Journal of Dental Sciences 20 (2025) 417–427

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.e-jds.com

Original Article

Immediate orthodontic treatment after regeneration of periodontal intrabony defects: A long-term retrospective study

Shing-Zeng Dung [a,b,c*], I-Shiang Tzeng [d], Cheng-Shan Li [a]

[a] *Department of Dentistry, Taipei Tzu Chi Hospital, Buddhist Tzu Chi Medical Foundation, New Taipei City, Taiwan*
[b] *Department of Surgery, College of Medicine, Tzu Chi University, Hualien, Taiwan*
[c] *College of Dentistry, National Yang Ming Chiao Tung University, Taipei, Taiwan*
[d] *Department of Research, Taipei Tzu Chi Hospital, Buddhist Tzu Chi Medical Foundation, New Taipei City, Taiwan*

Received 7 May 2024; Final revision received 3 June 2024
Available online 12 June 2024

KEYWORDS
Orthodontic treatment;
Periodontal regeneration;
Timing

Abstract *Background/purpose:* Orthodontic movement is often necessary for periodontally compromised patients to enhance esthetics, function, and long-term occlusal stability. However, the impact of orthodontic treatment immediately following the regeneration of intrabony defects on periodontal healing remains a topic of debate. The objective of this long-term case series study was to test the hypothesis that orthodontic treatment performed immediately after regenerative procedures for periodontal intrabony defects did not adversely affect periodontal healing.
Materials and methods: This case series study involved nine periodontally compromised subjects with a total of 17 intra-bony defects. Orthodontic brackets were applied immediately before surgery. Flaps were raised, and diseased roots were debrided. All intra-bony defects were filled with alloplastic bone grafts and covered with resorbable membranes, except for one defect treated with Emdogain. All patients initiated orthodontic treatment immediately after periodontal regenerative surgery. Clinical parameters, including probing depth, attachment level, and bone fill, were assessed at baseline and during final maintenance therapy.
Results: The mean follow-up duration was 12.8 years. None of the 17 surgically regenerated teeth were lost. The mean reduction in probing depth was 3.94 mm (95% confidence level, 3.19–4.68; $P < 0.001$), with a mean clinical attachment gain of 3.47 mm (95% confidence level, 2.90–4.03; $P < 0.001$). The mean radiographic bone fill was 4.89 mm ($P < 0.001$).
Conclusion: Based on the findings of this long-term case study, it can be concluded that immediate orthodontic treatment does not adversely affect the maturation process of periodontal regeneration outcomes and can be maintained for more than ten years.

* Corresponding author. Department of Dentistry, Taipei Tzu Chi Hospital, Buddhist Tzu Chi Medical Foundation, No. 289, Jianguo Rd., Xindian Dist., New Taipei City 23142, Taiwan.
E-mail address: tonyangela0103@gmail.com (S.-Z. Dung).

https://doi.org/10.1016/j.jds.2024.06.003

Introduction

Periodontally compromised patients often experience aesthetic and chewing problems such as tooth elongation, tilting, flaring out, diastema, and missing teeth, necessitating interdisciplinary orthodontic treatment and oral rehabilitation. Numerous studies have highlighted that orthodontic treatment undertaken under plaque-induced periodontitis may result in periodontal attachment loss and intrabony defects.[1,2] However, when orthodontic treatment is conducted on reduced but healthy periodontal tissue, tooth movement may affect adjacent bone density without causing bone and attachment loss.[3,4] Thus, controlling periodontal inflammation in severely compromised patients before orthodontic treatment becomes imperative.[5,6]

While non-surgical treatments, open flap debridement, or bone grafting procedures may improve periodontal intrabony defects, tissue healing between bone and the tooth root surface often results in the formation of a long junctional epithelium rather than true regeneration.[7] While orthodontic movement such as extrusion or tilting may improve periodontal intrabony defects, it does not lead to the formation of new connective tissue attachment.[8,9] Orthodontic intrusion, on the other hand, may increase the risk of root resorption, intra-osseous defects, epithelial downgrowth, and loss of periodontal support.[10] Therefore, restoring periodontal attachment before initiating orthodontic treatment is advisable.

Guided tissue regeneration, which utilizes regenerative membranes or growth factors to block or inhibit epithelial tissue downgrowth into periodontal bone defects, may effectively regenerate periodontal ligament, alveolar bone, and cementum, thus restoring periodontal support.[11] The sequence and timing of periodontal and orthodontic treatments significantly impact the quality and efficiency of both procedures.[12] Recent studies suggest that orthodontic treatment performed simultaneously or soon after periodontal surgery can be integrated into routine treatment for patients with compromised periodontal dentition, thus reducing treatment time.[6,13–19] Nevertheless, the long-term preservation of regenerative outcomes alongside simultaneous orthodontic tooth movement remains uncertain.

This long-term case series study examines nine cases in which orthodontic treatment was conducted immediately after regenerative procedures for periodontal intrabony defects, with follow-up and maintenance extending beyond ten years.

Materials and methods

Patient selection

Between January 2007 and December 2023, nine patients (two men and seven women) with a mean age of 44.2 $\pm$ 9.0 years (range: 30–59) were enrolled in the study. These patients presented with severe periodontitis and malocclusion, along with at least one tooth exhibiting an intrabony defect and an initial clinical probing depth $\geq$5 mm. The study subjects received treatment at the Periodontal Department of Taipei Tzu Chi Hospital, Taiwan. These data were part of the study approved by the institutional review board at the Taipei Tzu Chi Hospital (Protocol No.: 13-IRB029). Only medically healthy patients diagnosed with Stage IV Grade III periodontitis, seeking both periodontal regenerative procedures and orthodontic therapy, and maintaining their condition for more than 10 years, were included. Exclusion criteria comprised alcohol and drug abuse, uncontrolled diabetes, heavy smoker and any systemic diseases which may compromise periodontal and orthodontic therapy.

Initial phase and clinical assessments

Basic periodontal treatment, including patient education, oral hygiene instructions, and scaling and root planing, was administered to manage periodontal infection. Clinical parameters, including probing depth, attachment level, and bone fill, were evaluated by a single investigator (S.-Z. Dung) from baseline through the end of orthodontic treatment and during maintenance therapy. Probing depth (PD) and clinical attachment level (CAL) were assessed using a periodontal probe (XP23/UNC 15, Hu-Friedy, Chicago, IL, USA). Periapical radiographs were obtained before treatment and every six months thereafter. Cone-beam computed tomography (CBCT, KaVo, 3D eXam, Biberach, Germany) scans were taken before treatment and at the final follow-up.

Surgical procedures and orthodontic phase

Self-ligating orthodontic braces (Damon Q, Ormco, Orange, CA, USA) were applied preoperatively to mitigate potential post-operative severe tooth hypersensitivity that may be induced by the acid etching procedure. All surgeries were conducted by one of the authors (SD), who possesses over 20 years of experience in periodontal surgery.

The selected surgical area was anesthetized with mepivacaine plus epinephrine 1:100,000. Subsequently, full-thickness mucoperiosteal flaps were raised using various incision techniques based on the defect anatomy. Following this, all granulation tissue and root surfaces were meticulously debrided using hand, ultrasonic, and rotary instruments (Neumyer bur, Salvin, Charlotte, NC, USA). In one case, the root surface was treated with emdogain® (Straumann, Basel, Switzerland). Intra-bony defects in all cases were then filled with bidirectional calcium phosphate bone grafts (MBCP®, Biomatlante, Nantes, France) and covered with resorbable polylactic acid membranes (Epi-

Guide®, Curasan, Raleigh, NC, USA) or collagen membranes (PeriAid®, Collagen Matrix, Franklin Lakes, NJ, USA; Neomem®, Citagenix, Laval, QC, Canada; or EZ Cure®, Biomatlante, Nantes, France). Finally, the flap was positioned coronally and secured with resorbable Vicryl sutures (Ethicon, J&J, Taipei, Taiwan) to promote optimal first-intention wound healing.

Damon orthodontic wires (Cu—Ni—Ti, 0.014 round wire) were inserted after suturing the flaps (Fig. 1). Orthodontic treatment was commenced immediately after the regenerative surgical procedures to facilitate the creation of implant sites, alleviate tooth crowding, or close diastema and flare-out of the anterior teeth.

Postsurgical care and orthodontic treatment

Patients were instructed to take 500 mg of amoxicillin and nonsteroidal analgesics three times a day for three days, beginning at least 1 h prior to surgery. The Damon orthodontic wire (Cu—Ni—Ti, 0.014) was inserted after suturing the flap. Additionally, 0.12% chlorhexidine mouthwash (Beauteeth Co., New Taipei City, Taiwan) was gargled twice daily for two weeks to control postoperative infection. Following surgery, patients applied ice packs to the treated area. Tooth brushing was discontinued, and chewing at the surgical site was avoided for four weeks. Stitches were removed two weeks after surgery, and supragingival mechanical plaque control was implemented. Wound care was provided at two, four, eight, and twelve weeks postoperatively.

Active orthodontic treatment was scheduled every four to eight weeks. Supportive periodontal treatment was administered immediately before active orthodontic treatment and every two to six months following the completion of orthodontic treatment.

Follow-up and clinical assessments

Motivational support, reinforcement of oral hygiene practices, and instrumentation of sites as necessary were carried out during the long-term follow-up. Probing depths (PD) were measured at buccal and lingual sites using a periodontal probe (XP23/UNC 15, Hu-Friedy) for each treated tooth. Measurements were rounded off to the nearest millimeter and compared with baseline values. Additionally, the number of teeth lost during supportive periodontal therapy (SPT) was recorded.

Upon completion of treatment, orthodontic appliances were removed, and all patients received fixed retainers to prevent relapse. Bite plates were provided for bruxers to prevent occlusal trauma. The measurement of bone defect fills before and after treatment was conducted according to the method outlined by Tonetti et al.,[20] in their study the bone fill is defined as the value of baseline CEJ-BD (distance between cementoenamel junction to bottom of defect) minuses final CEJ-BD.

Statistical analysis

Each site was treated as a statistical unit. The site of each tooth with the deepest PD was chosen for statistical analysis. The data were presented as mean ± standard deviation (SD). Differences for PD, CAL, and bone fill between baseline and the final examination were evaluated using

Figure 1 Periodontal regenerative surgeries were performed twice, initially on the lower arch and then one week later on the upper arch. The orthodontic wire (0.014 Cu—Ni—Ti round wire) was inserted immediately after the flap was sutured to initiate orthodontic treatment.

the Wilcoxon Signed-Rank Test. Confidence intervals of the differences were calculated at 95%, and all tests were two-tailed, with a significance level set at 0.05.

Results

All surgeries were healed uneventfully with minimal post-operative discomfort. Data regarding patients, defect location, regenerative materials, and main outcomes are shown in Table 1. Mean follow-up years were 12.8 years (range: 10–15). During the 10–15 years follow-up, none of the 17 surgically regenerated teeth were loss. Only one patient lost two teeth during the 15 years of follow up. The mean number of teeth lost during the 10–15 years follow up was 0.22 per patient. Treatment outcome of the 17 teeth after 10–15 Year follow up was listed in Table 2. Mean PD decreased from 7.26 ± 1.62 mm to 3.31 ± 1.00 mm, resulting in a mean PD reduction was 3.94 mm (3.19–4.68) with a statistically significant difference between baseline and follow-up ($P < 0.001$). Mean CAL decreased from 7.57 ± 2.01 mm to 4.11 ± 1.24 mm. Mean distance of CEJ-BD decreased from 9.85 ± 1.86 mm to 4.96 ± 1.29 mm. CAL gain was 3.47 mm and mean radiographic bone fill was 4.89 mm with a statistically significant difference between baseline and follow-up ($P < 0.001$).

Figs. 2–4 showed a treatment summary of cases 1–3. Data from pretreatment and post-treatment CBCT also revealed a significant bone fill of the intrabony defects. Case 1 is a 40-year-old female patient with Stage IV periodontitis and complained of diastema and flare out of anterior teeth. During surgery, an intrabony defect extending close to the pulp at both the buccal and palatal sides of tooth #13 was noted (Fig. 2A). Regenerative therapy was subsequently performed to restore the lost periodontal tissue. The clinical probing depth of tooth #13 decreased from 11 mm to 5 mm at the last follow-up appointment (Fig. 2B). Both periapical radiographs taken initially and at the last follow-up (Fig. 2C) and a cone-beam computed tomography (CBCT) scan conducted 11.5 years after periodontal regenerative treatment (Fig. 2D) revealed significant filling of the intrabony defect at both the buccal and palatal sides, accompanied by an increase in bone density.

Case 2 involves a 40-year-old female patient diagnosed with Stage IV periodontitis, presenting with crowded posterior teeth, diastema, flare-out of anterior teeth, and severe bone loss (Fig. 3A and B). Clinical probing depths of teeth #16 and #17 measured 6–7 mm. Regenerative therapy was utilized to reconstruct lost periodontal tissues. Both periapical radiographs taken initially and at the last follow-up (Fig. 3C) and a cone-beam computed tomography (CBCT) scan conducted 12.5 years after periodontal regenerative treatment (Fig. 3D) revealed significant filling of the intrabony defect of tooth #17 at both the buccal and palatal sides, accompanied by an increase in bone density.

Case 3 involves a 59-year-old female patient diagnosed with Stage IV periodontitis, whose chief complaint is anterior teeth flare-out and missing teeth. The intrabony defect on the palatal side of tooth #21 extended to the apex and penetrated to the buccal side of tooth #22 (Fig. 4A). Periodontal regenerative surgery was performed on #21, while guided bone regeneration surgery was conducted for #22. The intrabony defect of #21 and the horizontal ridge defect of #22 were filled with synthetic bidirectional calcium phosphate bone grafts and covered with absorbable polylactic acid membranes (Fig. 4B). The orthodontic wire (0.014 Cu–Ni–Ti round wire) was inserted immediately after the flap was sutured to initiate orthodontic treatment. Both periapical radiographs taken

Table 1 Data on patients, defect sites, regenerative materials, follow up years, and number of tooth loss during the 10–15 years follow-up.

Case number	Gender	Age	Defect sites	Regenerative materials	Follow up (years)	Tooth loss[a]
1	F	40	13d	MBCP + NeoMem	10	0
2	F	40	26m	MBCP + EpiGuide	12	0
2	F	40	22d	MBCP + EpiGuide	12	0
2	F	40	16m	MBCP + EpiGuide	12	0
2	F	40	17d	MBCP + EpiGuide	12	0
3	F	59	21d	MBCP + EpiGuide	13	0
4	M	30	12d	MBCP + EpiGuide	13	0
4	M	30	22d	MBCP + EpiGuide	13	0
5	F	52	43d	MBCP + EpiGuide	10	0
6	F	46	23d	MBCP + EpiGuide	12	0
6	F	46	11m	MBCP + EpiGuide	12	0
6	F	46	12d	MBCP + EpiGuide	12	0
6	F	46	15d	MBCP + EpiGuide	12	0
7	F	43	21m	MBCP + PeriAid	14	0
7	F	43	32d	MBCP + PeriAid	14	0
8	F	36	11m	MBCP + EzCure	14	0
9	M	52	35d	MBCP + Emdogain	15	2

M, male; F, female; MBCP®, bidirectional calcium phosphate bone grafts, Biomatlante, Nantes, France; EpiGuide®, Curasan, Raleigh, NC, USA; Neomem®, Citagenix, Laval, QC, Canada; PeriAid®, Collagen Matrix, Franklin Lakes, NJ, USA; EZ Cure®, Biomatlante, Nantes, France; Emdogain®, Straumann, Basel, Switzerland.

[a] Tooth loss during the follow-up of the patient.

Table 2 Treatment outcome of the 17 teeth after 10—15 year follow up (Means ± SD).

	Initial visit (mm)	Final visit (mm)	Difference (mm, 95% confidence interval)	*P* value (Wilcoxon Signed-Rank Test)
PD (mm)	7.26 ± 1.62	3.31 ± 1.00	3.94 (3.19—4.68)	$P < 0.001$
CAL (mm)	7.57 ± 2.01	4.11 ± 1.24	3.47 (2.90—4.03)	$P < 0.001$
CEJ-BD (mm)	9.85 ± 1.86	4.96 ± 1.29	4.89 (4.16—5.61)	$P < 0.001$

PD, probing depth; CAL, clinical attachment level; CEJ-BD, distance between cementoenamel junction to bottom of defect.

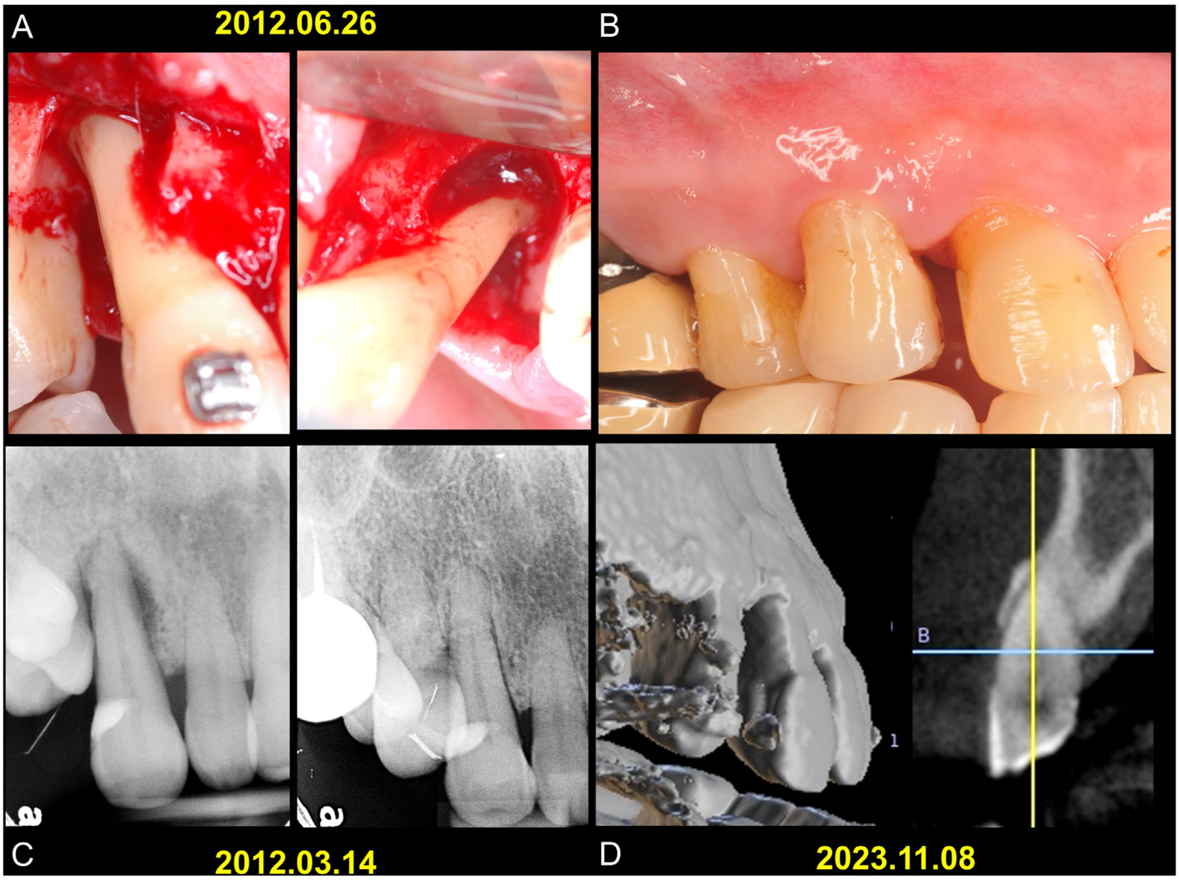

Figure 2 Case 1 is a 40-year-old female patient with Stage IV periodontitis and complained of diastema and flare out of anterior teeth. During surgery, an intrabony defect extending close to the pulp at both the buccal and palatal sides of tooth #13 was noted (Fig. 2A). Regenerative therapy was subsequently performed to restore the lost periodontal tissue. The clinical probing depth of tooth #13 decreased from 11 mm to 5 mm at the last follow-up appointment (Fig. 2B). Both periapical radiographs taken initially and at the last follow-up (Fig. 2C) and a cone-beam computed tomography (CBCT) scan conducted 11.5 years after periodontal regenerative treatment (Fig. 2D) revealed significant filling of the intrabony defect at both the buccal and palatal sides, accompanied by an increase in bone density.

initially and at the last follow-up (Fig. 4C) and a cone-beam computed tomography (CBCT) scan performed 14.5 years after periodontal regenerative treatment (Fig. 4D) revealed complete filling of the intrabony defect on the palatal side of tooth #21 and the transosseous defect on the buccal side of tooth #22, accompanied by an increase in bone density.

Discussion

In this case study, periodontal regenerative surgery and orthodontic treatment were conducted concurrently, with orthodontic treatment resuming immediately after the surgery. Significant reductions in PD and gains in CAL and radiographic bone level were maintained for up to 15 years. This suggests that orthodontic treatment performed immediately after regenerative procedures for periodontal intra-bony defects does not adversely affect periodontal healing. This study represents the first long-term case study, spanning over ten years, examining the outcomes of immediate orthodontic treatment following regeneration of periodontal intrabony defects.

The advantage of simultaneous orthodontic treatment with periodontal regenerative surgery lies in the ability to

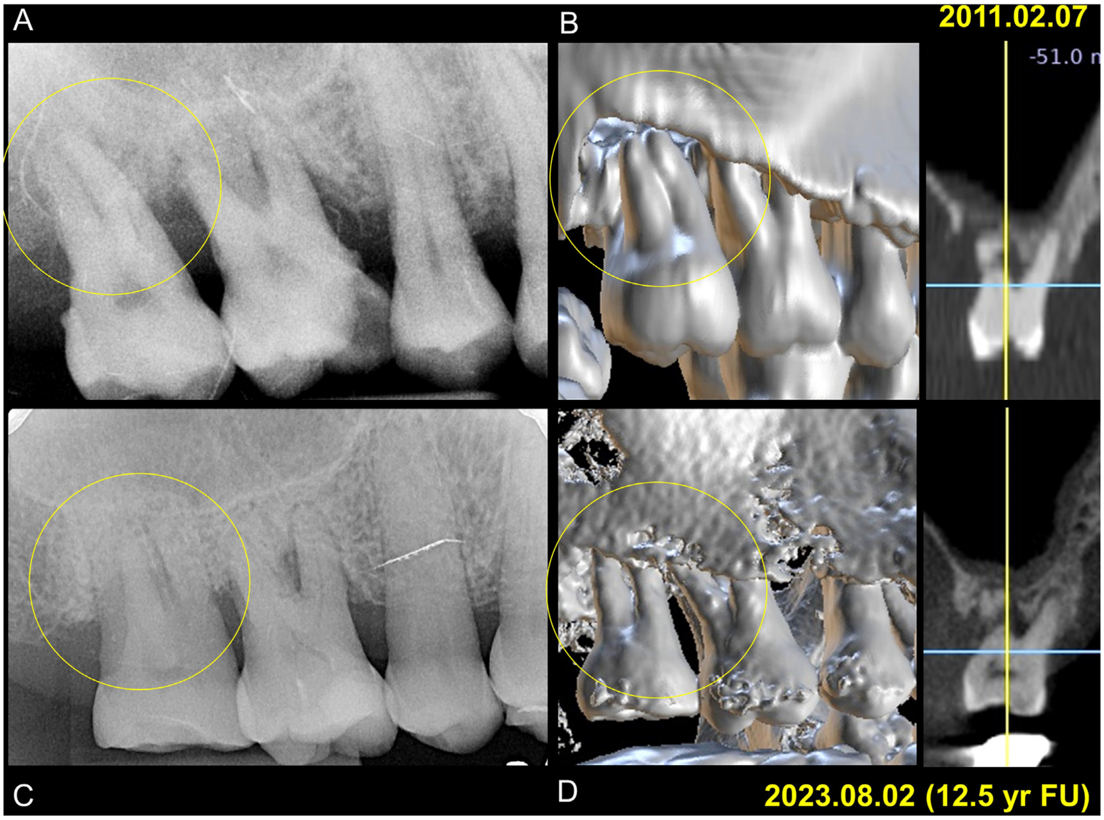

Figure 3 Case 2 involves a 40-year-old female patient diagnosed with Stage IV periodontitis, presenting with crowded posterior teeth, diastema, flare-out of anterior teeth, and severe bone loss. Clinical probing depths of teeth #16 and #17 measured 6—7 mm. Regenerative therapy was utilized to reconstruct lost periodontal tissues. Both periapical radiographs taken initially (Fig. 3A) and at the last follow-up (Fig. 3B) and a cone-beam computed tomography (CBCT) scan conducted initially (Fig. 3C) and 12.5 years after periodontal regenerative treatment (Fig. 3D) revealed significant filling of the intrabony defect of tooth #17 at both the buccal and palatal sides, accompanied by an increase in bone density.

shorten the overall treatment duration.[16—19] It's noteworthy that immediate orthodontic treatment did not compromise the maturation process of periodontal regeneration outcomes, which remained stable for over 10 years. However, it's important to emphasize that inadequate plaque control and maintenance care heightens the risk of treatment failure and subsequent destruction of periodontal tissues. Therefore, meticulous plaque control and maintenance therapy are essential to ensure the success and longevity of the treatment outcomes.[14,15]

When bone grafting procedures are performed prior to orthodontic treatment, concerns may arise regarding the potential interference of the materials with tooth movement.[21—23] Both animal experiments and clinical case reports have verified that the use of allografts and xenografts for bone grafting and periodontal regeneration does not impede tooth movement. Synthetic graft materials, while promising, require further investigation to determine their role in supporting orthodontic tooth movement.

Synthetic bidirectional calcium phosphate bone grafts have a unique micro- and macroporous structure that closely resembles the architecture of natural human bone. They were developed to control the resorbability of β-TCP by combining it with hydroxyapatite while maintaining osteoconductive properties. The specific ratio of hydroxyapatite and beta-tricalcium phosphate allows for better control of the bioabsorbability of the graft material, resulting in accelerated new bone formation.

Alloplasts utilized in this study have seldom been utilized in periodontal regenerative and orthodontic therapy. Miron in a review article indicated synthetic bone-grafting materials are primarily utilized when cultural and religious beliefs necessitate alternative solutions.[24] The selection of synthetic bone grafts or non-biologic resorbable membranes in the present study was driven by government regulations that prohibited the use of human or animal-derived regenerative materials, such as allografts, xenografts, collagen membranes, or enamel matrix derivatives, at the time.

Cortellini and Tonetti suggested that the selection of regenerative material is based on defect anatomy and the chosen flap design.[25] For the non-contained and severe defects in this study, a large flap is elevated, and stability is provided by applying combinations of barriers and fillers, or combinations of enamel matrix derivatives and fillers. Several animal and clinical studies have demonstrated the effectiveness of synthetic bone grafts and collagen membranes or enamel matrix derivative in promoting periodontal regeneration.[26—29] As far as the authors know, this clinical study is the first to evaluate the role of biphasic

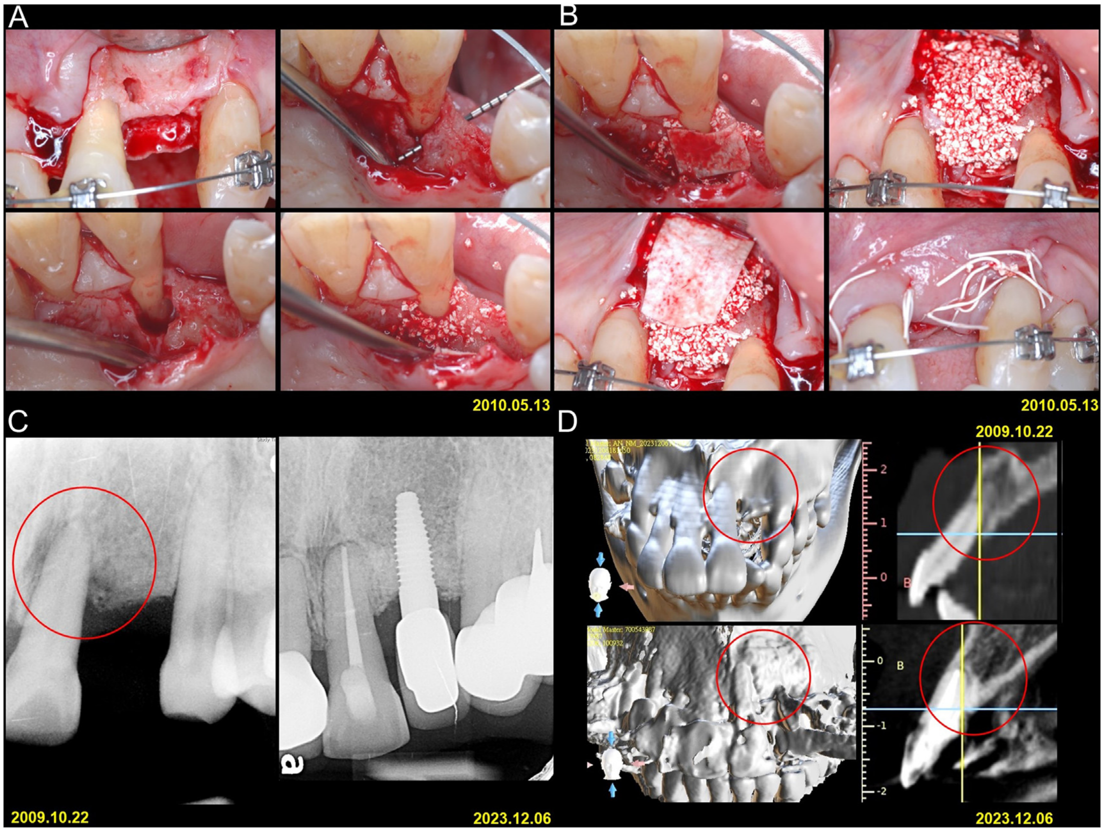

Figure 4 Case 3 involves a 59-year-old female patient diagnosed with Stage IV periodontitis, whose chief complaint is anterior teeth flare-out and missing teeth. The intrabony defect on the palatal side of tooth #21 extended to the apex and penetrated to the buccal side of tooth #22 (Fig. 4A). Periodontal regenerative surgery was performed on #21, while guided bone regeneration surgery was conducted for #22. The intrabony defect of #21 and the horizontal ridge defect of #22 were filled with synthetic bidirectional calcium phosphate bone grafts and covered with absorbable polylactic acid membranes (Fig. 4B). The orthodontic wire (0.014 Cu—Ni—Ti round wire) was inserted immediately after the flap was sutured to initiate orthodontic treatment. Both periapical radiographs taken initially and at the last follow-up (Fig. 4C) and a cone-beam computed tomography (CBCT) scan performed 14.5 years after periodontal regenerative treatment (Fig. 4D) revealed complete filling of the intrabony defect on the palatal side of tooth #21 and the transosseous defect on the buccal side of tooth #22, accompanied by an increase in bone density.

porous calcium phosphate in orthodontic tooth movement. In this study, all cases successfully underwent periodontal reconstruction using synthetic bone grafts combined with absorbable membranes or enamel matrix derivative, without hindering tooth movement or causing any long-term side effects. Currently, there is no histologic evidence supporting the combined use of synthetic bone grafts and absorbable membranes in the regeneration of periodontal intrabony defects. Additionally, further investigation is warranted to explore the histologic evidence of immediate orthodontic treatment following regenerative therapy for periodontal intrabony defects.

Periodontally compromised patients frequently present with aesthetic and chewing issues, necessitating interdisciplinary orthodontic treatment and oral rehabilitation.[3,4] The timing of orthodontic intervention necessitates professional judgment, considering the prognosis of the periodontal defect and the risk of treatment failure. Patients exhibiting poor plaque control, low compliance, smoking habits, inadequate glycemic control, or uncontrolled systemic diseases should undergo careful evaluation before undergoing periodontal surgery and orthodontic therapy. This comprehensive assessment ensures optimal treatment outcomes and minimizes the risk of complications associated with these interventions.

In severe periodontal patients, where periodontal bone height is significantly reduced, orthodontic treatment is often more suitable for tipping movements rather than bodily movements. In cases where tooth supporting tissue is insufficient, mini-screws or prosthetic implants may be utilized for absolute anchorage. It's essential to apply light and continuous forces during orthodontic treatment to minimize stress and reduce the risk of root resorption. Additionally, for adult periodontal patients undergoing orthodontic treatment, it's advisable to simplify the orthodontic device to facilitate plaque control.[10] This may involve reducing the use of wire loops and elastomeric ligatures and transitioning to self-locking brackets and stainless-steel ligatures. In molar areas, it's recommended to replace ring sleeve devices with adhesive devices.

Effective control of inflammation, meticulous plaque removal, and reduction of bleeding on probing, along with regular professional periodontal maintenance during orthodontic treatment, are critical for the success of combined periodontal and orthodontic therapy.[3–5] Consideration should be given to tooth splinting after orthodontic treatment to address increased tooth mobility due to decreased bone height, tooth discomfort, or aesthetic and functional concerns.[30] Patients with severe periodontal disease are advised to use a fixed retainer made of permanent multi-strand non-rigid stainless-steel wire, and if necessary, wear an occlusal bite plate to prevent recurrence. This comprehensive approach ensures the success and long-term stability of treatment outcomes in patients with severe periodontal disease undergoing orthodontic therapy.

Periodontal regenerative surgery in periodontally compromised patients can be conducted before, simultaneously with, or after orthodontic treatment, depending on the specific needs and circumstances of each patient. In general, regenerative treatment of deep and narrow intrabony defects tends to be more predictable and effective compared to broad and shallow defects, which have a poorer prognosis. To address this challenge, Stezel and Flores-de-Jacoby utilized orthodontic treatment to correct crowded and less favorable patterns of bone defects in the lower anterior area. This approach aimed to create a more favorable defect morphology and facilitate the placement and fixation of regenerative membranes.[31]

Similarly, several studies have reported successful transformation of broader intrabony defects into more favorable deeper and narrower defects for periodontal regeneration using orthodontic compression forces.[28,32,33] These studies highlight the potential of orthodontic intervention to optimize the conditions for successful periodontal regeneration in cases with initially unfavorable defect morphologies.

Early studies predominantly began with non-surgical periodontal treatment or flap surgery, followed by the initiation of orthodontic treatment once a stable periodontal condition was achieved.[34,35] This sequential approach aimed to address periodontal issues and establish a favorable environment for orthodontic tooth movement. By ensuring periodontal health and stability before orthodontic intervention, this approach aimed to optimize treatment outcomes and minimize the risk of complications associated with untreated periodontal disease.

For individuals with severe periodontal bone loss or significant horizontal or vertical ridge defects that are not conducive to tooth movement, periodontal or guided bone regeneration may be recommended before initiating orthodontic treatment. This approach aims to address the underlying periodontal issues and optimize the bone support and architecture before undertaking orthodontic tooth movement. Nemcovsky was a pioneer in combining periodontal regenerative surgery with orthodontic treatment.[36] In his approach, orthodontic treatment was initiated six months after periodontal regenerative treatment. This innovative integration of periodontal and orthodontic therapies aimed to optimize treatment outcomes by allowing sufficient time for periodontal healing and stabilization before initiating orthodontic tooth movement. Zachrisson,[3] Kokich,[4] and Nemcovsky[36] have suggested that orthodontic treatment should be initiated three to six months after periodontal regeneration. While performing periodontal regenerative surgery before orthodontic treatment can enhance periodontal support, reduce the risk associated with orthodontics, and improve the overall stability of combined periodontal and orthodontic therapy, it may also prolong the overall treatment duration. This delay allows for adequate healing and stabilization of the periodontal tissues before orthodontic forces are applied, thereby optimizing treatment outcomes and minimizing potential complications. However, it's essential to balance the benefits of sequential treatment with the desire to minimize treatment duration, considering each patient's unique needs and preferences.

Ogihara and Wang conducted a randomized, parallel clinical trial to assess the clinical efficacy of limited orthodontics combined with enamel matrix derivative (EMD) and demineralized freeze-dried bone allograft (DFDBA) in treating 2- or 3-wall intrabony defects.[37] Forty-seven randomized patients, with either a 2- or 3-wall intrabony defect of $\geq$6 mm depth, were assigned to either the ortho/EMD/DFDBA group or the EMD/DFDBA group. Intrabony defects were surgically treated with EMD and DFDBA 4 weeks before the initiation of orthodontic forces. Results demonstrated that both treatment approaches, EMD/DFDBA alone and ortho/EMD/DFDBA, were effective in treating 2- or 3-wall intrabony defects within the 1-year study period. However, the ortho/EMD/DFDBA group exhibited statistically significant open probing attachment level gain compared to the EMD/DFDBA group specifically in 2-wall defects. This suggests that combining limited orthodontics with EMD and DFDBA may offer additional benefits in terms of CAL gain, particularly in certain types of intrabony defects.

In a prospective case series conducted by Ghezzi et al., 10 patients presenting with radiographic vertical defects and PD $\geq$ 6 mm along with pathologic tooth migration were included.[38] Each patient received treatment for one intrabony defect using a combination of enamel matrix derivative and collagen bovine mineral bone. Orthodontic therapy was initiated for all patients one month after the periodontal surgery. The results indicated a mean reduction in probing depth of 3.7 mm and a mean CAL gain of 4.4 mm following the combined periodontal and orthodontic treatment. These findings suggest that the combination of EMD and collagen bovine mineral bone, followed by orthodontic therapy, was effective in reducing PD and improving CAL in patients with radiographic vertical defects and pathologic tooth migration.

Frost introduced the theory of regional accelerated phenomena (RAP), which observed accelerated bone metabolism and decreased bone density in surgical wounds.[39] Building upon this theory, Sebaoun et al. conducted a study involving cortical bone perforation on the buccal and lingual sides of the upper first molar.[40] Animals were sacrificed at the third and eleventh week post-surgery to analyze the catabolic and anabolic activity of bone, as well as changes in periodontal ligaments. The results demonstrated that at 3 weeks following surgical injury to the alveolus, the catabolic and anabolic turnover were three-fold greater and dissipated to a steady state by postoperative week 11.

Yaffe proposed that periodontal flap surgery could induce a regional acceleration phenomenon. In a study involving rat mucoperiosteal flap surgery, it was observed that surgical wounds accelerated bone metabolism after 10 days, with the effect subsiding after 120 days.[41] This suggests a transient but significant impact of periodontal flap surgery on bone metabolism, supporting the concept of regional acceleration phenomenon in periodontal surgery.

Binderman proposed that cutting gingival fibers and periodontal ligament fibers during periodontal flap surgery could facilitate tooth movement.[42] In severe periodontal patients with reduced periodontal support and mobile teeth, the compromised periodontal attachment may indeed contribute to faster tooth movement. This suggests that the altered periodontal condition in such patients may inadvertently aid orthodontic treatment by reducing resistance to tooth movement. However, careful consideration of the overall periodontal health and stability is essential to ensure successful treatment outcomes and minimize potential complications.

In this study, patients did not undergo corticotomy during periodontal surgery, yet significant de-crowding and closure of interdental spaces were achieved within three months after surgery. This raises questions about the necessity of corticotomy during flap surgery to achieve rapid orthodontic results. Further evaluation is warranted to determine whether corticotomy provides additional benefits in accelerating orthodontic treatment during periodontal surgery to provide more insights into this matter.

Re et al.,[43,44] Cardaropoli et al.,[45–47] and Kokich[4] have suggested that periodontal surgery, when performed early (within 1–2 weeks), may accelerate the metabolism of periodontal bone and ligaments. This acceleration could facilitate orthodontic tooth movement. Only a few controlled clinical trials have provided data indicating that orthodontic treatment, either simultaneously with or shortly after (within 1 month) periodontal surgery, could be incorporated into the routine treatment of patients with compromised periodontal dentition.[15–17] This approach not only reduces treatment time but also addresses both periodontal and orthodontic needs concurrently. However, it's important to note that the available studies thus far have mostly provided short-term outcomes, and further long-term evaluation is needed to fully assess the efficacy and stability of this treatment approach.

In a split-mouth, one-year controlled clinical trial conducted by Attia et al., a total of 45 defects in 15 patients were divided into three groups and treated.[15] The groups consisted of regenerative therapy with immediate orthodontic tooth movement, regenerative therapy with delayed orthodontic tooth movement (test groups), and regenerative therapy alone (control group). The results of the study indicated that the group receiving regenerative therapy with immediate orthodontic tooth movement exhibited the best clinical outcomes. Specifically, the mean reduction in PD and gain in CAL were 4.0 mm and 5.1 mm, respectively, for the immediate application of orthodontic tooth movement. In comparison, the delayed application of orthodontic movement resulted in a mean PD reduction and CAL gain of 3.7 mm and 4.3 mm, respectively. Additionally, the group undergoing immediate orthodontic tooth movement demonstrated a mean bone fill of 3.7 mm. These findings suggest that combining regenerative therapy with immediate orthodontic tooth movement may lead to superior clinical outcomes compared to regenerative therapy alone or regenerative therapy with delayed orthodontic movement.

In a 12- and 24-month multi-center, parallel-group, randomized clinical trial conducted by Jepsen et al., the outcomes of early (4 weeks post-surgery) versus late (6 months post-surgery) orthodontic therapy following regenerative surgery of intrabony defects were compared.[16,17] A total of 43 patients with stage IV periodontitis were randomized to receive either early or late orthodontic therapy following regenerative surgery. The results indicated that there were no statistically significant differences between the two groups for CAL gain and PD reduction. Specifically, the group receiving early orthodontic therapy exhibited a mean CAL gain of 5.96 ± 2.10 mm and a mean PD reduction of 4.43 ± 1.62 mm. These findings suggest that the timing of orthodontic therapy following regenerative surgery did not significantly impact the clinical outcomes in terms of CAL gain and PD reduction.

The data of the present long-term case study indicates a mean reduction of 3.94 mm in probing depth (95% confidence level, 3.19–4.68; $P < 0.001$), an attachment gain of 3.47 mm (95% confidence level, 2.90–4.03; $P < 0.001$), and a bone fill of 4.89 mm in the defect (95% confidence level, 4.16–5.61; $P < 0.001$). The differences in treatment outcomes between the present study and those of Attia et al. and Jepsen et al. may be attributed to variations in initial PD, CAL, defect morphology, tooth type, and regenerative materials. While previous studies primarily focused on the treatment outcome of intrabony defects in anterior teeth with pathologic tooth migration, the present study demonstrates a favorable treatment outcome not only for anterior teeth but also for intrabony defects in posterior teeth. The present case study shows a promising long-term outcome of orthodontic treatment performed immediately after regenerative procedures for periodontal intrabony defects. Data from the present study suggests orthodontic tooth movement may stimulate early healing phase of periodontal regeneration. However, the impact of orthodontic treatment on wound healing immediately after periodontal regenerative surgery remains unclear and need further histological evidence and long-term controlled studies.

Declaration of competing interest

The authors declare no conflicts of interest.

References

1. Wennström JL, Stokland BL, Nyman S, Thilander B. Periodontal tissue response to orthodontic movement of teeth with infrabony pockets. *Am J Orthod* 1993;103:313–9.
2. Ericsson I. The combined effects of plaque and physical stress on periodontal tissues. *J Clin Periodontol* 1986;13:918–22.
3. Zachrisson BU. Clinical implications of recent orthodontic-periodontic research findings. *Semin Orthod* 1996;2:4–12.
4. Kokich VG. Adjunctive role of orthodontic therapy. In: Newman MG, Takei HH, Klokkevold PR, Carranza FA, eds. *Carranza's clinical periodontology*, 10th ed. St. Louis, Missouri: Saunders, 2006:856–70.
5. Roccuzzo M, Marchese S, Dalmasso P, Roccuzzo A. Periodontal regeneration and orthodontic treatment of severely

periodontally compromised teeth: 10-year results of a prospective study. *Int J Periodontics Restor Dent* 2018;38:801—9.
6. Martin C, Celis B, Ambrosio N, Bollain J, Antonoglou GN, Figuero E. Effect of orthodontic therapy in periodontitis and non-periodontitis patients: a systematic review with meta-analysis. *J Clin Periodontol* 2022;49(Suppl 24):72—101.
7. Caton J, Nyman S, Zander H. Histometric evaluation of periodontal surgery. II. connective tissue attachment levels after four regenerative procedures. *J Clin Periodontol* 1980;7: 224—31.
8. Polson A, Caton J, Polson AP, Nyman S, Novak J, Reed B. Periodontal response after tooth movement into intrabony defects. *J Periodontol* 1984;55:197—202.
9. Ingber JS. Forced eruption. I. A method of treating isolated one and two wall infrabony osseous defects-rationale and case report. *J Periodontol* 1974;45:199—206.
10. Ericsson I, Thilander B, Lindhe J, Okamoto H. The effect of orthodontic tilting movements on the periodontal tissues of infected and non-infected dentitions in dogs. *J Clin Periodontol* 1977;4:278—93.
11. Diedrich PR. Guided tissue regeneration associated with orthodontic therapy. *Semin Orthod* 1996;2:39—45.
12. Kao RT, Nares S, Reynolds MA. Periodontal regeneration — intrabony defects: a systematic review from the AAP regeneration workshop. *J Periodontol* 2015;86(2 Suppl):S77—104.
13. Aimetti M, Garbo D, Ercoli E, Grigorie MM, Citterio F, Romano F. Long-term prognosis of severely compromised teeth following combined periodontal and orthodontic treatment: a retrospective study. *Int J Periodontics Restor Dent* 2020;40:95—102.
14. Tietmann C, Bröseler F, Axelrad T, Jepsen K, Jepsen S. Regenerative periodontal surgery and orthodontic tooth movement in stage IV periodontitis: a retrospective practice-based cohort study. *J Clin Periodontol* 2021;48:668—78.
15. Attia MS, Hazzaa HH, Al-Aziz FA, Nassar HA. Evaluation of adjunctive use of low-level diode laser biostimulation with combined orthodontic regenerative therapy. *J Int Acad Periodontol* 2019;21:63—73.
16. Jepsen K, Tietmann C, Kutschera E, et al. The effect of timing of orthodontic therapy on the outcomes of regenerative periodontal surgery in patients with stage IV periodontitis: a multicenter randomized trial. *J Clin Periodontol* 2021;48: 1282—92.
17. Jepsen K, Tietmann C, Martin C, et al. Synergy of regenerative periodontal surgery and orthodontics improves quality of life of patients with stage IV periodontitis: 24-month outcomes of a multicenter RCT. *Bioengineering* 2023;10:695.
18. Tu CC, Lo CY, Chang PC, Yin HJ. Orthodontic treatment of periodontally compromised teeth after periodontal regeneration: a retrospective study. *J Formos Med Assoc* 2022;121: 2065—73.
19. Zasčiurinskienė E, Basevičienė N, Lindsten R, Slotte C, Jansson H, Bjerklin K. Orthodontic treatment simultaneous to or after periodontal cause-related treatment in periodontitis susceptible patients. part I: clinical outcome. a randomized clinical trial. *J Clin Periodontol* 2018;45:213—24.
20. Tonetti MS, Pini-Prato G, Cortellini P. Periodontal regeneration of human intrabony defects. IV. determinants of healing response. *J Periodontol* 1993;64:934—40.
21. Ahn HW, Ohe JY, Lee SH, Park YG, Kim SJ. Timing of force application affects the rate of tooth movement into surgical alveolar defects with grafts in beagles. *Am J Orthod Dentofacial Orthop* 2014;145:486—95.
22. Araújo MG, Carmagnola D, Berglundh T, Thilander B, Lindhe J. Orthodontic movement in bone defect augmented with Bio-Oss: an experimental study in dogs. *J Clin Periodontal* 2001; 28:73—80.
23. Re S, Corrente G, Abundo R, Cardaropoli D. Orthodontic movement into bone defect augmented with bovine bone material and fibrin sealer: a reentry case report. *Int J Periodontics Restor Dent* 2002;22:365—71.
24. Miron RJ. Optimized bone grafting. *Periodontol 2000* 2024;94: 143—60.
25. Cortellini P, Tonetti MS. Clinical concepts for regenerative therapy in intrabony defects. *Periodontol 2000* 2015;68: 282—307.
26. Nery EB, LeGeros RZ, Lynch KL, Lee K. Tissue response to biphasic calcium phosphate ceramic with different ratios of HA/beta TCP in periodontal osseous defects. *J Periodontol* 1992;63:729—35.
27. Shi H, Ma J, Zhao N, Chen Y, Liao Y. Periodontal regeneration in experimentally-induced alveolar bone dehiscence by an improved porous biphasic calcium phosphate ceramic in beagle dogs. *J Mater Sci Mater Med* 2008;19:3515—24.
28. Zafiropoulos GG, Hoffmann O, Kasaj A, Willershausen B, Weiss O, Van Dyke TE. Treatment of intrabony defects using guided tissue regeneration and autogenous spongiosa alone or combined with hydroxyapatite/b-tricalcium phosphate bone substitute or bovine derived xenograft. *J Periodontol* 2007;78:2216—25.
29. Sculean A, Windisch P, Szendröi-Kiss D, et al. Clinical and histologic evaluation of an enamel matrix derivative combined with a biphasic calcium phosphate for the treatment of human intrabony periodontal defects. *J Periodontol* 2008;79:1991—9.
30. Nyman S, Lindhe J, Lundgren D. The role occlusion for the stability of fixed bridges in patients with reduced periodontal tissue support. *J Clin Periodontol* 1975;2:53—66.
31. Stelzel MJ, Flores-de-Jacoby L. Guided tissue regeneration in a combined periodontal and orthodontic treatment: a case report. *Int J Periodontics Restor Dent* 1998;18:189—95.
32. Kazandjian G, Scopp IW, Stahl S. Combined orthodontic-periodontal treatment of an infrabony defect. a case report. *J Periodontol* 1979;50:479—82.
33. Cao T, Xu L, Shi J, Zhou Y. Combined orthodontic-periodontal treatment in periodontal patients with anteriorly displaced incisors. *Am J Orthod Dentofacial Orthop* 2015;148:805—13.
34. Melsen B, Agerbaek N, Markenstam G. Intrusion of incisors in adult patients with marginal bone loss. *Am J Orthod Dentofacial Orthop* 1989;96:232—41.
35. Nevins M, Wise RJ. Use of orthodontic therapy to alter infrabony pockets. 2. *Int J Periodontics Restor Dent* 1990;10: 198—207.
36. Nemcovsky CE. Orthodontic tooth movement following guided tissue regeneration: report of three cases. *Int J Adult Orthod Orthognath Surg* 1996;11:347—55.
37. Ogihara S, Marks MH. Enhancing the regenerative potential of guided tissue regeneration to treat an intrabony defect and adjacent ridge deformity by orthodontic extrusive force. *J Periodontol* 2006;77:2093—100.
38. Ghezzi C, Viganò VM, Francinetti P, Zanotti G, Masiero S. Orthodontic treatment after induced periodontal regeneration in deep infrabony defects. *Clin Adv Periodontics* 2013;3:24—31.
39. Frost HM. The biology of fracture healing. an overview for clinicians. part I and part II. *Clin Orthop Relat Res* 1989;248: 283—309.
40. Sebaoun JD, Kantarci A, Turner JW, Carvalho RS, Van Dyke TE, Ferguson DJ. Modeling of trabecular bone and lamina dura following selective alveolar decortication in rats. *J Periodontol* 2008;79:1679—88.
41. Yaffe A, Fine N, Binderman I. Regional accelerated phenomenon in the mandible following mucoperiosteal flap surgery. *J Periodontol* 1994;65:79—83.
42. Binderman I, Gadban N, Bahar H, Herman A, Yaffe A. Commentary on: periodontally accelerated osteogenic orthodontics (PAOO) - a clinical dilemma. *Int Orthod* 2010;8:268—77.
43. Re S, Corrente G, Abundo R, Cardaropoli D. Orthodontic treatment in periodontally compromised patients: 12-year report. *Int J Periodontics Restor Dent* 2000;20:31—9.

44. Re S, Cardaropoli D, Abundo R, Corrente G. Reduction of gingival recession following orthodontic intrusion in periodontally compromised patients. *Orthod Craniofac Res* 2004;7: 35—9.
45. Corrente G, Abundo R, Re S, Cardaropoli D, Cardaropoli G. Intrusion of migrated incisors with infrabony defects in adult periodontal patients. *Am J Orthod Dentofacial Orthop* 2001; 120:671—5.
46. Cardaropoli D, Re S, Corrente G, Abundo R. Reconstruction of the maxillary midline papilla following a combined orthodontic-periodontic treatment in adult periodontal patients. *J Clin Periodontol* 2004;31:79—84.
47. Cardaropoli D, Re S, Manuzzi W, Gaveglio L, Cardaropoli G. Bio-Oss collagen and orthodontic movement in the treatment of intrabony defects in the esthetic zone. *J Clin Periodontol* 2006;26:553—9.