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REVIEW ARTICLE

Periodontal considerations during orthodontic intrusion and extrusion in healthy and reduced periodontium

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Abstract

In patients with advanced periodontal disease, pathological tooth migration may occur, which may require subsequent orthodontic treatment for both aesthetic and functional purposes. When planning orthodontic treatment mechanics, intrusive or extrusive forces are frequently indicated. Understanding tissue reactions during these movements is essential for clinicians when devising a comprehensive orthodontic-periodontal treatment plan. This knowledge enables clinicians to be fully aware of and account for the potential effects on the surrounding tissues. The majority of our understanding regarding the behavior of periodontal tissues in both healthy and compromised periodontal conditions is derived from animal studies. These studies offer the advantage of conducting histological and other assessments that would not be feasible in human research. Human studies are nevertheless invaluable in being able to understand the clinically relevant response elicited by the periodontal tissues following orthodontic tooth movement. Animal and human data show that in dentitions with reduced periodontal support, orthodontic intrusion of the teeth does not induce periodontal damage, provided the periodontal tissues do not have inflammation and plaque control with excellent oral hygiene is maintained. On the contrary, when inflammation is not fully controlled, orthodontic intrusion may accelerate the progression of periodontal destruction, with bacterial plaque remnants being displaced subgingivally, leading to further loss of attachment. Orthodontic extrusion, on the other hand, does not seem to cause further periodontal breakdown in dentitions with reduced periodontal support, even in cases with deficient plaque control. This is attributed to the nature of the tooth movement, which directs any plaque remnants coronally (supragingivally), reducing the risk of adverse effects on the periodontal tissues. This specific type of tooth movement can be leveraged to benefit periodontal conditions by facilitating the regeneration of lost hard and soft periodontal tissues in a coronal direction. As a result, orthodontic extrusion can be employed in implant site development, offering an advantageous alternative to more invasive surgical procedures like bone grafting. Regardless of the tooth movement prescribed, when periodontal involvement is present, it is essential to prioritize periodontal therapy before commencing orthodontic treatment. Adequate plaque control is also imperative for successful outcomes. Additionally, utilizing light orthodontic forces is advisable to achieve efficient tooth movement while minimizing the risk of adverse effects, notably root resorption. By adhering to these principles, a more favorable and effective combined orthodontic-periodontal approach can be ensured. The present article describes indications, mechanisms, side effects, and histological and clinical evidence supporting orthodontic extrusion and intrusion in intact and reduced periodontal conditions.

KEYWORDS
healthy periodontium, interdisciplinary treatment, orthodontic extrusion, orthodontic intrusion, orthodontic treatment, periodontal disease, reduced periodontium

1 | INTRODUCTION

Orthodontic intrusion and extrusion, or apical and coronal tooth movements, are vertically oriented tooth movements. They often occur in concert with a comprehensive orthodontic treatment due to the fact that continuous archwires are used to achieve these movements, which implies that for every extrusive force there is also an equal and opposite intrusive force and vice versa. Well-planned orthodontic mechanics, especially with the support of skeletal anchorage, are necessary in order to achieve either extrusion or intrusion of a single tooth or groups of teeth, without the concomitant opposite force on neighboring teeth. In addition, even when intrusive or extrusive tooth movements are planned, due to the location of the application of the force with respect to the center of resistance, this intrusive or extrusive movement is rarely exclusive, meaning that there is also some associated labial/vestibular or lingual/palatal crown movement.

When performing these orthodontic tooth movements in a healthy and intact periodontium versus a healthy but reduced, or diseased, periodontium, different tissue reactions may be expected. It seems perhaps superfluous, but it is necessary to stress that any desired intrusive or extrusive orthodontic tooth movements in the case of a reduced periodontium should always be performed under circumstances where any inflammation or active disease is controlled and under remission, in order to minimize the possibility of any adverse effects ensuing. Adequate plaque control is crucial when performing these types of tooth movements regardless of the conditions, whether in a healthy and intact or healthy but reduced periodontium.

The present article aims to discuss these two different orthodontic tooth movements, namely intrusion and extrusion, detailing their indications, mechanisms, potential side effects, and results from experimental animal studies and human studies or case series with regard to their effect on the periodontium. These effects will be looked at separately for cases with a healthy and intact periodontium, a healthy but reduced periodontium, or a diseased periodontium. Finally, clinical recommendations, based on the current evidence, will be provided for each type of tooth movement individually.

2 | ORTHODONTIC INTRUSION

2.1 | Indications for orthodontic tooth intrusion

Intrusion of teeth, namely the apical displacement into the alveolar bone, is considered to be one of the most difficult tooth movements to apply due to a lack of available anchorage, sometimes with the need for patient cooperation, and unpredictable retention results. Many orthodontic methods are available to produce this intrusion, either of single teeth or groups of teeth, which can be carried out in certain clinical situations. One such situation is the intrusion of the maxillary anterior teeth in order to decrease a gummy smile (excessive gingival display), or the mandibular (and sometimes maxillary) anterior teeth in order to correct a deep bite,[1] especially when traumatic,[2] or when leveling a deep curve of Spee. Another clinical situation where tooth intrusion is planned is in cases where intrusion of the posterior teeth is desired in patients with an anterior open bite or excessive anterior facial height. This may be combined in some cases with concomitant extrusion of the anterior teeth to help close the open bite.

Intrusion of single or multiple teeth is also desired in situations where there is overeruption of a tooth due to a missing antagonist tooth,[3,4] which is especially the case in individuals who lost their antagonist teeth at a younger age[5,6] or in the presence of periodontal disease and pathological tooth migration.[4,7] Continuous tooth eruption is a critical factor to consider in the treatment of patients, as it can vary in intensity among individuals.[8–10] While physiological continuous tooth eruption does not require any particular attention, excessive eruption or extrusion due to underlying pathology may necessitate intervention. Equally, continuous eruption of teeth adjacent to implant-supported crowns also requires particular attention as it may create aesthetically unfavorable outcomes, especially in the maxillary anterior region, due to the vertical step created between natural and implant-supported teeth.[11,12] Understanding this continuous eruption process is vital, particularly when monitoring long-term orthodontic intrusion outcomes, as it may elevate the risk of instability in such cases.

The treatment of pathological extrusion (pathological tooth migration) in the context of periodontal disease is a common indication to perform an intrusion of the affected tooth or teeth.[13,14] In particular in the anterior region, tooth migration following periodontal disease is often a combination of extrusion and a certain degree of proclination, seen clinically as flaring and elongation of the incisors,[15] and this kind of migration is often associated with the presence of infrabony defects. The European Federation of Periodontology (EFP) recently published clinical practice guidelines for the treatment of stage IV periodontitis, focusing on the implementation of inter-disciplinary treatment approaches.[16] Pathologic tooth migration, characterized by tooth elongation, drifting, and flaring, was recognized as a major stage IV periodontitis phenotype with the need for orthodontic correction. The expert panel recognized that orthodontic therapy in these cases can be planned only after subgingival instrumentation and/or periodontal surgery, if needed, with the goal of achieving shallow, maintainable pockets and controlling periodontal inflammation.

In these cases, orthodontic intrusion is a reliable therapeutic approach to realigning migrated teeth, improving both aesthetics and function once periodontal therapy is performed. This can have a beneficial effect on periodontal parameters, including clinical crown length and marginal bone level, and may pave the way toward periodontal regeneration procedures if deemed necessary.

Additional reasons requiring orthodontic tooth intrusion may encompass the alignment of gingival margins with neighboring teeth. This is particularly relevant when addressing protruded and malpositioned teeth, particularly in instances where such intervention is concomitant with restorative procedures. This collaborative approach assists the restorative dentist in attaining enhanced aesthetic results, as illustrated in Figure 1. The gingival margin in these cases will move apically together with the tooth.[17] Leveling of a cant in the occlusal plane is another situation where tooth intrusion may be prescribed.

2.2 | Mechanisms of orthodontic tooth intrusion

When intrusion is desired, this can generally be achieved by using anchorage from the neighboring teeth, which implies biomechanically that the neighboring teeth will be subject to extrusive forces and display a certain amount of extrusion. One such example is the use of a continuous archwire with a reverse curve of Spee to level a deep curve of Spee,[18] or when intruding single teeth using the direct neighboring teeth as anchorage with fixed appliances. Another example of intrusion of certain teeth with the extrusion of others is in cases of severe anterior tooth wear where it is desired to intrude anterior teeth and extrude posterior teeth, thus allowing space for the restoration of worn anterior teeth.[19,20]

One must always keep in mind that intrusion forces rarely pass directly through the long axis of the teeth and through the center of resistance. For this reason, in addition to the intrusive force, there is also a moment created that produces a vestibular or labial crown tip when using vestibular orthodontic brackets. If bone loss has occurred and intrusion is carried out, the moment produced may be greater as the center of resistance of the tooth is displaced apically (Figure 2). If using lingual brackets, the moments created can be different due to the fact that the force application is different with respect to the center of resistance of the tooth. On some occasions,

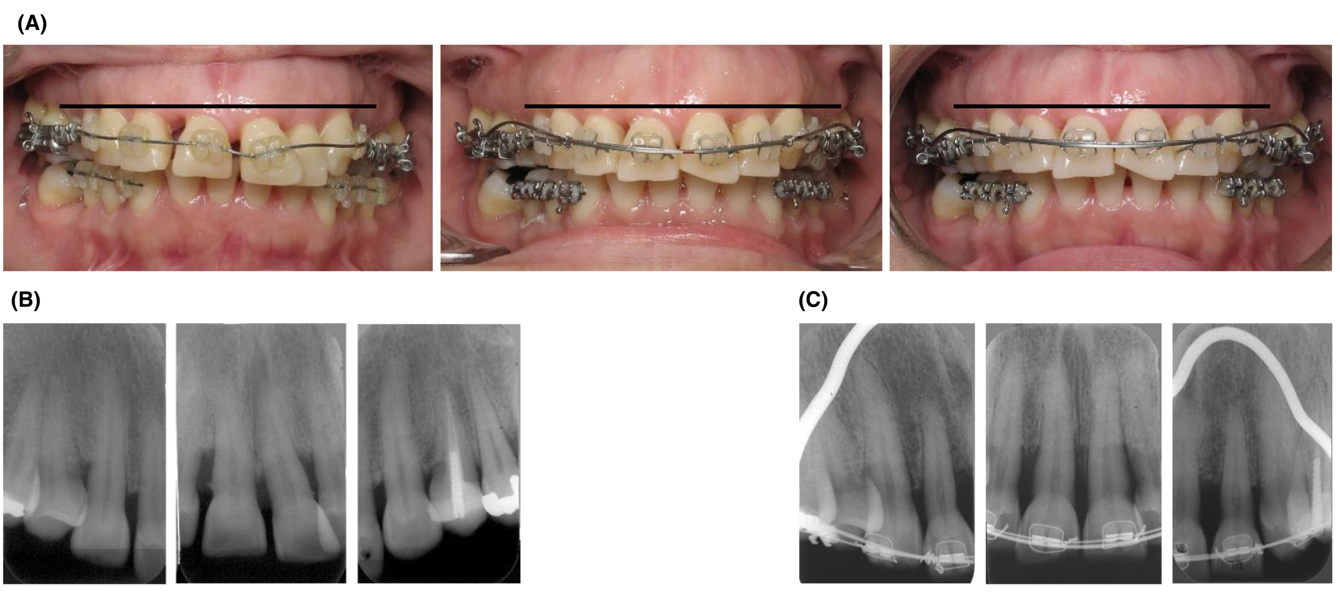


FIGURE 1 Orthodontic intrusion of the maxillary anterior teeth using an intrusion arch, showing (A) the leveling of the gingival margins clinically, as well as intraoral periapical radiographs of the maxillary anterior teeth (B) before treatment and (C) after initial intrusion (patient treated in the postgraduate clinic at the University clinics of dental medicine, University of Geneva).

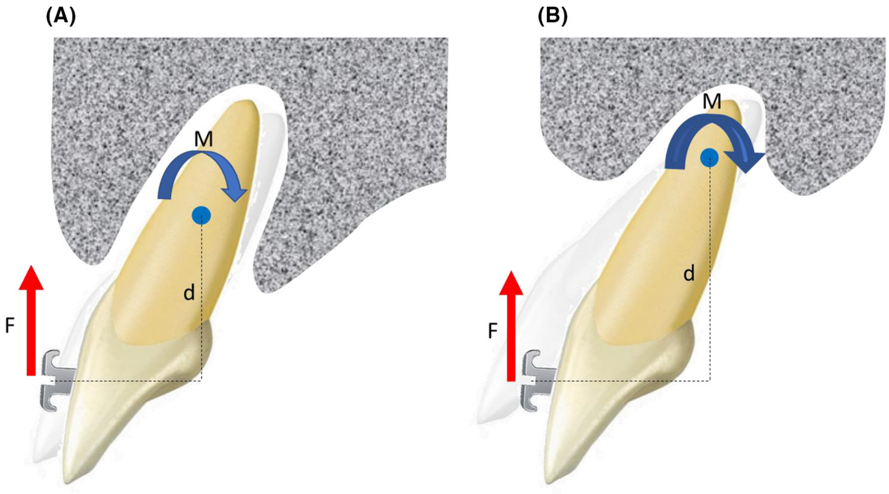


FIGURE 2 Tooth intrusion, carried out with fixed appliances and a round archwire, (A) in a patient with a normal periodontium is accompanied by a moment around the center of resistance of the tooth in question (F = force, M = moment, d = distance between the force application and the center of resistance); (B) in a patient with reduced periodontium and bone loss leads to an apical displacement of the center of resistance in teeth with reduced periodontal support. When the alveolar bone level is reduced, the distance between the applied force and the center of resistance is increased, leading to a moment of greater magnitude (M = F × d) [*Figure created with the help of Louise Ait-Lounis*].

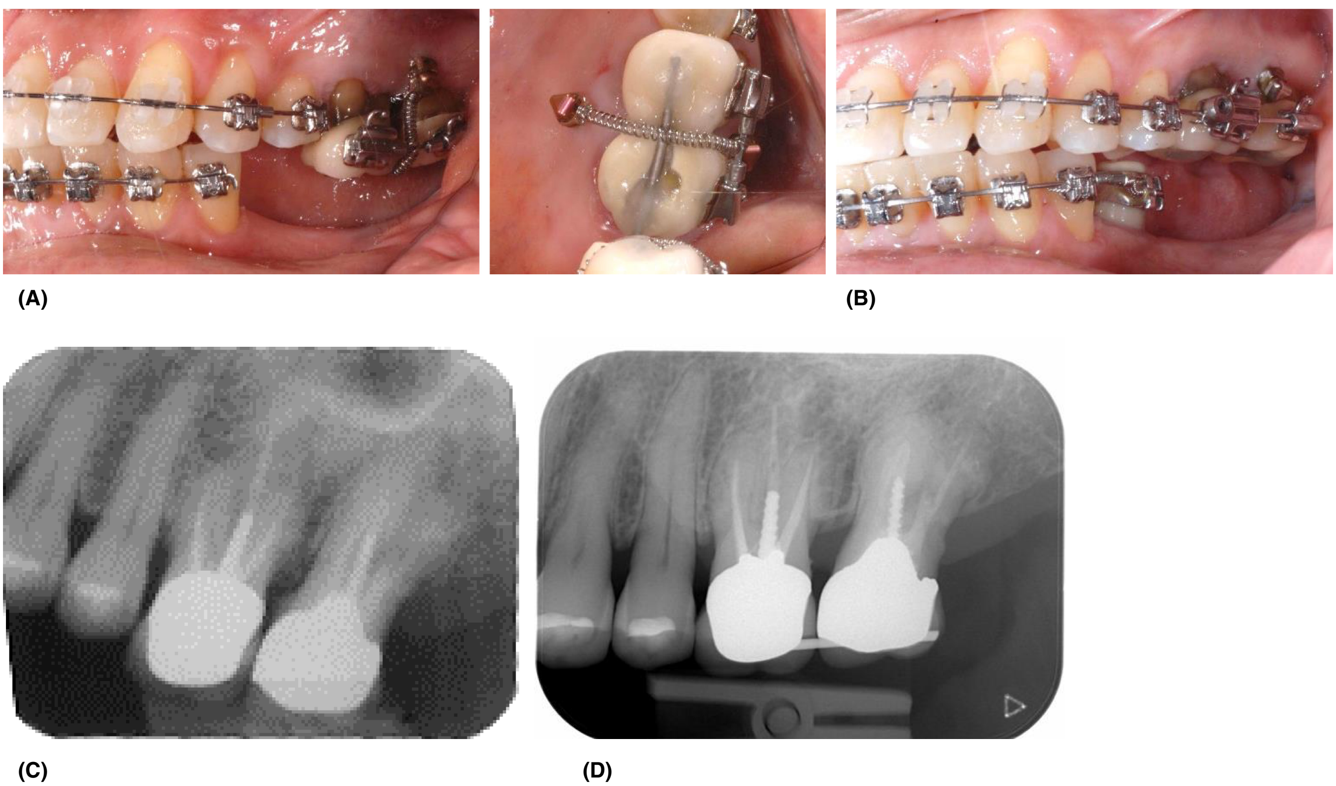


FIGURE 3 Orthodontic intrusion of the teeth 26 and 27 that had overerupted following early extraction of the lower teeth, showing (A) lateral and occlusal views of skeletally anchored intrusion mechanics, and (B) the result after several millimeters of intrusion. Periapical radiographs show no adverse effects when comparing (C) before orthodontic treatment to (D) after orthodontic treatment (patient treated in the postgraduate clinic at the University clinics of dental medicine, University of Geneva).

for orthodontic intrusion using continuous forces via fixed appliances and archwires, brackets can be intentionally bonded more incisally or occlusally than usual to promote intrusion.

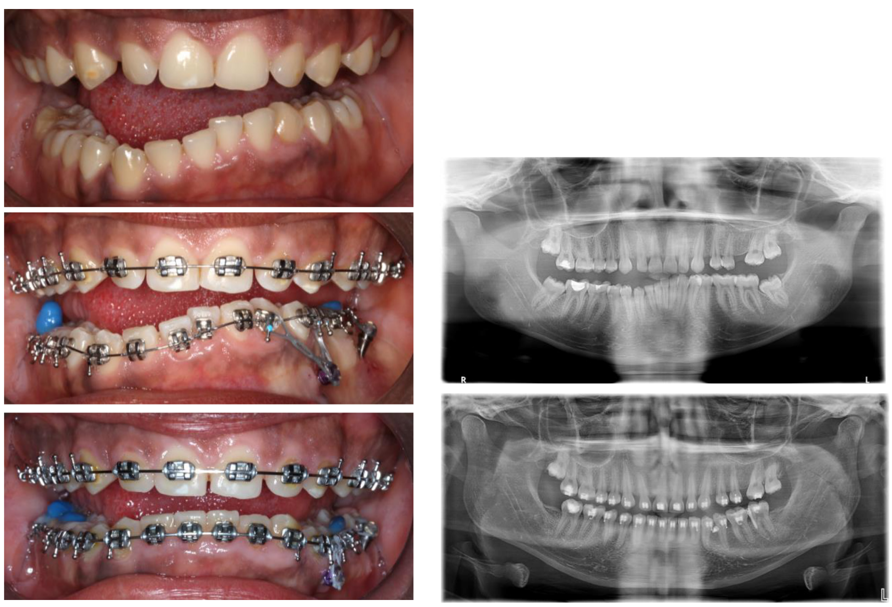
Otherwise, another force system or source of anchorage can be sought, and this may be through the application of intermaxillary occlusal forces through bite blocks or magnetic appliances[21–25] or systems that rely on extraoral or soft tissue forces such as using a J-hook or high-pull headgear[26] or a transpalatal arch with an acrylic button placed a couple of millimeters away from the palate where intrusive forces are exerted by the tongue.[27]

Alternatively, skeletal anchorage (such as inter-radicular miniscrews, palatal miniscrews or implants, miniplates, or infrazygomatic screws) can also be used (Figures 3 and 4), where intrusion is seen to be much more effective.[28–39] The amount of intrusion resulting from using skeletal anchorage has been found to be greater compared to conventional techniques.[40] Bardideh et al.[39] in a meta-analysis looking at intrusion of teeth in patients with deep bite, using skeletal anchorage, found a higher true intrusion when using miniscrews compared to other methods of incisor intrusion. A recent systematic review has shown that the amount of intrusion of posterior teeth achieved with skeletal anchorage is between 2.1 and 4.6 mm (but mostly between 2 and 3 mm) with an intrusive force varying from 100 to 500 cN.[41] Nevertheless, there has been shown to be some relapse of the intrusion of molars using skeletal anchorage after a period of 2.5 years, and the relapse rates reported in meta-analysis data are 12% for the maxillary molars and 27% for the mandibular molars.[42]

Skeletal anchorage can also be used in order to keep the posterior teeth from undergoing continuous eruption, such as in growing children with a hyperdivergent skeletal pattern and a Class II malocclusion. In these cases, blocking the eruption of both the posterior maxillary and mandibular dentitions by holding these teeth with skeletal anchorage can have the favorable effect of increasing chin projection and thus reducing facial convexity, as well as decreasing the mandibular plane angle.[43] This is achieved through mandibular anterior autorotation, which is favorable in these cases.

Commonly used before the advent of skeletal anchorage and still in use today, one-couple systems[44] can be used for intrusion, typically of incisors. For this purpose, light force against the teeth to be intruded is critical. An intrusion arch[45] typically employs posterior molar anchorage against the incisors. Because the intrusive force must be light, the reaction force against the posterior anchor teeth must also be light, meaning that extrusion and tipping forces, the reactive forces and moments on these teeth, are minimized as these are probably counterbalanced by the occlusal forces exerted from the contraction of the masticatory muscles under healthy conditions.[46] Evidently, the magnitude of occlusal forces related to the masticatory musculature would determine the extent of this counterbalancing effect, as would the health of the masticatory system, with individuals presenting with neuromuscular diseases, for example, possibly lacking the capacity to provide sufficient forces to counterbalance these effects.

One can also use an indeterminate two-couple system by tying an intrusion arch into bracket slots on incisor teeth, rather than tying it with one-point contact directly onto an archwire.[47,48] The utility arch, for example, popularized by Ricketts,[49] is an oft-used design. It is formed from rectangular wire so that it will not roll in the molar tubes, bypasses the canine and premolar teeth, and is tied into the incisor bracket slots. The resulting long span provides excellent load deflection properties, so the light force necessary for intrusion can be created. The one-couple intrusion arches mentioned above can look quite similar. The difference comes when the utility arch is tied into the incisor bracket slots, creating a two-couple system. Using utility arches, three-piece intrusion arches, the segmented arch technique, and other similar systems can achieve a certain amount of incisor intrusion, and this has been found to routinely achieve about 1.5 mm of maxillary incisor intrusion and 1.9 mm of mandibular incisor intrusion in non-growing patients based on meta-analysis data.[50] This is likely, however, to depend on age, with growing children potentially presenting different amounts of tooth movement. The proximity of the roots to the cortical bone may define the physiological limit to the amount



(A) (B)

FIGURE 4 Skeletally anchored orthodontic intrusion of the severely overerupted mandibular left hemidentition due to the presence of a unilateral scissorbite, showing the (A) clinical progress of the case, along with the (B) panoramic radiographs before and after 6 months of intrusion and the reduction in mandibular body bone height following intrusion (patient treated in the postgraduate clinic at the University clinics of dental medicine, University of Geneva).

of incisor intrusion. The adverse effects of using these methods are usually extrusive movement of the posterior teeth and labial tipping of the anterior teeth.

Even with appropriate light force, intrusion does not occur as quickly as other types of tooth movement. Posterior intrusion occurs at a rate of about 0.5 mm per month. Molar intrusion is more difficult to achieve than incisor intrusion because molars are large, multirooted teeth. Although several studies claim that molar intrusion is possible, they lack adequate evaluations of molar intrusion.[51] Moreover, when intruding posterior teeth, orthodontic tooth movement into the maxillary sinus may occur, but this seems to be possible, even at a rate of 0.6–0.7 mm per month for molar intrusion, according to a recent systematic review.[52]

2.3 | Potential side effects of orthodontic tooth intrusion

The intrusion of teeth, however, is not without side effects. Firstly, orthodontic pain may occur, but this is no different from the pain experienced with any orthodontic tooth movement.[53] More importantly, intrusive movements may lead to root resorption, alveolar bone resorption, or pulpal necrosis.[54] Intrusive forces are expected to produce pressure zones in the interradicular and apical regions of the alveoli. During orthodontic intrusion, therefore, the stress concentration occurs on a very small surface present on the periradicular alveolar bone and the root apex, which may increase the risk of root resorption when compared with other orthodontic tooth movements.[45,54–56] The maxillary and mandibular incisors are more susceptible to orthodontically induced root resorption,[57] perhaps due to their uniradicular morphology.[32,57,58] In fact, using a 3D finite element model, Gupta et al.[59] evaluated the stress distribution on the maxillary central incisors following orthodontic intrusion, observing that the maximum stress pattern was found to be at the apex of the incisors (Figure 5).

Quantitative analysis has demonstrated that after anterior intrusion, an average of 0.72 mm of root resorption should be expected for each incisor.[60] Treatment-related factors such as the type of mechanics applied and treatment duration might, of course, have an impact on the resultant resorption. An average amount of root resorption of 0.41 mm is expected for molar intrusion.[60] Robust evidence suggests that increased force levels can cause greater resorption; however, this may not be the case for molar intrusion movements, perhaps because of their morphology.[57,61] The amount of force applied during molar intrusion is important, but much more care should be taken with anterior region intrusion. Orthodontically induced root resorption may thus be promoted by intrusion mechanics and should be expected in the majority of patients; however, these values are probably within acceptable clinical limits.

Bardideh et al.[39] in a meta-analysis looking at the intrusion of teeth in patients with deep bites, using skeletal anchorage, found that root resorption was similar when using skeletal anchorage compared to other methods of incisor intrusion. In all investigated intrusion groups, moderate apical root resorption (about 1–2 mm) was observed. St Martin et al.[62] in their review on the influence of miniscrew-assisted intrusion of teeth found a moderate amount of root resorption after intrusion using miniscrews. In addition, it can be stated that treatment characteristics and root characteristics should be considered before performing tooth intrusion. Variables such as duration and magnitude of force could carry significance. Concerning individual susceptibility, a history of trauma, prior root canal therapy, or specific hormonal disorders might pose potential risk factors for root resorption. In such cases, a prudent approach to intrusion is advised.[39,62] Consequently, it is critical to apply the lowest yet still effective forces for intrusion[63] in an attempt to minimize root resorption.

When looking more specifically at periodontal patients, one potential problem with intrusion in adults with periodontal involvement is the prospect that a deepening of periodontal pockets might be produced by this treatment. Careful stabilization of the dental arch segments during incisor intrusion is even more important in these patients, and skeletal anchorage via alveolar bone screws may be particularly advantageous.

In periodontal patients, tooth intrusion would ideally prompt a reestablishment of the periodontal ligament fibers. However, there exists no substantive evidence to anticipate such an outcome. What seems to happen instead is the formation of a tight epithelial cuff, improving the clinical position of the gingiva in relation to the crown, while periodontal probing depths do not increase. Sustaining diligent oral hygiene, as demonstrated by clinical observations, can facilitate the retention of teeth treated in this manner, with minimal impact on root length and alveolar bone height, as evidenced.[2] It has been suggested that a force value of 10 cN applied to maxillary incisors in vivo might produce the most effective tooth intrusion and bone remodeling, which favors bone defect regeneration.[63]

With regard to orthodontic tooth intrusion, clinical recommendations would include using light forces, being vigilant about the risk of root resorption and potential pulpal disturbances, and incomplete root formation in younger individuals with the intrusion of non-apexified teeth. The amount of intrusion achieved depends on treatment time, force level, and the design of the appliance. Animal and human studies have clearly documented that the tissue reactions seen in relation to intrusion vary according to the periodontal status at the start of the treatment.

2.4 | What have animal studies taught us about the healthy and intact periodontium during orthodontic tooth intrusion?

Animal studies have proved invaluable as models for studying orthodontic intrusion, as these allow for a histological evaluation of the different tissues as well as experimental tooth movement during conditions of active periodontal disease, both of which are unethical to perform on human subjects for the sake of research.

FIGURE 5 Orthodontic intrusion with the aid of skeletal anchorage, (A) before and (B) after roughly 1 year of orthodontic treatment, resulting in unfortunate (C) orthodontically induced apical inflammatory root resorption witnessed radiographically on periapical radiographs before treatment and after roughly 1 year of orthodontic treatment (patient treated in the postgraduate clinic at the University clinics of dental medicine, University of Geneva).

Detailed information regarding the events taking place in the periodontal tissues during orthodontic intrusion in animal models dates to 80 years ago. Bunch[64] was one of the first authors to study tissue changes occurring in *Canis lupus familiaris* (dogs) following "depression" of teeth. A continuous force was applied, as depression forces remained at each reactivation. During the first 7 days, no depression was observed. At the end of the experiment, all teeth were depressed from 0.8 to 1.9 mm, and other minor movements were also observed, such as mesiodistal tipping. Histologically, irregular resorption and deposition of bone adjacent to the depressed teeth was observed, with bone resorption occurring at the apex of the depressed tooth and bone spicules oriented apically in the direction of periodontal ligament tension.

A few years later, Moyers and Bauer[65] emphasized the role of the blood supply in the periodontal ligament and reported that intrusion cuts off the blood supply that makes movement possible. They also discussed the question of light versus strong forces, which was subsequently studied by Dellinger,[66] who performed experimentally induced intrusion movements in the molars of four *Macaca speciosa* (stump-tail macaque monkeys). His results showed that the periodontal ligament was thin and compressed at the apical and inter-radicular areas, and it was stretched and widened from the gingival attachment down to the root apex, corresponding to the state of tension. Active bone resorption was seen along the path of intrusion at the sites of periodontal ligament compression. In the same regions, root resorption occurred. Osteoclasts were numerous in these pressure areas and were found mainly in Howship's lacunae. The tension regions of the periodontal ligament were stretched and widened. The periodontal ligament fibers were angulated obliquely in an apical direction, and osteoblasts were present in this area and aligned along the new-forming bone. The author pointed out that root resorption was not the mechanism of intrusion, showing that 50 g of force gave the greatest intrusion and showed only slight root resorption, whereas forces of 300 g produced much less intrusion but severe root resorption. It was concluded that bone resorption and apposition are the main mechanisms during orthodontic intrusion, similarly to what is seen in other types of orthodontic tooth movement.

The effect of orthodontic intrusion on the vascularity of the apical periodontal ligament was also studied by Clark et al.[67] in a rodent model. Their findings suggest that a continuous intrusive tooth load for 30 min can already influence the microvascular bed of the rat apical periodontal ligament, causing an increase in its vascular volume.

A *Rattus norvegicus* (Wistar rat) model was also used previously by Bondevik,[68] who applied intrusive forces varying from roughly 30–100 cN. In the early phases of force application, the periodontal ligament in the interradicular and apical areas showed areas of compression, and cell-free as well as semi-cell-free zones. Bone resorption was also observed, whereas, in the marginal and middle third regions, stretched fibers were the predominant feature. In the latter phases (14–21 days after force application), bone resorption in all regions of the alveoli was observed, regardless of the amount of force applied. Widening of the periodontal ligament space and a decrease in the incidence of cell-free and semi-cell-free zones were also found, as well as root resorption. Bone resorption on the alveolar crest seems to be the consequence of the pressure exerted against the crest by the free gingival fibers as the tooth is intruded. Interestingly, if the amount of intrusion was more than 5 mm, dentogingival and dentoperiosteal fibers, despite adequate oral hygiene measures, seemed to tear off from the cementum, leading to increased sulcus depth without alveolar bone resorption.

The important clinical question of the potential linear relationship between the amount of orthodontic intrusion and the amount of gingival remodeling in the same direction was studied by Murakami et al.[69] in non-human primates *Macaca fuscata* (Japanese macaque monkey), who investigated the relationship between tooth intrusion (using a continuous force of 80–100 g) and sulcus depth when tooth intrusion is increased from 1.1 to 5.5 mm. The authors reported that the gingiva moved in the same direction as orthodontic tooth intrusion, but only to about 60% of the amount of intrusion. Consequently, the clinical crown shortened and the gingival sulcus deepened, and both of these mechanisms contributed to about 40% of the tooth intrusion. The epithelium was always attached to the cemento-enamel junction, and the dentogingival and dentoperiosteal fibers that terminated in the cementum gradually parted from it. Similarly to Bondevik,[68] when intrusion was beyond average (>5 mm), few fibers seemed to terminate in the cementum. No detrimental effect of orthodontic tooth movement was reported, while new attachment was found to occur. Kokich et al.[70] recommend selective tooth intrusion in this context to level gingival margins.

The deepening of the gingival sulcus during orthodontic intrusion was also observed by other authors. Choi et al.[71] during 2-week experimental molar intrusion in a rodent model followed by 1–2 weeks of retention found that the sulcus depth increased during the intrusion movement but went on to decrease after 2 weeks of retention. Similarly, the number of osteoclasts increased during intrusion and decreased during retention. Interestingly, only root resorption occurred during and after molar intrusion. The authors also reported that the lengthening of the junctional epithelium during molar intrusion may increase the chance of bacterial infiltration and gingiva permeability. With a healthy and intact periodontium, the apical end of the epithelium moves along with the tooth; however, the free gingival margin does not move immediately with the tooth. When inflammation is present, active proliferation and migration of the junctional epithelium occur, resulting in a periodontal pocket and apical movement of the attachment level.[71]

Finally, when molar intrusion is carried out in the presence of a healthy and intact periodontium in a *Canis lupus familiaris* (dog) model, the formation of a pseudo-pocket has been shown to occur through gingival coverage of the crown.[72] Compression from supra-alveolar fibers after orthodontic intrusion leads to alveolar crest resorption and contributes to decreasing the increased sulcus depth.

TABLE 1 Summary of periodontal outcomes during orthodontic tooth intrusion.

Intrusion moves the dento-gingival complex apically	
Aspect	**Periodontal outcome for intrusion**
Gingival margin position	Moved in the same direction as the teeth
Width of keratinized gingiva	No noticeable change
Sulcus depth	No significant change observed but gingival margin movement indicates a potential reduction in sulcus depth
Mucogingival junction	Displaced
Periodontal ligament	Decreased thickness, increased cellular density, and increased mitoses
Alveolar crest	Follows the tooth during intrusion; slight bone loss observed
	Intrusion and retroclination: increased bone thickness
	Maxillary incisor intrusion: labial bone thickness decrease
Cementum	Stimulation of the formation of cellular cementum

2.5 | What have human studies taught us about the healthy and intact periodontium during orthodontic tooth intrusion?

Several systematic reviews have clearly summarized the close relationship between orthodontics and periodontology and the way that each field can contribute to optimizing treatment of combined orthodontic–periodontal clinical problems (see Table 1).[73–78] In patients with a healthy and intact periodontium, orthodontic movement has no clinically relevant detrimental effects on periodontal tissues, provided that periodontal health and adequate oral hygiene are assured prior to orthodontic treatment and constantly monitored throughout treatment. In patients with a healthy but reduced periodontium and good plaque control, successful tooth movement can be conducted without compromising the periodontal support, with periodontal outcomes being like those obtained in patients with a healthy and intact periodontium.[76] However, performing orthodontic tooth movement in patients with untreated periodontitis and continuing the orthodontic movement despite periodontitis developing during treatment is considered a treatment error.

Clinical studies have evaluated the response of various tissues to intrusion forces by clinical and/or radiographic means. In subjects with a healthy and intact periodontium, Erkan et al.[17] aimed to study the rate of accompanying gingival movement, the changes in attached and keratinized gingiva, and the need for orthodontic intrusion of mandibular incisors. The authors found that the width of attached and keratinized gingivae did not change after treatment, but the gingival margin moved in the same direction as the teeth by 79%, whereas the mucogingival junction was displaced by 62% of the total intrusion. The length of the clinical crown also decreased significantly after treatment. It seems, although not proven histologically, that the reduction in the gingival height was due to compression of the gingiva. Unlike the periodontal ligament and the bone, the gingiva does not seem to be subject to resorption but rather a retraction due to stretching of the gingival fibers without peeling off from the tooth surface, preventing periodontal pocket formation.

In a clinical and radiographic study, Bellamy et al.[19] focused on changes in alveolar bone level and root length when orthodontic intrusion of abraded incisors was performed during 16–40 months, in order to facilitate tooth restorations. Intrusion was identified in cephalometric radiographs, and bone level and root length were in periapical radiographs. Their data showed that the bone level followed the tooth during intrusion, but a small amount of bone loss occurred, and root resorption was also observed. There were no significant associations with age, sex, treatment time, intrusion, or pre-treatment bone level. It was concluded that incisor intrusion in adults moves the dentogingival complex apically and that the potential iatrogenic consequences of alveolar bone loss and root resorption are minimal and comparable with the consequences of other orthodontic tooth movements.

Atik et al.[79] assessed changes in the thickness of the alveolar envelope using pre-intrusion and post-intrusion cone-beam computed tomography images. With maxillary incisor intrusion, the alveolar bone thickness at the labial bone decreased significantly in patients with miniscrew-assisted incisor intrusion, and this was strongly correlated with the amount of incisor intrusion. Changes in the labial inclination and the amount of intrusion should therefore be considered during upper incisor intrusion, as these factors increase the risk of alveolar bone loss. A decrease in labial bone can occur when intrusion and proclination of the incisors are carried out.

In a cohort study of 34 adult female patients with Class II malocclusion and incisor protrusion, Hong et al.[80] evaluated alveolar bone changes on lateral cephalograms following extraction and orthodontic treatment with upper incisor intrusion and retraction. A significant increase in labial alveolar bone thickness at 9 mm apical from the cementoenamel junction was found, with the amount of intrusion being correlated with the alveolar bone thickness changes. Intrusion and retroclination in this case, after the extraction of premolars, can thus lead to an increase in labial alveolar bone thickness.

2.6 | What have animal studies taught us about the periodontium during orthodontic intrusion of periodontally affected teeth?

When looking at orthodontic intrusion of periodontally affected teeth, once again, animal models help us better understand what happens to the periodontal tissues during these movements. Although there may be certain benefits of intruding teeth for the improvement of the periodontal condition around these teeth, such as in the case of infrabony pockets, this remains highly dependent on and sensitive to the presence of plaque and oral hygiene maintenance.

Polson et al.[81] used the rhesus monkey as a model to create localized infrabony pockets around isolated incisors. The root surfaces were planed to the level of the bone at the base of the angular bone defect. An oral hygiene regime was begun and continued throughout the study. The experimental teeth were orthodontically moved into and through the original area of the infrabony defect. After 2 months, this resulted in the resolution of the angular defect, the formation of a long junctional epithelium on the root surface, and unchanged levels of connective tissue attachment. On the tension side, the crest of the bone was located apical to the level of root planning, and the epithelium lined the portion of the root that was instrumented. The authors concluded that orthodontic tooth movement into infrabony periodontal defects did not affect the levels of connective tissue attachment.

Other studies show promising results, claiming that when bodily movement of teeth into infrabony defects after proper periodontal therapy is performed in a monkey model, new attachment formation is reported histologically.[82]

Based on these data, intrusion of teeth into an infrabony pocket does not seem to result in a decrease in marginal bone level in monkeys with a healthy but reduced periodontium provided gingival inflammation is controlled. If this is not the case, however, the presence of a diseased periodontium with gingival inflammation results in a loss of alveolar bone height. This was elegantly shown in a *Canis lupus familiaris* (dog) model in a study by Ericsson et al.[83] that stressed the importance of plaque control during orthodontic intrusion. Orthodontic intrusion in the presence of bacterial plaque led to the formation of angular infrabony defects and loss of attachment because of a shift of supragingivally located plaque into a subgingival position. It is thus recommended to perform repeated professional scaling during active intrusion or tipping of teeth such as maxillary incisors, which is particularly important since orthodontic intrusion may shift supragingival plaque subgingivally[83,84] when oral hygiene is inadequate, resulting in periodontal destruction.

Wennstrom et al.,[85] in a study in *Canis lupus familiaris* (specifically Beagle dogs), also showed that tooth movement into infrabony defects may enhance the rate of attachment loss when inflammation is present. After surgically creating angular defects, plaque was allowed to accumulate, and teeth were moved into and through these infrabony defects. As a result, additional loss of connective tissue attachment with undermining resorption was noticed after 6 months of follow-up.

Similarly, Melsen et al.[86] investigated the influence of oral hygiene on tissue reactions related to orthodontic intrusion of teeth with a reduced periodontium in a *Macaca fascicularis* (crab-eating macaque monkey) model. Experimentally induced periodontitis was created, followed by a flap operation during which the epithelium and the granulation tissue were removed. A notch at the pocket bottom just above the bone was placed before the beginning of orthodontic tooth movement, which was intrusion along the long axis of the incisors with light forces. The histologic analysis showed that intrusion improved the quantity of the new attachment in terms of new cementum formation and new connective tissue/collagen attachment on the intruded teeth, but only if a healthy but reduced periodontium was maintained throughout tooth intrusion. This new attachment was formed only by the periodontal ligament cells, which increased their activity. On the contrary, intrusion in the presence of plaque had a deleterious effect since a pronounced resorption of the marginal bone was observed. The distance between the apical part of the notch and the junctional epithelium increased between 0.7 and 2.3 mm, and attachment coronally to the notch was a consistent finding in the group where intensive oral hygiene was performed. Melsen[87] had previously shown on the healthy and intact periodontium of the same monkey model that orthodontic intrusion of teeth does not result in a decrease of the marginal bone level provided that gingival inflammation is kept to a minimum with an appropriate oral hygiene protocol.

One must interpret the results of the histological (and clinical) studies of Melsen and her group with caution since the reported benefits associated with a combined orthodontic-periodontal approach have not been confirmed by other authors. Moreover, perhaps newer techniques such as guided tissue regeneration or other regenerative procedures may be more promising when the formation of new attachments is desired. In fact, due to the lack of predictability of these movements, some authors have recommended that intrabony defects be first treated with surgical periodontal regenerative procedures, followed by orthodontic intrusion.[15,88] Other authors recommend that when wide bony defects are present, orthodontic intrusion can be used to improve the defect anatomy prior to carrying out regenerative procedures.[89,90]

Although not universally accepted, in several clinical studies, it is recommended to commence orthodontic tooth movement 7–10 days after periodontal therapy (not including regenerative periodontal procedures). Nemcovsky et al.[91,92] highlighted the potential benefits of orthodontic tooth movement beginning shortly after periodontal therapy using *Rattus norvegicus* (Wistar rat) as a model, where bony defects were surgically created and orthodontic tooth movement started 1 week subsequent to surgery. The authors evaluated the effect of probing depth, bone healing, and the level of the junctional epithelium. Orthodontic tooth movement restrained epithelial apical down-growth, decreased pocket depth, and enhanced bone healing. As orthodontic treatment could not avoid the formation of a long epithelial attachment, the authors suggested that periodontal regenerative surgery could be indicated prior to orthodontic movement.

On a cellular level, it is well established that cell populations capable of generating a new attachment originate from the periodontal ligament.[93,94] During intrusion, the periodontal ligament cells are displaced coronally, while simultaneously the cell activity increases,[95] thus promoting new attachment formation.[86] Intrusion affects the periodontal status by decreasing the thickness of the periodontal ligament, increasing the cellular density, increasing the number of mitoses and periradicular cells, and stimulating the formation of cellular cementum.[96,97]

Histological differentiation due to orthodontic intrusion is more apparent over the apical root third, with several changes being observed over the middle root third and minimal alterations seen over the cervical root third. These include changes in cellular and intercellular structures.[98] The areas mentioned above present a varying degree of cellular disorganization (cementoblasts, cementum cells, and fibroblasts) characterized by loss of cell membrane and cellular lysis. The periodontal membrane and intercellular space show local loss of their fibrous pattern and become amorphous or granular, simulating the hyalinization process as presented by the pioneering studies of Reitan and Kvam.[99] Cementoblasts are not differentiated, and the extracellular background is not mineralized, resulting in the loss of osteoid. Macrophage-like cells containing numerous lysosomes, phagocytes, and peptic cystids appear and remove necrotic elements, while clastic-type cells are also observed, albeit without any organization or clear boundaries. The surface of cementum shows irregularities and resorption areas, whereas blood supply also changes mainly through the appearance of a sparse network of blood vessels with lysis of their endothelial continuity. The presence of erythrocytes in the extracellular material and periodontal membrane indicates oedema development in the region.[98]

The development of newly formed capillaries with large endothelial cells under mitotic activity has been found, indicating angiogenesis and revascularization of the periodontal membrane. Active collagen production and newly formed non-mineralized osteoid are compatible with the initiation of a cementum restoration process. Active fibroblasts with their normal cellular features have been found to participate in periodontal membrane restoration, the characteristic feature being that the restorative processes seem to start from the periphery of the hyalinized zones and from regions close to the sites of cementum resorption.[98]

Whether all these results from animal models can be extrapolated to the situation in humans can be questioned, but since histology is the only reliable method for the evaluation of attachment level, all these findings should be taken into consideration.

2.7 | What have human studies taught us about the periodontium during orthodontic intrusion of periodontally affected teeth?

In the treatment of adult patients with a previous history of periodontal disease, intrusion of elongated and migrated incisors is suggested to close the anterior diastema and realign the malpositioned teeth. In periodontally compromised subjects with periodontally affected teeth, clinical data suggest that intrusion of teeth can considerably improve the level of attachment when there is absolute control of the inflammation and bacterial biofilms.[100–102] Moreover, for periodontally affected teeth, when tooth movement is associated with the presence of infrabony defects, teeth can be moved into these defects until there is no further clinical evidence of the predisposing defect. This is likely, however, not related to the creation of new attachment but rather to the formation of a long junctional epithelium on the root surface, as previously shown in animal studies.

Finite element studies have shown that tooth displacement and periodontal ligament load were greater in the healthy but reduced periodontium than the healthy and intact periodontium, reinforcing the need of using light orthodontic forces in these populations.[103] Compensating for increased periodontal stresses due to the presence of a reduced periodontium by minimizing orthodontic force seems to be essential based on these studies.[104]

Cardaropoli et al.[101] evaluated the orthodontic treatment results of 10 adult patients who had severe periodontal disease, with migration and radiological evidence of an infrabony defect on a maxillary central incisor. Orthodontic tooth movement, using light and continuous forces, was initiated 7–10 days after periodontal surgical therapy, for a duration of 10 months. The combined orthodontic-periodontal approach for intruding migrated incisors with infrabony defects in adult periodontal patients found that probing depth, clinical crown length, marginal bone level, and bone defect radiological dimensions were all improved following orthodontic intrusion (Figure 6). The mean residual probing depth was 2.8 mm, and the mean intrusion of the incisors was 2.1 mm. Moreover, radiographs showed a reduction of the infrabony defects. These results show the efficacy of a combined orthodontic-periodontal approach. Intrusive movement, after proper periodontal surgical therapy, can positively modify both the alveolar bone and the soft periodontal tissues.

The same group[102] aimed to evaluate periodontal tissue response following periodontal surgery and orthodontic intrusion in migrated upper central incisors with infrabony defects. The active orthodontic treatment started 7–10 days after surgery, and maintenance therapy was performed every 2–3 months until the end of the orthodontic treatment. At the end of the treatment, the mean pocket depth reduction was 4.4 mm, and the mean clinical attachment gain was 5.5 mm. Furthermore, the mean vertical and horizontal bone fill was 1.4 mm for both dimensions. Starting orthodontic treatment early after periodontal surgery therefore seems to be effective in determining the coronal shift of the soft tissues, which is an important concern from an aesthetic point of view, but it is not known whether delaying the commencement of orthodontic treatment has an inferior effect.

Re et al.[100] performed a clinical study including patients with severe periodontal disease and pathologic migration of the anterior teeth. One week after the end of nonsurgical or surgical periodontal

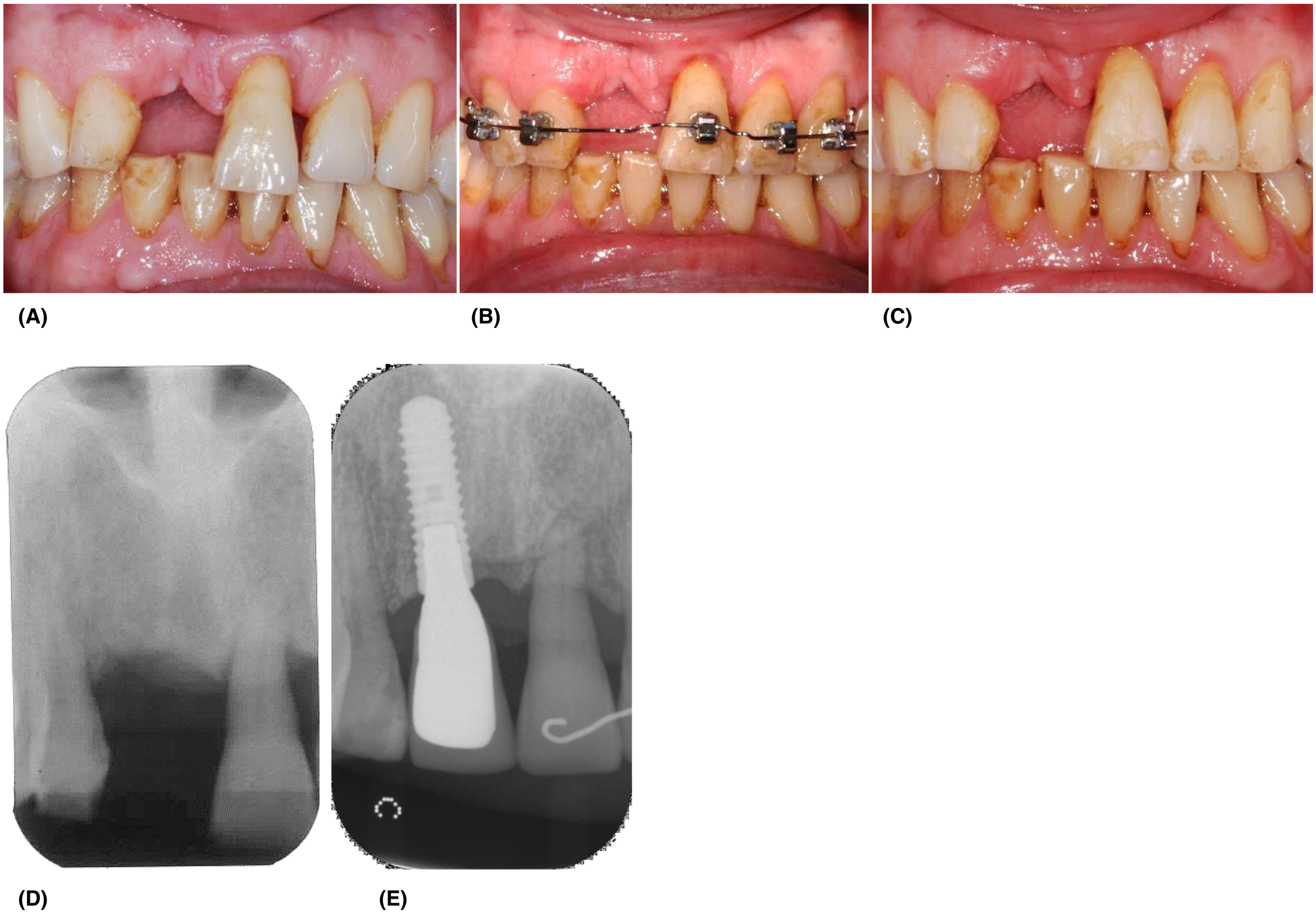


FIGURE 6 Orthodontic intrusion of tooth no. 21 in order to reduce the deep bite and accommodate an implant in the position of the 11, (A) before, (B) during, and (C) after orthodontic treatment. Periapical radiographs are shown (D) before treatment and (E) 10 years after implant placement, showing bone levels having been maintained (patient treated in the postgraduate clinic at the University clinics of dental medicine, University of Geneva).

treatment, the patients were treated with intrusive mechanics using the segmented arch technique. A strict oral hygiene maintenance program was followed, including a control every 2 weeks and a professional tooth cleaning every 3 months. The follow-up after the end of the orthodontic treatment varied between 2 and 12 years. The outcomes observed during the 2–12-year follow-up period indicated a lack of alteration in the periodontal condition from the conclusion of the treatment. This implies that orthodontic intervention does not present a contraindication, even in cases where significant bone loss has occurred due to periodontal disease.

The same group[105] evaluated the effect of orthodontic intrusion on the reduction of gingival recession around maxillary incisors in adult periodontal patients to investigate whether a thin or a thick gingival biotype responded differently. Periodontal treatment consisted of open flap surgery, followed by orthodontic treatment after 7–10 days. Results showed that periodontal pocket depth and gingival recessions decreased significantly, and these reductions remained stable at the 1-year follow-up. The mean recession reduction was approximately 1 mm on the buccal sites and 1.7 mm on the mesial sites. The mean reduction in buccal recessions was almost half of the mean distance of intrusion. It seems that buccal gingiva can follow the vertical tooth displacement by approximately 50%, meaning that a 50% reduction in recessions after orthodontic intrusion of periodontally compromised teeth can occur. No difference was observed, however, in this sample between those with thin and thick biotypes.

In a classic study, Melsen et al.[2] performed the intrusion of extruded and spaced incisors in 30 periodontally treated adult patients who had advanced periodontal disease with marginal bone loss, evaluating the periodontal condition by looking at changes in the marginal bone level and the amount of root resorption using clinical examination, intraoral radiographs, and study casts. The results based on a clinical judgment of probing depth showed that, despite large interindividual variation, intrusion was beneficial to clinical crown length, which was generally reduced by 0.5–2.5 mm following intrusion, and that the marginal bone level approached the cementoenamel junction in most cases (Figure 7). All cases demonstrated root resorption varying from 1 to 3 mm. The total amount of alveolar support was either unaltered or increased in the majority of cases. The authors state that intrusion, especially in teeth with an increased crown root ratio due to healthy but reduced periodontal support, was best performed when forces were light (5–15 cN per tooth) with the line of action of the force passing through or close to the center of resistance, the gingiva status was healthy, and no interference with perioral function was present, in order to prevent root resorption. A recent finite element study states that in a healthy but reduced periodontium, forces of 20 cN seem to be safe.[106]

When looking at alveolar bone changes following intrusion, the study of Atik et al.,[79] which measured alveolar bone level in all aspects of the mandibular incisors using cone-beam computed tomography, found a more significant loss in the buccal and lingual sides of the mandibular central incisors that had been intruded.

In several cases, when pathological periodontitis-induced extrusion is accompanied by the absence of interdental papilla, orthodontic intrusive movements together with space closure may be able to create a new contact point between two elongated and spaced teeth, thus reducing the distance with the bone crest and enhancing the papilla possibilities to refill the interproximal space. The presence of an interdental papilla is determined by the distance from the contact point to the bone crest. It is accepted that when the distance is 5 mm or less, the papilla is almost always present, and when the distance is more than 7 mm, the papilla is missing. As reported by Olsson and Lindhe,[107] periodontal biotype can influence the degree of recession, as subjects with a thin periodontal biotype, experience more recession than those with a thick biotype.

The studies of Cardaropoli et al.[108] and Re et al.[105] also aimed to evaluate the combined orthodontic-periodontal treatment in the reconstruction of midline papillas lost following periodontitis. The intrusive movement started 7–10 days after open-flap periodontal surgery, and teeth were intruded and diastemas were closed by means of continuous light forces, about 10–15 g per tooth. The papilla presence index showed improvement from the initial to the final measurements and showed no changes at 1-year follow-up, and this was regardless of the gingival biotype assessed. At the end of orthodontic treatment, a predictable reconstruction of the interdental papilla was thus reported, both in patients with thin and wide gingiva.

In several studies,[15,100,101] at the end of a combined treatment with periodontal therapy and orthodontic intrusive movement, a significant decrease in the probing depth values has been shown, along with a radiographic reduction of the infrabony defect volume. New supracrestal and periodontal ligament collagen fibers may be gained on the tension side, which can transfer the orthodontic force stimulus to the alveolar bone.[88]

Interestingly, it is worth mentioning that orthodontic intrusion can also be carried out with the addition of a fiberotomy, although it is not frequently carried out. This has been shown to potentially improve periodontal conditions, with more intrusion and less alveolar bone resorption.[72,109,110] The EFP, in its clinical practice guidelines, has even suggested that circumferential fiberotomy of the supracrestal periodontal fibers may be considered as an adjunct surgical procedure to improve attachment levels during orthodontic tooth intrusion[16] in patients with stage IV periodontitis. Another recommendation of the EFP in this context is to consider using skeletal anchorage to enhance orthodontic tooth movement where indicated.

2.8 | Clinical recommendations for orthodontic intrusion

In response to the question of whether or not orthodontic intrusion may have negative effects on periodontal tissues, it is well documented that in dentitions characterized by diminished periodontal support, orthodontic tooth intrusion does not induce periodontal damage, provided the periodontal tissues are devoid of

FIGURE 7 Orthodontic case following periodontal therapy, with a combination of anterior intrusion and posterior extrusion, with an improvement in the smile. Shown here are (A) pre-treatment and (B) post-treatment extraoral photographs where aesthetic improvement is visible; (C) intraoral frontal pre-treatment and (D) intraoral frontal post-treatment photographs showing improvement in soft tissue root coverage of the tooth 11; (E) pre-treatment and (F) post-treatment intraoral periapical radiographs showing minor apical root resorption with an apparent improvement in bone coverage of the root of the tooth 11 (patient treated in the postgraduate clinic at the University clinics of dental medicine, University of Geneva).

inflammation and stringent plaque control is upheld through correct oral hygiene practices. The intrusion of teeth with a healthy but reduced periodontium results in a reshaping of the alveolar process, with no influence on the extent of periodontal support. However, this presupposes that the intrusion is meticulously conducted while maintaining complete control over the periodontal condition. The challenge linked to the intrusion of teeth with a healthy but reduced periodontium primarily revolves around the delicate management of the very light orthodontic forces.

Remarkably, studies have indicated that employing precisely calibrated and low-magnitude orthodontic forces for tooth intrusion, even in the presence of periodontal bone loss, is not only viable without promoting further bone loss but can potentially contribute to an augmentation of connective tissue attachment. Thus, in cases of advanced periodontal involvement, teeth should only be moved after periodontal therapy has been performed and infection can be controlled. There is no consensus regarding the optimal timeframe between periodontal treatment and the commencement of orthodontic intrusion. However, drawing from the existing data, it might be reasonable to recommend a waiting period of 7–10 days prior to initiating orthodontic intrusion. Nonetheless, a conservative approach is often favored by numerous clinicians, who wait between one and 6 months following periodontal therapy before initiating any orthodontic force application to the teeth. The EFP recommends not waiting for a prolonged healing period after periodontal and regenerative treatment before commencing orthodontic treatment in patients with Stage IV periodontitis, since a short period of 1 month results in comparable outcomes to waiting for a more prolonged period of 6 months.[16]

On the contrary, in the presence of plaque-induced inflammation, similar forces may cause rapid periodontal tissue breakdown, as shown by different animal and human studies. In situations where pathologically deepened pockets and vertical bony defects are present, the act of intrusion itself could potentially pose a risk factor for additional attachment loss. This is attributed to the possibility of displacing marginally situated dental plaque further apically into an already deepened pocket.

In conclusion, periodontal therapy should always precede orthodontic treatment. In a healthy but reduced periodontium, orthodontic forces and tooth movement within biological limits do not cause periodontal breakdown. The combination of proper orthodontic and periodontal treatment improves reduced periodontal conditions. Both nonsurgical and surgical procedures can be effective in the treatment of periodontal disease in association with orthodontics. The use of light forces (5–15 cN per tooth) is recommended to move teeth efficiently and potentially reduce the amount of root resorption. This is of capital importance in teeth with reduced periodontium, as the specific implications result in further loss of periodontal support and an increase in the crown–root ratio.

3 | ORTHODONTIC EXTRUSION

3.1 | Indications for orthodontic tooth extrusion

The extrusion of teeth, namely their orthodontic coronal displacement, is a movement that resembles a physiologic eruption in its direction, while the extrusive forces stimulate the tooth to exceed the limits of the eruption mechanism. During adulthood, there is generally no obvious tooth eruption such as that observed during an individual's growth phase when the permanent teeth replace the primary teeth and when the occluding teeth continue their eruption to compensate for the vertical growth of the lower third of the face.[111] By the time an individual reaches adulthood, most of the eruption of the permanent teeth is usually complete, although they often undergo minor positional changes over time (continuous eruption) due to factors such as age-related dental changes, dental wear, and the natural remodeling of the supporting structures, such as the bone and periodontal ligament, that can affect vertical tooth position and alignment. These changes may result in variable tooth movement or displacement within the dental arch.[8,10]

Many orthodontic methods have been implemented to produce orthodontic extrusion, either of a single tooth or a group of teeth, which can be used in certain clinical situations.

Extrusion of a group of teeth is carried out in cases of anterior open bite, when often the treatment of this malocclusion necessitates extrusion of the anterior upper teeth, lower teeth, or both after controlling for any functional disturbances. It is important to mention that in the treatment of the anterior open bite, intrusion of the posterior teeth may also be indicated, as previously discussed; thus, the treatment goal may be a combination of extrusion of the anterior and intrusion of the posterior teeth (Figure 8). In other cases, it may be desired to almost exclusively extrude the anterior teeth, and treatment mechanics may be applied with the aim of doing so (Figure 9).

Extrusion of posterior teeth is desired and suitable in the treatment of patients with deep bites and an excessive curve of Spee. This is often perceived as a relative intrusion of the anterior teeth. It is attained by impeding the eruption of the incisors, creating vertical space into which the posterior teeth can erupt when they are not in direct occlusal contact. This approach is particularly relevant for younger individuals. As the eruptive potential of the teeth is smaller among older individuals, active extrusion of the posterior teeth would be necessary in this choice of treatment in order to achieve correction of the deep bite.

When discussing the extrusion of a single tooth, we may consider the treatment of impacted teeth when orthodontic forces are implemented to displace them vertically, often combining intraosseous tooth movement to begin with and subsequent movement in the oral cavity to finalize tooth position. Nevertheless, lateral displacement of the impacted teeth is often necessary in order to facilitate the success of this effort. Since multiple factors usually come into play in the differential diagnosis and treatment of such impacted teeth, we will not be discussing in more detail the mechanisms of tooth movement in this specific situation and its effects on the periodontium in the present article.

Another example of extrusion of a single tooth, or partial extrusion of a single tooth, is the extrusion of the mesial root of a tooth, which is witnessed in cases where mesially tipped molars are uprighted in adult individuals. This can be combined with, in some cases, an intrusion of the distal root of such a mesially tipped molar.

Occasionally, extrusion of a tooth with a subgingival root fracture is recommended to provide access to the remaining part of the tooth, allowing more adequate tooth structure for restoration. As it will be discussed below, this demands the application of controlled extrusive orthodontic forces on the tooth, inhibiting the coronal displacement of the alveolar process and exposing the cervical part of the root of the tooth for better access during restorative procedures.

In other situations, orthodontic extrusion can contribute to the improvement of dental aesthetics by elongating a tooth that is noticeably shorter or worn down compared to neighboring teeth. In some cases, leveling the gingival margin with neighboring teeth may also be desired to respond to the aesthetic demands of a particular patient.

Extrusive displacement of small apical parts of roots can also be carried out to help create vertical bone, which facilitates implant placement where there is insufficient bone to accommodate an implant, sometimes even eliminating the need to consider a bone graft prior to implant placement since the bone is regenerated via the orthodontic extrusion.

Last but not least, single tooth extrusion may be carried out in some patients for periodontal reasons. Following the diagnosis of one or two wall defects resulting from periodontal disease,

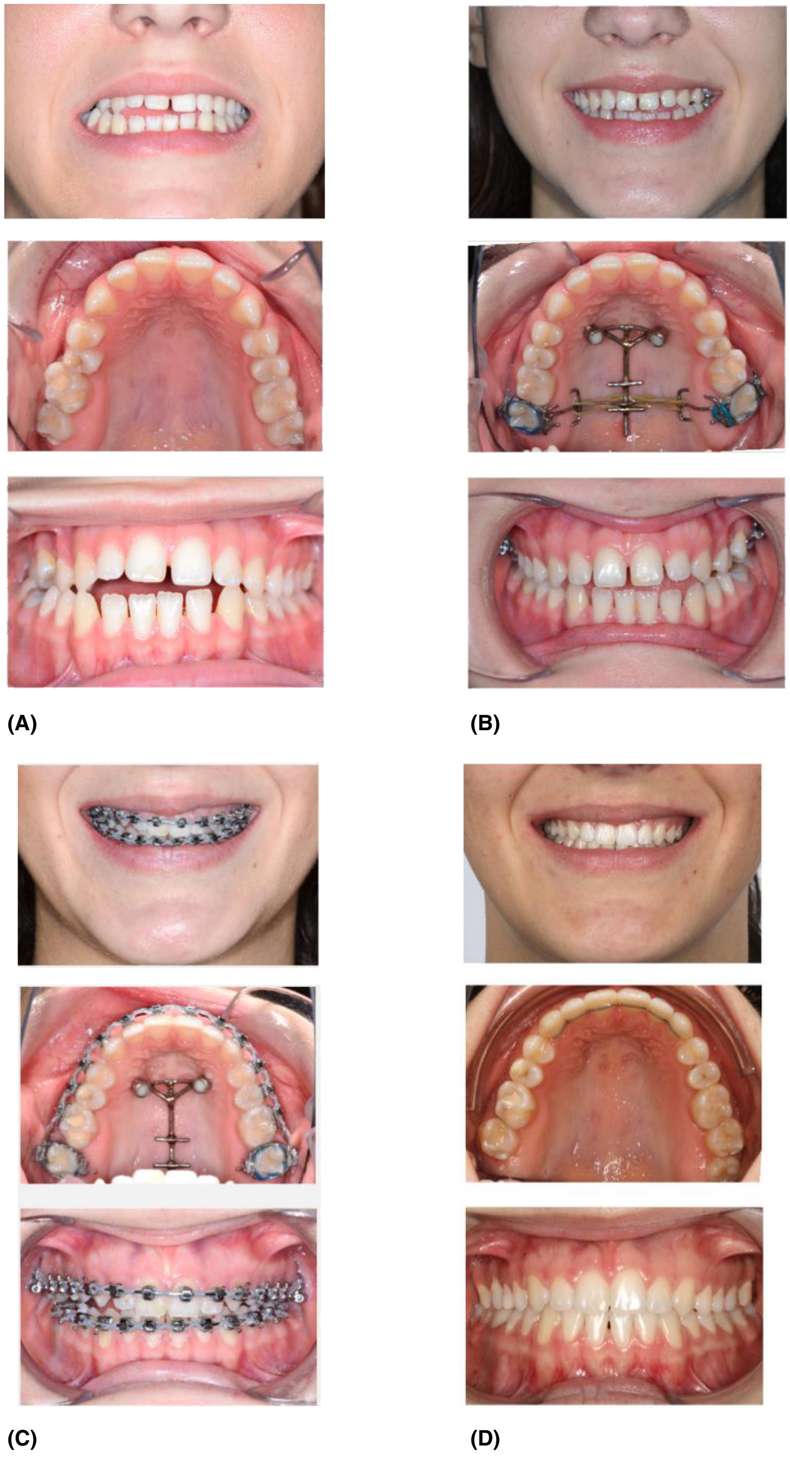


FIGURE 8 Orthodontic case with anterior open bite treated with concomitant intrusion of the posterior teeth and extrusion of the anterior teeth with successful open bite closure and increase of incisor exposure upon smile. Shown here are the (A) pre-treatment photograph where the open bite is evident, (B) the skeletally anchored molar intrusion appliance in situ, (C) following the placement of fixed orthodontic appliances and continuous archwires to achieve concomitant posterior intrusion and anterior extrusion, and (D) the end-of-treatment photographs (patient treated in the postgraduate clinic at the University clinics of dental medicine, University of Geneva).

orthodontic extrusion can be employed to reposition a tooth occlusally, which then facilitates the continuation of the surgical periodontal treatment.

3.2 | Mechanisms of orthodontic tooth extrusion

Orthodontic tooth extrusion is obtained after the application of continuous or intermittent extrusive forces on the tooth that may initiate different periodontal tissue reactions that have not been well explored. One common orthodontic approach to achieving extrusion is by steadily applying continuous forces via fixed appliances using continuous archwires with sweeps or by using fixed appliances with brackets intentionally bonded more gingivally than usual to promote extrusion.

If one wishes to apply a more controlled orthodontic extrusive force, segmented arch mechanics are recommended, which implement continuous extrusive forces and have the advantage of

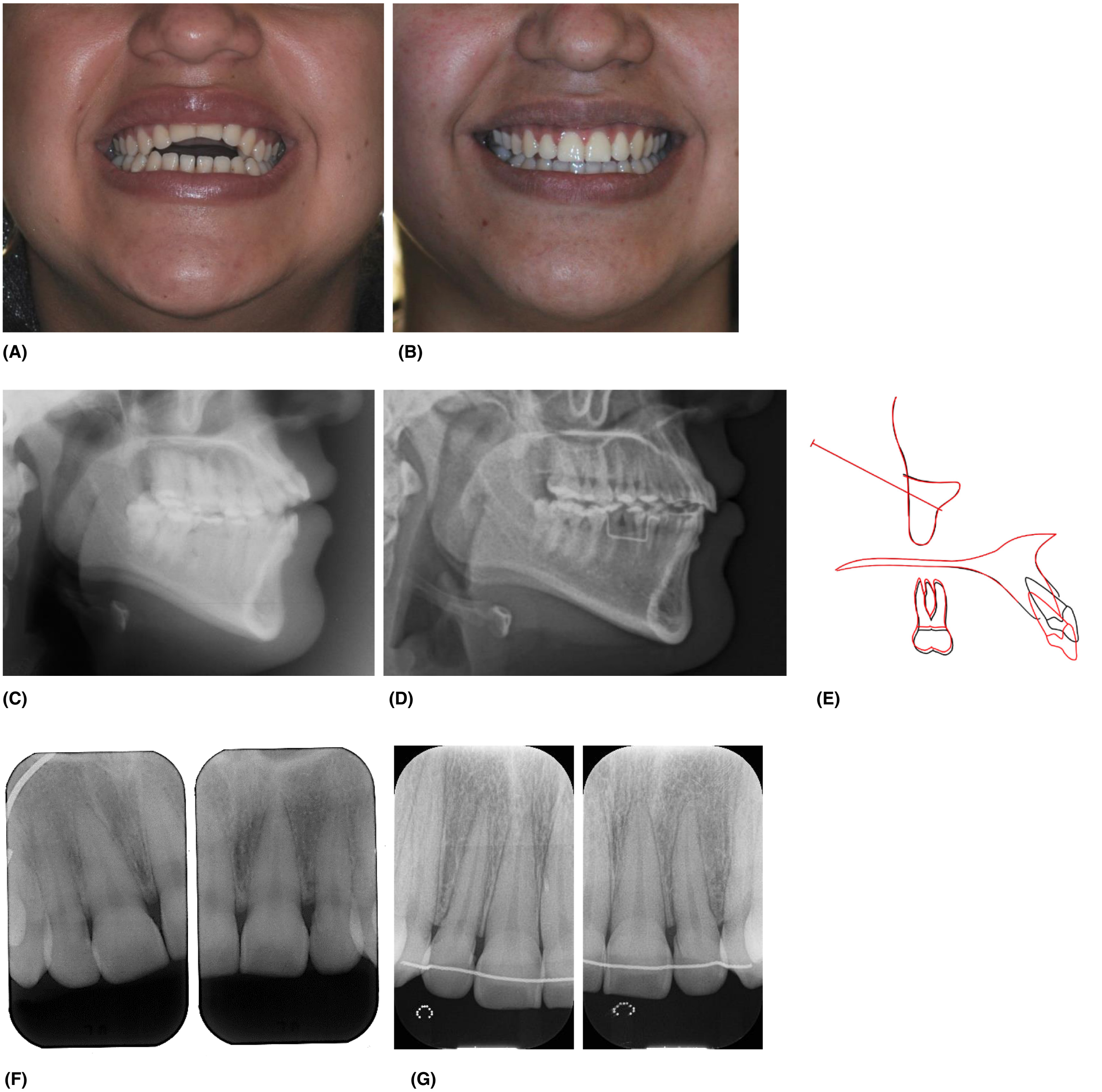


FIGURE 9 Orthodontic case with anterior open bite treated with extrusion of the anterior teeth with successful open bite closure and increase of incisor exposure upon smile. Shown here are the (A) pre-treatment and (B) post-treatment extraoral photographs where incisor exposure is visible; (C) pre-treatment and (D) post-treatment lateral cephalometric radiograph showing a lower maxillary incisor edge in respect to the upper lip line and stomion; and (E) maxillary superimposition (with the black tracing representing the initial situation and the red tracing representing the final situation) showing the extrusion of the maxillary incisors evidenced by the lower in respect to the upper lip and stomion; (F) pre-treatment and (G) post-treatment intraoral periapical radiographs showing no significant resorption of the maxillary incisor roots (patient treated in the postgraduate clinic at the University clinics of dental medicine, University of Geneva).

allowing better control over the force magnitude.[112] Extrusive forces can also be applied to the upper incisors by using Burstone torquing sectional arches when palatal root torque is indicated.[112]

On the contrary, extrusive forces can be applied intermittently with regard to the duration or magnitude of force application. This is the case when using vertical elastics with an intermittent application of force. However, this approach entails fluctuating force magnitudes, either due to the rapid deterioration of elastic force, diminishing to approximately two-thirds of its initial strength within around an hour of wear,[113] or related to the extent of mouth opening during regular functions such as speaking, shouting, or yawning.[114]

Intermittent forces are also applied when we consider the forces exerted on teeth by small vertical steps bent on the arch wires, particularly those ranging around 0.3–0.5 mm. These steps lead to an initial vertical displacement of the tooth, followed by the neutralization of the bending effect once the intended vertical tooth displacement is attained, taking into account the adaptation of the periodontal ligament. This is then followed by a passive force period. Similar intermittent extrusive forces are applied during the use of orthodontic aligners, when the bonded attachments on the teeth guide them in small extrusive steps when the appliances are in use.[115,116]

It is important to stress that most of the above-mentioned mechanisms to achieve tooth extrusion do not apply pure extrusive forces of the root in the line of the root axis. Extrusive mechanics are usually combined with palatal or lingual crown tipping and vestibular displacement of the root apices due to the location of the force application, which is on the orthodontic bracket. This should be kept in mind when considering tissue reactions and the side effects during tooth extrusion, for example, after the use of vertical elastics or the application of extrusive arches using the segmented arch technique.

Pure orthodontic extrusion would ideally only produce tension within the periodontal ligament, without any areas of compression. In reality, however, this is a rather theoretic possibility, since if the tooth is tipped while being extruded, areas of compression will inevitably be created.

The optimal force for pure extrusion is the one sufficient to cause optimal stretching of the healthy and intact periodontal tissues and the periodontal fibers without any additional force exerted on the compression zone. It is generally accepted that the force magnitude should not exceed 25–30 cN for incisors,[117] or according to Proffit, these forces fall within a spectrum ranging from 35 to 60 cN. The specific force applied depends on the particular tooth to be extruded, whether it is a single-rooted anterior tooth or a multi-rooted posterior tooth, respectively.[115] Forces of 15 cN for the fine root of a lower incisor have been proposed to be sufficient for the slow extrusion of such a single-rooted tooth.[118] With an optimal force, the expected rate of extrusion would be in the order of 1 mm per month.

3.3 | Potential side effects of orthodontic tooth extrusion

During orthodontic extrusion, there can be potential side effects, although they are generally rare and often temporary. It's essential to bear in mind that these observed side effects are likely more closely associated with the unintended tipping movements mentioned earlier, which occur concurrently with the extrusive actions, rather than being direct outcomes of the pure extrusive movement. Side effects can include pulp reactions during the orthodontic tooth extrusion, discomfort and pain, or root resorption.

Tooth sensitivity and necrosis: The teeth undergoing orthodontic extrusion may become sensitive to hot or cold temperatures and pressure. This sensitivity is typically temporary and tends to subside once the extrusion process is complete. On rare occasions, extrusion of incisors has been linked to necrosis during treatment, seen in one study to occur in 0.5% of the 400 cases studied.[119] Pulp reactions after orthodontic extrusion were studied in an experimental model of humans. These reactions involve circulatory disturbances with congested and dilated blood vessels, odontoblastic degeneration, vacuolization, and oedema of the pulp tissues, and by the 4th week, the manifestation of fibrotic changes. The odontoblastic degeneration was considered as a probable result of compromised blood supply.[120,121] Findings from other clinical studies indicate that maxillary incisors with a history of severe periodontal injury have a higher susceptibility to pulp necrosis during orthodontic extrusion than non-traumatized teeth.[119] These pulp reactions could explain the rare observation that orthodontic extrusion can sometimes cause minor changes in tooth coloration, albeit often temporary in nature.

Discomfort or pain: Patients may experience mild discomfort or soreness in the teeth during orthodontic extrusion, as is usually the case during the initial phases of other kinds of orthodontic tooth movement, something that can be alleviated with analgesics[53] such as paracetamol. Otherwise, the patient can be recommended to temporarily interrupt the extrusion forces, such as when vertical elastics are used.

Root resorption: In rare cases, orthodontic extrusion can lead to root resorption. However, this occurrence is uncommon and generally associated with excessive or prolonged forces during the extrusion process that could also be linked to the palatal/lingual tipping effect that may occur during the extrusive mechanics as mentioned above. In an animal experimental model, Weekes and Wong[122] observed that root resorption occurred at the interproximal region of the cervical third of the root after extrusion, demonstrating that orthodontic extrusion is not without risk. This has been supported by the findings of experimental tooth extrusion and intrusion in humans during 8 weeks, where quantitative assessment of the proportion of the resorbed area of the root surface was evaluated on micrographs while the severity of root resorption was assessed by visual scoring of the roots. It was found that orthodontic extrusion caused some root resorption, though four times less than during intrusion, with large variation between individuals. Nevertheless, it was found that the intra-individual extent of root resorption due to intrusion or extrusion was correlated. Therefore, orthodontists should be aware that tooth extrusion can also cause root resorption, especially in susceptible patients.[54]

3.4 | Tissue reaction during orthodontic extrusion

Animal experimental studies have been performed in the past to elucidate the tissue reactions during orthodontic extrusion (see Table 2). Oppenheim[123] and Reitan[117] reported that extrusion produces stretching of the periodontal fibers, including the supracrestal fibers, which results in bone formation at the apex and the alveolar crest of an extruding tooth. Reitan likewise demonstrated that the subcrestal periodontal fibers rearranged their position and returned to their normal alignment rather quickly during retention, whereas the supracrestal fibers could remain stretched for longer periods of time.[117] In a classic radiographic study, Ritchey and Orban[124] observed that, as a tooth erupted or extruded, the alveolar crest would

TABLE 2 Summary of periodontal outcomes during orthodontic tooth extrusion.

Extrusion leads to a coronal displacement of periodontal tissues	
Extrusion and fiberotomy prevents coronal displacement of periodontal tissues	
Aspect	**Periodontal outcome for extrusion**
Gingival margin position	The free and attached gingiva move in the direction of tooth extrusion
Width of keratinized gingiva	Increases on labial surfaces
Sulcus depth	Decrease in sulcus depth
	Formation of epithelial attachment at the cementoenamel junction of the extruded teeth
Mucogingival junction	Unchanged
Periodontal ligament	Stretching of periodontal fibers, particularly supracrestal fibers, leading to bone formation at the apex and alveolar crest
	Coronal movement of intact connective tissue attachment, resulting in the shallowing of infrabony defects
	Rearrangement of subcrestal periodontal fibers to return to their normal alignment during retention
Alveolar crest	Bone deposition occurring at the crest of the alveolar bone, resulting in the widening of the attached gingiva
Cementum	Repair of radicular resorption with the apposition of cellular cementum

usually maintain a normal relationship with the cementoenamel junction.

The gingival movement with orthodontic tooth extrusion was evaluated on four upper incisors of monkeys that were extruded vertically (from 2.6 to 10.9 mm) in five experimental animals, comparing them with teeth in three control animals.[125] It was found that the free gingiva moved approximately 90% and the attached gingiva moved about 80% in the same direction as the extruded teeth, causing an increase in the width of the attached gingiva on the labial surface, while the gingival sulcus depth decreased by approximately 20% of the extrusion distance, and the clinical crown height increased by about 20%. It was noticed that the position of the mucogingival junction remained the same before and after the experiment, while epithelial attachment was formed at the cementoenamel junction of the extruded teeth. No pocket formation or inflammation occurred during extrusion, as properly conducted tooth extrusion did not result in any clinical or histologic problems in the gingival tissues.[125]

Similarly, in a recent animal experiment on *Canis lupus familiaris* (dogs),[126] extrusion using orthodontic appliances and light forces resulted in bone apposition at the alveolar bone crest, increasing the width of the attached gingiva. Mechanical stresses applied during orthodontic extrusion stimulated angiogenic growth factors that contributed to the formation of gingival tissue and periodontal fibers and the deposition of new bone via osteoblastic activity. Coronal displacement of periodontal tissues occurred during extrusion, which could be avoided using supracrestal fiberotomy (discussed subsequently). In this study, repaired radicular resorption with cellular cementum was detected in the extruded teeth.[126]

3.5 | Tissue reaction during orthodontic extrusion and fiberotomy

As mentioned previously, coronal displacement of periodontal tissues has been observed during extrusion, which can be avoided using fiberotomy, i.e., the resection of the supracrestal attachment fibers, something that can be favorable in periodontal therapy aiming to decrease or eliminate angular bone defects or in treatment aiming at crown lengthening procedures. The reaction of the periodontal tissues to orthodontic extrusion has been studied when combined with fiberotomy.[127] In five *Canis lupus familiaris* (dogs), the mesial roots of hemisected mandibular premolars were used to be extruded for 8 weeks, with fiberotomy and activation every 2nd week, while the distal roots served as reference roots. After the active extrusion period, a retention period of 8 additional weeks was followed. It was found that orthodontic extrusion combined with supracrestal fiberotomy caused coronal displacement of the tooth, associated with pronounced recession of the gingival margin and extensive loss of connective tissue attachment. Nevertheless, the degree of gingival recession and the amount of connective tissue attachment loss were less extensive than the amount of tooth extrusion, indicating that repeated fiberotomy does not completely prevent coronal migration of the attachment apparatus.[127] These findings were confirmed by more recent studies,[126] opening possibilities for the clinical application of favorable crown lengthening procedures. Thus, in cases where displacement of the bone margin and attachment along with tooth extrusion is not suitable, as is the case in crown–root fractures, periodical circumferential supracrestal fiberotomy may be indicated at the start of treatment and every 2 subsequent weeks during orthodontic extrusion.[128]

As an alternative, when rapid extrusion is performed with stronger traction forces, the migration of supporting tissues is less pronounced (Figure 10). This is due to the rapid movements exceeding the capacity for physiological adaptation of the periodontal apparatus, causing a similar but milder effect than repeated fiberotomy during extrusion, whereby rapid extrusion is accomplished with forces higher than 50 cN.[129] It should be noted that rapid extrusion carries a risk of tearing the periodontal ligament and causing tooth ankylosis, although this has only been reported anecdotally.[130]

3.6 | Forced orthodontic eruption

What is often referred to as a forced orthodontic eruption is a nonsurgical treatment option that aims to modify the structure of the

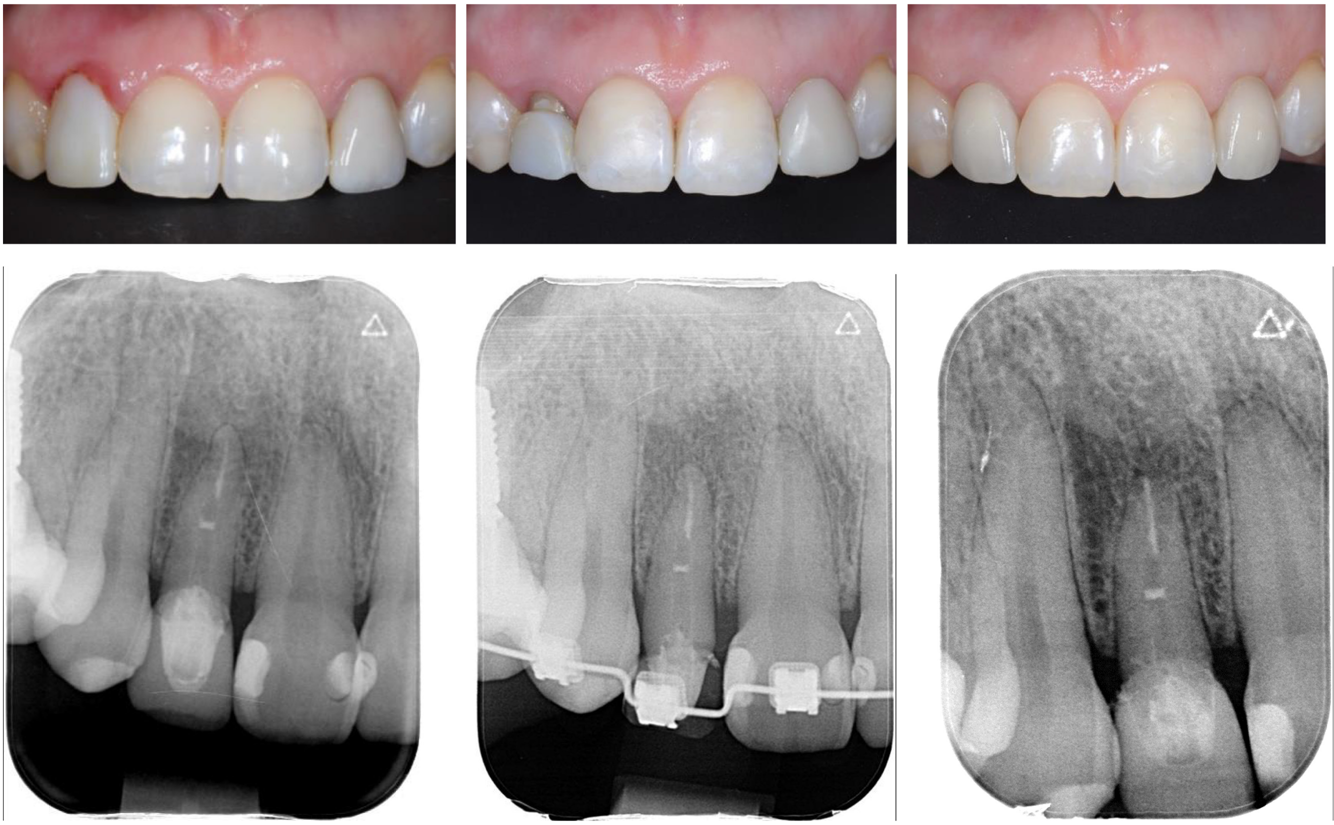


FIGURE 10 Orthodontic extrusion carried out for the purposes of crown lengthening. Shown below are intraoral photographs and periapical radiographs of the tooth 12 before extrusion, after orthodontic extrusion, and after prosthetic rehabilitation (carried out by Dr G. Garavaglia; private practice, Geneva).

bone and gingival tissues, ultimately improving the bone and soft-tissue conditions for the purposes of implant site development. A multidisciplinary treatment approach involving forced eruption, followed by extraction of the tooth in question, and immediate implant placement can be planned to achieve improved aesthetic and functional outcomes. In compromised periodontal cases, it has been seen that the growth of new bone and soft tissues in a coronal direction is possible, eliminating the need for additional, more invasive surgical procedures.[131] A more aesthetically pleasing and functional restoration supported by dental implants is thus favored, while this technique offers several advantages, including the leveling of isolated bone defects, clinical crown lengthening, repositioning of the gingival margin, improving anchorage for dental implants, and increasing the amount of attached gingiva and bone. As tooth movement occurs in a coronal direction, the periodontal tissue, including bone, migrates in the same direction with the stretching of the periodontal fibers, resulting in a coronal shift of the bone at the base of the defect. This procedure can also increase the volume of the soft tissue by promoting the growth of the attached gingiva. A prerequisite to this procedure being effective is that the apical third of the root needs to have an intact fiber apparatus in the absence of systemic diseases such as diabetes mellitus that could impair bone healing. By regenerating periodontal tissue support, forced orthodontic eruption enables the subsequent placement of dental implants, yielding predictable treatment outcomes.[132]

Korayem et al.[133] suggested that forced orthodontic eruption with light forces can promote crestal alveolar bone development in the vertical and bucco-lingual directions, mainly in the occlusal third of the root. The findings were based on 18 articles, most of them case reports or case series describing forced orthodontic eruptions of non-restorable or periodontally hopeless maxillary anterior teeth. In all cases, clinically significant gains in alveolar bone and gingival tissue were reported, resulting in significant quantitative and qualitative improvements in the future planned implant sites and being a viable alternative to conventional surgical augmentative procedures for implant site development. Thus, the supporting soft tissues would move vertically with the corresponding tooth during a forced orthodontic eruption, so as to create the ideal conditions for implant placement.[132] It is recommended to apply light continuous forces for forced orthodontic eruptions of 15–50 cN with an expected extrusion rate of no more than 2 mm per month,[133] keeping in mind that this extrusive force will not be purely extrusive but will likely lead to some changes in the inclination of the tooth.

3.7 | What have human and animal studies taught us about the periodontium during orthodontic extrusion of periodontally affected teeth?

During orthodontic treatment, the accumulation of bacterial plaque in the gingival margin is a frequent situation, and often it is asked if orthodontic tooth movement could cause periodontal destruction. Experimental studies performed on *Canis lupus familiaris* (dogs) to elucidate this point demonstrated that extrusive orthodontic forces were prone to shifting plaque into a supragingival location and, as a consequence, provide better conditions and decrease the risk for the development of infrabony pockets.[83] The beneficial effects on the extruded teeth after induced experimental periodontitis were demonstrated in the experimental study of van Venrooy and Yukna[134] using a split-mouth model on *Canis lupus familiaris* (dogs). The extruded teeth were shown to have shallower pocket depths, less gingival inflammation, and no bleeding on probing, while the control teeth with periodontitis presented no demonstrable changes using radiographic evaluation.[134]

As previously mentioned, one of the indications for orthodontic tooth extrusion is the augmentation of clinical crown length or the decrease of irregularities in alveolar bone levels. The previously described procedure of forced orthodontic eruption could be used in these situations for the treatment of infrabony pockets, implying that this extrusive movement would guide the intact connective tissue attachment toward a more coronal position, and this would have the advantage of shallowing out the bony defect.[135] It should be kept in mind that this treatment approach to reduce or eliminate infrabony pockets by tooth extrusion may create supraocclusion of the extruded tooth that necessitates the shortening of the crown, with possible endodontic treatment and eventual prosthetic restoration.

The orthodontic extrusion of teeth has been advocated as an effective method for managing one- and two-wall infraosseous defects,[135] and numerous case reports[15,136–139] have been published in this respect to illustrate the potential benefits of tooth extrusion on the adjacent soft and hard tissues, although no studies with a higher level of evidence exist to support this procedure.

Finally, we should consider that, similarly to healthy teeth, teeth following treatment of severe periodontitis may still undergo all possible orthodontic movements, including extrusion, without any limitations despite the reduced periodontal support, as long as the periodontium is healthy but reduced. Nevertheless, it is biologically reasonable to decrease the magnitude of the extrusive force that is applied to the tooth to correspond to the stretching of the reduced periodontal ligament. Having said this, one more point that should be taken into account is the apical displacement of the center of resistance of the tooth, which may create changes in the direction of the extrusive force when compared with a tooth with a healthy and intact periodontium with normal bone levels.

TABLE 3 Key features concerning orthodontic tooth intrusion.

Orthodontic tooth intrusion: summary
Some indications
Correcting gummy smile, anterior teeth in deep bite, posterior teeth in open bite
Addressing overeruption due to missing teeth or periodontal issues
Enhancing aesthetics by aligning gingival margins and leveling the occlusal plane
Possible mechanisms
Using neighboring teeth as anchorage, with continuous archwires
Segmental force systems, one-couple systems, or utility arches
Skeletal anchorage (miniscrews, implants) is highly effective
Expected rate of orthodontic tooth intrusion
Approximately 0.5 mm/month
Potential side effects
Expected orthodontic pain
Potential issues including root resorption, bone loss, and pulpal necrosis
Special consideration needed for periodontal patients
Animal studies – healthy periodontium
Observable bone changes in various animal studies
Human studies - healthy periodontium
Generally, no significant detrimental effects with proper care
Gingival margin moves with teeth, minimal bone loss
Animal studies – periodontally affected teeth
Intrusion may benefit periodontal conditions in animals
Careful plaque control is crucial
Human studies – periodontally affected teeth
Apical displacement of the tooth's center of resistance in reduced periodontal support
Intrusion may improve attachment levels (questionable) with inflammation control
Light forces are essential in individuals with a reduced periodontium
Conclusion
Orthodontic tooth intrusion requires careful management, considering various factors in both healthy and periodontally compromised conditions

3.8 | Clinical recommendations for orthodontic extrusion

In contrast to orthodontic intrusion, orthodontic extrusion does not seem to have potentially negative effects on periodontal tissues in dentitions with reduced periodontal support, even in cases where plaque control is not perfect. Due to the nature of the tooth movement, any bacterial plaque remnants would be moved in a coronal direction and thus supragingivally, which would not incur the risk of further

TABLE 4 Key features concerning orthodontic tooth extrusion.

Orthodontic tooth extrusion: summary
Some indications
Openbite correction (anterior teeth), deep bite correction (posterior teeth)
Impacted teeth
Subgingival root access
Aesthetic improvement
Vertical bone augmentation for implants
Periodontal regeneration (vertical defects)
Possible mechanisms
Continuous or intermittent forces
Common: fixed appliances, segmented arch mechanics
Burstone torquing arches for maxillary incisors
Intermittent forces: elastics, aligners
Expected rate of orthodontic tooth extrusion
≤1 mm/month
If more: forced eruption
Possible side effects
Sensitivity, necrosis
Discomfort, pain
Root resorption
Tissue reactions
Stretch of periodontal fibers
Promotion of bone formation
Coronal migration of tissues
Properly conducted: no pockets, inflammation
Animal or human studies
Animal studies: coronally shift plaque, shallower pockets
Humans: manage infraosseous defects, benefit on tissues
After severe periodontitis, extrusion with reduced force
Apical displacement of the tooth's center of resistance in reduced periodontal support
Conclusion
Generally safe for reduced support; lower magnitude forces with bone loss; possible regeneration of bone and supporting tissues in coronal direction

periodontal breakdown. It may be reasonable, however, to apply lower magnitude orthodontic forces in the presence of periodontal bone loss than in a patient with a healthy and intact periodontium.

Besides the lack of risk of creating further periodontal breakdown with orthodontic extrusion, this type of tooth movement may even be used to the advantage of periodontal conditions by aiding in the regeneration of lost hard and soft periodontal tissues in a coronal direction. Thus, orthodontic extrusion of teeth can be employed in implant site development, which would obliviate the need for more invasive surgical procedures such as bone grafting. In addition, orthodontic extrusion with fiberotomy can be used in cases where it is desired to decrease or eliminate angular bone defects or in treatment aiming at crown lengthening procedures where the soft tissues will not follow the movement of the tooth crown.

As with orthodontic intrusion, periodontal therapy should always precede orthodontic treatment, and the combination of appropriate orthodontic and periodontal treatment can improve reduced periodontal conditions. Consensus is lacking with regard to when to perform orthodontic tooth movement, namely extrusion, following periodontal treatment, but a period of a few months might be reasonable in order to make sure that any inflammatory processes have subsided.

4 | CONCLUSIONS

As has become evident from the detailed discussion of orthodontic intrusion and extrusion, both of these types of tooth movement are feasible under any circumstances where there is a healthy or at least non-inflammatory periodontium (see Tables 3 and 4 for key features of orthodontic intrusion and extrusion, respectively). Whether a healthy and intact periodontium or a healthy but reduced periodontium is present, these tooth movements are possible, albeit perhaps with different force levels and vigilance in these two scenarios. Different indications of these two types of movements require different orthodontic mechanics with a good level of control, but plaque control (both with regard to the oral hygiene regime at home and professional prophylaxis every 3–6 months) is essential to maintaining a healthy periodontium or even in the hopes of achieving some periodontal tissue regeneration. In patients with Stage IV periodontitis, the EFP recommends that the patient's periodontal condition be monitored closely, ideally at every orthodontic appointment.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

PERMISSION TO REPRODUCE MATERIAL FROM OTHER SOURCES

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