defect was treated with regenerative periodontal surgery (decalcified freeze-dried bone allograft).	The combined treatment offered realigned teeth with acceptable occlusion. After regenerative therapy, there was significant fill of the defect and no evidence of bleeding on probing.

[a]Orthodontic Tooth Movement, [b]Guided Tissue Regeneration, [c]Clinical Attachment Level, [d]Pocket Depth, [e]expanded Polytetrafluoroethylene, [f]Probing Pocket Depth, [g]Ethylenediaminetetraacetic acid, [h]Enamel Matrix Derivative with Demineralized Freeze-Dried Bone Allograft

Table IIc. Orthodontic tooth movement in relation to angular bony defects treated with periodontal regenerative therapy: Systematic review studies subgroup.

Authors	Type of study	Subjects	Type of movement	Results
Gkantidis et al. 2010[9]	Systematic review	88 human articles included from 2076 screened. 17 animal articles included from 552 screened.	OTM[a]-GTR[b].	From the studies in the literature there is no clear indication concerning the timing of GTR in cases of teeth that require orthodontic intrusion.

[a]Orthodontic Tooth Movement, [b]Guided Tissue Regeneration

Moreover, intrusion seven to ten days after OFD of migrated maxillary incisors with infrabony defects has been shown to result in CAL gain, PPD reduction and an elimination or decrease in defect volume.[36,54-56] Therefore, in the management of pathologically migrated teeth, adjunctive orthodontic treatment may be the best clinical practice due to the additional aesthetic benefits offered by resolving the commonly encountered midline diastema and elongated teeth in the aesthetic zone. Interestingly, it was suggested that early OTM might be effective in assisting the coronal shift of the soft tissues with considerable aesthetic gain.[36] The best results were obtained when tooth intrusion was performed with light forces (5–15 g per tooth) and with the line of action of the force passing close to the CR.[4] It is important to note that the periodontal surgical treatment preceding orthodontic intrusion is essential for the large decrease in PPD observed. The systematic review studies agree with the above conclusions but the lack of sound scientific evidence is stressed.[9,62]

Histologically, in all but one of the experimental studies, it was shown that an infrabony defect was filled without the formation of a new attachment but with LJE healing.[39,41,43-45] Similarly, Geraci et al.[40] observed new connective tissue attachment formation in two- and three-wall infrabony defects. It is possible that the different methodologies used for the creation of the defects might account for the reported results. It seems that two- and three-wall pockets have an increased potential for regeneration due to greater possibilities for in-growth of connective tissue from the lateral walls.[12] Although in the animal study,[40] three-wall infrabony defects were successfully treated with OTM, reviews[53,61] of clinical studies argue that orthodontic movement alone cannot reproducibly improve three-wall pockets. A similar conclusion was indicated for interproximal craters. Therefore, it is important to appreciate that, after proper inflammation control, OTM alone may be successfully used to resolve one- and two-wall defects, whereas in cases of three-wall lesions and interproximal craters, pre-orthodontic regenerative or osseous surgery, respectively, may be necessary. The need for surgery should be based on the patient's response to initial treatment, the patient's periodontal resistance, the location of the defect and the predictability of maintaining defects non-surgically while the patient is wearing orthodontic appliances.[53]

Furcation defects (Class I, Class II and Class III)

It has been shown that it is hard to manage furcation defects during orthodontic treatment.[53,61] A retrospective study[38] showed that if tipped molars with furcation involvement are orthodontically uprighted, simultaneous extrusion might increase the severity of the furcation defects, especially in the presence of inflammation. Excessive force application and poor inflammation control, rather than OTM, may have been the main reasons for periodontal deterioration. Nonetheless, pre-orthodontic osseous (for Class I) or regenerative therapy (for Class II) and other treatment modalities such as OFD, hemisection and root amputation (for Class III) might be indicated depending on the type of furcation lesion.[53,61] Indeed, an experimental study[46] performed in animals reported that intrusion after OFD in Class III furcation defects may improve bone in-fill and reduce the clinical size of these defects.

Alveolar bone defects

Alveolar bone defects, such as extraction sites, may also be successfully treated with adjunctive OTM,[42,44,52] but bone apposition was found to be less compared with infrabony defects.[44] An interesting approach when managing extraction site defects of teeth with a poor prognosis for subsequent implant placement is the use of orthodontic extrusion of the 'hopeless' teeth in order to enhance the soft and hard tissue topography of potential implant recipient sites, prior to tooth extraction.[52]

Adjunctive orthodontic treatment in periodontal defects treated with regenerative surgery

It has been indicated that OTM might be a stimulating factor for bone apposition.[42,44] This could be due to an increase in the number of mitotic cells in the PDL[14] enhancing connective tissue healing, as well as restricting JE apical down-growth.[45] Therefore, it is suggested that, even if OTM itself does not guide new connective tissue attachment formation, it could be used to enhance the results of regenerative therapy.[45,74] In turn, regenerative periodontal procedures, with the use of bone synthetic materials,[80] could be implemented prior to OTM in order to create

favourable pre-orthodontic conditions in complex cases.[9] Although clinical studies have shown it is possible to treat deep infrabony defects with OFD and subsequent OTM by inducing osteogenesis,[55] only periodontal regeneration procedures have been proven capable of providing new connective tissue attachment in humans.[82]

Feasibility of OTM in regenerated areas

Animal studies indicate that teeth can be moved into defective bone areas previously filled with a xenograft with no adverse effect on the regenerative healing process or root resorption.[63,66] It has been observed that, after OTM, the biomaterial was replaced by new bone. However, the success of OTM when using synthetic bone replacement material is strongly linked to the choice of material, according to the likelihood of its resorption, or its participation in the remodelling processes.[80] Similar findings were shown in a case report,[70] in a descriptive case series[73] and a clinical review study.[78] Specifically, in the review study,[78] it was concluded that OTM in, and tooth eruption through, certain non-autogenous bone graft materials is possible and might provide positive results. However, when reviewing different regenerative materials, the report supported that hydroxyapatite (HA) ceramic cannot be recommended prior to OTM due to possible adverse effects related to dental malformations, root resorption or stagnation of tooth movement. However, tricalcium phosphate (TCP) was reported to be promising. In addition, it was mentioned that bioglasses used in conjunction with OTM may show positive results but their use is questioned. The low level of currently available evidence was stressed, as was the impossibility of providing recommendations or guidelines related to material use.[78] An RCT has also reported the successful outcome of OTM in two- and three-wall defects treated with allografts (EMD/DFDBA).[79] Moreover, a clinical case series has shown that OTM could be successfully undertaken after GTR with no damage to the regenerated tissues.[69,77] An extensive review on the different types and indications of regenerative materials is beyond the scope of the present study. However, additional research is considered necessary to avoid risks and possible adverse effects when moving teeth into allografts.

Time of initiation of OTM after regenerative surgery

Several clinical studies indicated that OTM was initiated only 10 to 14 days after bone grafting procedures with a xenograft.[70,73] A clinical trial even concluded that immediate application of OTM with regenerative therapy had the best clinical and radiographic outcome compared with delayed treatment (two months later) and with no adjunctive OTM.[81] The early initiation of OTM after bone grafting with bovine bone was also supported in a prospective case series.[82] In contrast, orthodontic-regenerative therapy with resorbable and non-resorbable membranes required a longer healing time prior to the initiation of OTM (two to six months, up to one year) to facilitate adequate tissue healing.[69,72,74,77] A systematic review concluded that there is no clear indication concerning the timing of GTR in cases of teeth that require orthodontic intrusion.[9]

The benefit of OTM on the regenerative process

Most of the reviewed studies reported that OTM, although feasible, has no or minor additional benefits for the regenerated tissues when performed after regenerative therapy.[46,64,65,77] In contrast, studies that included control groups[67,79,81] determined that subsequent OTM enhanced the regenerative potential of surgical techniques. The variability in the timing of OTM after regenerative therapy and the heterogeneity in defect morphology observed in the reviewed studies could possibly account for the differences. It might be suggested that, if OTM starts well after regenerative surgery, there might not be significant changes in the clinical parameters since tooth movement occurs in mature bone.[79] Moreover, the additional benefit of OTM on eliminating three-wall defects treated with EMD/DFDBA was shown to be inconsequential, since this defect morphology is conducive for periodontal regeneration. Adjunctive OTM might be more beneficial after regenerative treatment in the case of two-wall infrabony pockets.[79] In addition, OTM performed prior to regenerative surgery was reported capable of increasing the success rate of future GTR, but this evidence is limited to a case report study.[75] It seems that additional research is needed to further explore the possible benefit of OTM on regenerative therapy as well as identify the best timing of initiation of OTM after or prior to regenerative procedures.

Level of scientific evidence

The reviewed studies present a low level of evidence and are mostly limited to experimental animal research and case reports or case series with limited sample sizes. When evaluating the results of the current search, it was considered that in animal studies the repair of the bony defects could be attributed to specific metabolic characteristics of bone tissue of each species, which may significantly differ from the bone metabolism in humans.[9] However, it is essential to study and/or review the animal study outcomes, as this is mostly the only in-depth histological evidence available. In addition, since the resulting articles showed great diversity in methodology, it was not possible to perform a quantifying review. Perhaps standardisation of future studies will permit comparability between the different clinical protocols. Nonetheless, an effort was made to critically evaluate the best evidence currently available and draw useful clinical recommendations.

Clinical recommendations

The present results in general support the concept that adjunctive orthodontic treatment should be performed in adults to modify the tissue topography, reduce or eliminate angular bony defects and therefore obviate the need for excessive bone removal.[59] Treatment can also be successfully applied in conjunction with regenerative surgery in cases in which healing with formation of new connective tissue attachment is desirable. Furthermore, treatment may create a periodontal architecture that facilitates oral hygiene and helps in the prevention of further tissue breakdown.[36,37] The most common types of adjunctive OTM presented in this review are bodily tooth movement and intrusion of pathologically migrated incisors into infrabony defects, extrusion and uprighting of mesially tipped molars and extrusion of teeth away from infrabony lesions. Since the recommended interdisciplinary clinical protocol differs based on the type of angular bony defect present, a proper diagnosis is essential. A pretreatment three-dimensional assessment of the defect morphology with cone-beam computed tomography (CBCT), in addition to the traditional clinical and radiographic evaluation of the patient, is helpful in identifying the type of periodontal procedure and adjunctive tooth movement warranted in each defect site. Nevertheless, the importance of proper inflammation control, regular periodontal maintenance (in a two- to three-month recall basis) and communication between the orthodontist and the periodontist is stressed during this interdisciplinary treatment approach.

Conclusions

The literature indicates that adjunctive orthodontic treatment in adult patients with advanced periodontal disease could be a reliable therapeutic option for realigning migrated teeth, improving the occlusion, aesthetics, function and bone architecture in complex clinical cases. Future studies should employ well-designed RCTs in large cohorts of adult populations to provide statistical evidence of the efficacy and effectiveness of OTM alone or in combination with periodontal regenerative surgery. Such studies will also address the few controversies noted in the present review.

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