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L. Young
I. Binderman
A. Yaffe
L. Beni
A. D. Vardimon

Fiberotomy enhances orthodontic tooth movement and diminishes relapse in a rat model

Authors' affiliations:
L. Young, I. Binderman, Department of Oral Biology, The Maurice and Gabriela Goldschleger, School of Dental Medicine, Tel Aviv University, Tel Aviv, Israel
L. Young, L. Beni, A. D. Vardimon, Department of Orthodontics, The Maurice and Gabriela Goldschleger, School of Dental Medicine, Tel Aviv University, Tel Aviv, Israel
A. Yaffe, Department of Prosthodontics, Hebrew University, Hadassah School of Dental Medicine, Jerusalem, Israel

Correspondence to:
Professor Itzhak Binderman
Department of Oral Biology
School of Dental Medicine
Tel Aviv University
Tel Aviv 69978, Israel
E-mail: binderma@post.tau.ac.il

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Structured Abstract

Objectives – Accelerated orthodontic tooth movement is triggered by procedures that include mucoperiosteum flap surgery and surgical scarring of cortical bone. Our aim was to test whether fiberotomy by itself will accelerate orthodontic tooth movement and diminish relapse.

Materials and Methods – In 34 *Wistar rats*, alveolar bone resorption and molar tooth movement were measured after fiberotomy, apical full-thickness flap without detachment of gingiva from the roots, or no surgery. Orthodontic appliance was installed at time of surgery and activated for 14 days, generating movement of the first maxillary molar buccal and then removed.

Results – Percent of sections in which alveolar bone resorption was detected was significantly higher ($p < 0.05$) after fiberotomy (27%) in comparison with apical flap surgery (12%) or no surgery (6%), after 30 days. Also, at the end of active phase, the molar moved significantly faster ($p < 0.01$) and twice the distance after fiberotomy (0.54 ± 0.33) in comparison with apical surgery (0.26 ± 0.12) or no surgery (0.3 ± 0.09). Sixteen days after the appliance was removed, only 12% relapse was recorded in the fiberotomy group, while almost total relapse in other two groups.

Conclusion – We conclude that fiberotomy solely accelerated orthodontic tooth movement and diminished relapse.

Key words: accelerated orthodontics; alveolar bone resorption; apical flap; fiberotomy; periodontally accelerated osteogenic orthodontic

Introduction

Clinical findings suggest that increased osteoclastic activity of the alveolar bone is the key element in defining the kinetics of orthodontic tooth movement (1,2). Recently, a mucoperiosteum flap elevation and selective buccal and lingual decortication of alveolar bone have been advocated to achieve periodontally accelerated osteogenic orthodontic tooth movement and enhanced post-treatment stability (PAOO) (3,4). This procedure was characterized by a burst of increased regional accelerated phenomenon (RAP) (5), an increase in cortical bone porosity and dramatic turnover of alveolar bone (6).

In fact, one should distinguish between the different periodontal procedures that trigger alveolar bone resorption. Our studies (7,8) and others (6,9,10) have demonstrated that disruption of the marginal gingiva from the root surface and separation of the mucoperiosteum from the alveolar bone caused an abrupt drop of cellular strains of gingival fibroblasts (11), activating a chain of signals that propagate osteoclastogenic alveolar bone resorption on its PDL surfaces of the alveolar bone. Detachment of the mucoperiosteum from bone surfaces usually yields a direct mild burst of local bone remodeling on its outer surfaces, which is termed as RAP effect (5,7). In addition, a corticotomy procedure traumatizes the bony surfaces creating a series of wounds that further stimulate a highly resorptive phase. It is well described that application of orthodontic forces increases tensile forces on PDL fibers stimulating a bone formation signal. While the release of tensile forces on the opposite side (compression side) will trigger resorption of the PDL bone surfaces (12).

Recently, Sebaoun et al. (4) suggested that the decortication injury, rather than the rasing of the mucoperiosteum flap, is the trigger for PDL activity, alveolar bone resorption, and osteopenia allowing PAOO. In contrast, we propose that orthodontic forces are highly effective when detachment of dentogingival fibers is executed by fiberotomy. Our hypothesis is that fiberotomy is sufficient to enhance remodeling of alveolar bone, consequently accelerating orthodontic tooth movement. In the present study in a rat model, we compared the effect of fiberotomy surgery to that of apical flap surgery and to no surgery to accelerate orthodontic tooth movement and to diminish relapse after activation of an orthodontic appliance on the first molar.

Materials and methods

Ethics

This research was carried out in accordance with the Helsinki Accord at the animal care unit of the Faculty of Medicine, Tel Aviv University. In the present experiment, 34 male *Wistar rats*, 5–6 month old and of 450–500 g weight, were divided into three experimental groups.

Experimental design

The rats were acclimatized for 1 week before the experimentation start date. At the day of surgery or at times of measuring the tooth movement, the rats were anesthetized using a mixture of 25 mg/kg body weight of ketamine HCl (Malgene 1000, Rhone Merieux, Lyon, France) and 42 mg/kg body weight of xylazine hydrochloride (Rampun Bayer, Leverkusen, Germany) by intramuscular injection (IM).

In group A, which comprised of 13 rats, a fiberotomy surgical procedure was performed. Using a scalpel, surgical detachment of the dentogingival fibers was performed from around the root surfaces at a supra-crestal position of all the molars. To ensure the detachment of the dentogingival fibers of the marginal gingiva, a small periosteal elevator was then used. In group B, which comprised of 14 rats, an apical mucoperiosteum flap surgical procedure was performed. Using a scalpel, an incision was made at the molar teeth apices level. Then, a full-thickness mucoperiosteal flap was elevated from the underlying bone coronally using a small periosteal elevator. The apical mucoperiosteal flap was short of the marginal gingiva, and there was no detachment of the dentogingival fibers from the root surface. In both groups, the surgery was performed bilaterally around all maxillary molars, on the buccal and palatal aspects. All flaps were easily adapted back to their original position 20–30 s after surgery. In group C, which comprised of seven rats, no surgery was performed. In all three groups, an orthodontic appliance was applied to the palatal aspect of the right first maxillary molar, generating buccal movement of the tooth; the left side served as a split-mouth control. There was no reactivation during the 14 days of treatment. Tooth movement was measured at six time points, under general anesthesia ($T_{0,}$ $T_{0\ +30'}$, T_7, $T_{14,}$, T_{21}, T_{30}).

Two rats from the fiberotomy group and two rats from no surgery group were killed 30 min after activation of the orthodontic appliance ($T_{0+30'}$). They served to measure the immediate response to force application on molar tooth movement. In all other rats, after the activation period of 14 days, the orthodontic appliance was removed, and the displacement of the first molar was recorded up to day 30.

The orthodontic appliance

Lateral movement of the rat's right first maxillary molar in the buccal direction was accomplished by means of NiTi 0.012-inch orthodontic wire that was threaded in a tunnel, drilled mesiodistally in both maxillary incisors and bonded with Transbond^{TM} XT (3M Unitek, Monrovia, CA 91016, USA). In its passive state, the wire was positioned parallel to the incisal edges of the incisors; when activated, it was bent so that its distal end was placed against the palatal surface of the first right maxillary molar (Fig. 1). To prevent the wire from sliding from the molar tooth coronally, a small occlusal stop was made above the wire, using Transbond^{TM} XT (Fig. 1). The mandibular incisors were cut close to the gingival level to avoid grinding of the maxillary incisors. This unilateral design of the appliance secured solely expansion of the right first maxillary molar, with no involvement of the intermaxillary suture. The orthodontic appliance was removed after 14 days due to the constant grinding and eruption of the maxillary incisors that interfered with the retention of the orthodontic wire.

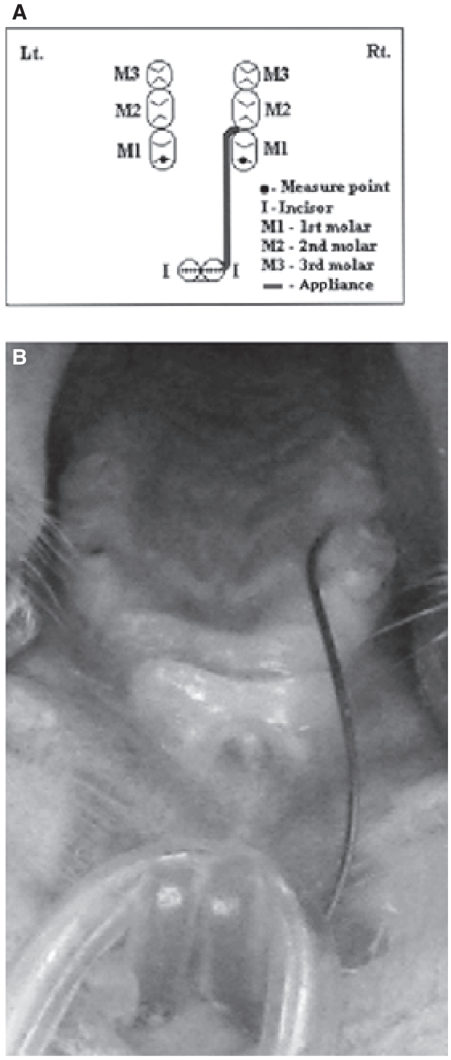

Fig. 1. The orthodontic appliance. (A) Schematic occlusal view. (B) Occlusal view in the rat's mouth.

Tooth movement measurements

A modified Mitutoyo digital caliper (Mitutoyo Corporation, 20–1, Sakado 1-chrome, Takatsu-ku, Kawasaki, Kanagawa, Japan) was used to measure intra-orally the movement of the right first maxillary molar (13). At the most mesial point of the central fossa of the first maxillary molars, on both sides of the maxilla, indentations were drilled for insertion of the caliper's tip ends for accurate measurements (Fig. 1a). The mean and SD of three consecutive measurements of the distance between the first molars, cross-arch, were calculated; T_0 being the initial reference distance. This distance was subtracted from each time point T_n.

Microradiography

The rats were euthanized by CO_2 30 days after surgery. The maxilla was carefully dissected and fixed in 4% buffered formaldehyde. 5–6 sections of 1–1.5 mm thick were prepared from all the molars of the maxilla in a bucco-palatal direction from the anterior aspect posteriorly. Microradiography of the sections was performed in a mesio-distal direction, using a Kodak periapical safety film in a Hewlett Packard X-ray cabinet, for 5 s at 25 kV. Films were scanned and evaluated in a modified technique (14,15), according to three categories: no resorption, buccal resorption, and palatal resorption of the alveolar bone.

Statistical analysis

The mean and standard deviation (SD) of first molar tooth movements were statistically analyzed for changes with time, within the same group or between groups, using one-way ANOVA. Statistical significance was considered when $p < 0.05$. In each group, the alveolar bone loss data are presented as percentage of the total sections. Statistical analysis was performed, using Fisher's exact test to examine whether the treatment had a significant influence on the type and amount of bone resorption. Statistical significance was considered when $p < 0.05$.

Results

Weight of the animals

In all three groups, the weight of the rats decreased during the 14 days of active phase. After the orthodontic appliance was removed (day 14), the rats regained most of their weight. There was no significant difference in the rats' weight among the groups.

Tooth movement

The immediate displacement of the first right maxillary molar was measured in rats that were killed 30 min after activation of the orthodontic appliance ($\mathbf{T_{0+30'}}$). The mean magnitude of tooth movement was of 0.003 mm when no surgery was performed, while after fiberotomy, a mean of 0.013 mm of tooth movement was recorded. These measurements are < 2% of the maximum tooth movement achieved at the end of the activation phase (14 days) in the corresponding experimental groups. Seven days after the activation of the orthodontic appliance (T_7), an average tooth movement of 0.2 $\pm$ 0.06 mm was measured in group C, in which no surgical procedure was performed. Rats that underwent surgical procedure of apical flap (group B), the first right maxillary molar movement was 0.16 $\pm$ 0.13 mm after 7 days. In group A, in which a surgical procedure of fiberotomy was performed, a significantly greater ($p < 0.01$) tooth movement of 0.32 $\pm$ 0.16 mm was recorded, in comparison with groups C and B. At the end of the active phase (T_{14}), the molar tooth moved up to maximum of 0.54 $\pm$ 0.33 mm in group A (fiberotomy), in comparison with 0.26 $\pm$ 0.12 mm and 0.3 $\pm$ 0.09 mm in groups B and C, respectively. The results indicate that fiberotomy induced about twofold greater molar tooth movement than after apical surgery or no surgery (Table 1). Taken together, the rate of tooth movement was enhanced significantly ($p < 0.01$) after fiberotomy surgery in comparison with the other two groups, both at T_7 and T_{14}.

On day 14 (T_{14}), the orthodontic appliances of all experimental groups were removed and stability of

Table 1. **The distance between 1st molars after orthodontic tooth movement and its relapse, in a rat model**

	Fiberotomy		Apical flap		No Surgery	
	Mean	SD	Mean	SD	Mean	SD
Day 0	7.24	0.46	7.21	0.29	7.24	0.05
Day 7	7.58*	0.43	7.46	0.27	7.45	0.06
Day 14	7.78*	0.47	7.54	0.27	7.55	0.06
Day 21	7.76	0.47	7.36	0.28	7.41	0.10
Day 30	7.72†	0.46	7.27†	0.26	7.29†	0.06

Distance between 1st molars in mm.
*The amount of tooth movement was enhanced significantly ($p < 0.01$) after fiberotomy surgery in comparison with apical flap surgery or after no surgery, both at T_7 and T_{14}.
†At the end of the experiment (T_{30}), 85% relapse was recorded after apical flap surgery or no surgery as compared with a 12% relapse after fiberotomy surgery ($p < 0.001$).

the tooth displacement was evaluated. At T_{21}, in groups B and C, a 57 and 46% tooth displacement relapse occurred, respectively, in comparison with a 5% relapse in group A. At the end of the experiment (T_{30}), 85% relapse was recorded in groups B and C as compared with a 12% relapse in group A ($p < 0.001$). This means that fiberotomy also contributed to positional stability of the dentition after orthodontic tooth movement (Fig. 2).

Microradiography – Bone resorption

Microradiography of sections of the maxilla demonstrated significantly ($p < 0.05$) more alveolar bone loss, mostly of the PDL aspect of the buccal plate, after fiberotomy (group A) than in the apical flap (group B) or in the no surgery group (group C) (Fig. 3a). At day 30, in the fiberotomy group, 27% of 68 sections revealed alveolar bone resorption, 20% was on the buccal aspect. In the apical flap group, alveolar bone resorption was found in only 12% of 64 sections, 7% on the buccal aspect. In the no surgery control group, only 6% of 16 sections resorption was found, none of which was on the buccal aspect (Fig. 3b).

Discussion

Previous studies have shown that mucoperiosteum flap surgery, which includes fiberotomy, is

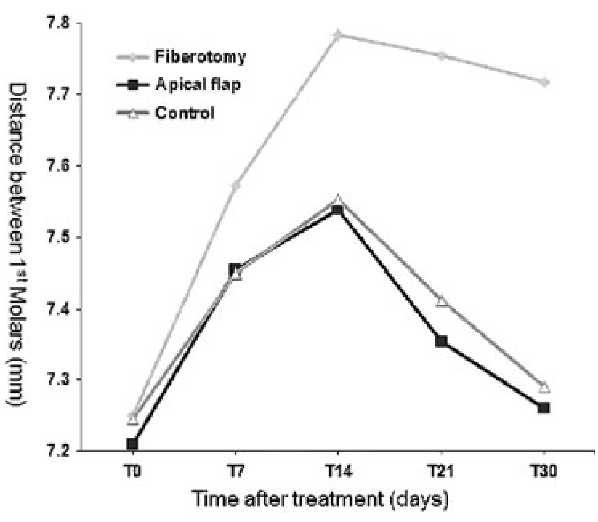

Fig. 2. Dynamics of tooth movement of the first right maxillary rat molar throughout the experimental period of 30 days.

a signal for alveolar bone remodeling and bone loss, in a rat model (8,10). In the present study, microradiography revealed a significantly larger amount of sections with alveolar bone resorption on the PDL aspect of the buccal plate following fiberotomy. Significantly, fewer sections revealed resorption following apical flap surgery. No resorption was found in the rats that underwent no surgery. Interestingly, only a small amount of alveolar bone resorption was observed on the palatal aspect of the teeth in all three experimental groups. The resorption on the palatal side is similar in all groups and is most likely a result of local injury due to the position of the orthodontic appliance. It is possible that the marked resorption of the buccal plate is attained because it is composed mostly of alveolar bone, while the palatal plate is mostly basal bone. Also, it may account to higher density of the palatal bone. As fiberotomy stimulated alveolar bone resorption, while the orthodontic tensile forces on the palatal aspect of the alveolar bone increased bone apposition, the net bone loss of palatal aspect of alveolar bone was not significant.

During tooth eruption, the newly formed alveolar bone that is surrounding the root is embedded in the basal bone. Therefore, we propose that the effect of fiberotomy on bone resorption occurs at the envelope of the alveolar bone; while the apical flap affects mostly the outer surfaces of the jaw bone. It seems that the resorption on the buccal plate following apical flap surgery is of RAP nature, while the resorption following fiberotomy is mainly directed by strain relaxation of fibroblasts of the marginal gingiva (11,16). The orthodontic force directed buccally may also contribute to the extensive bone resorption that was observed on its periodontal buccal aspect.

In our previous studies, we found that detachment of marginal gingiva from root surface produces an immediate drop of gingival fibers strain and relaxation of gingival cells that triggers cellular release of ATP. Extracellular ATP further activates a pathway, which leads to a burst of osteoclastic alveolar bone resorption (11,16). As marginal gingiva is a key in controlling alveolar bone remodeling, it contributes to

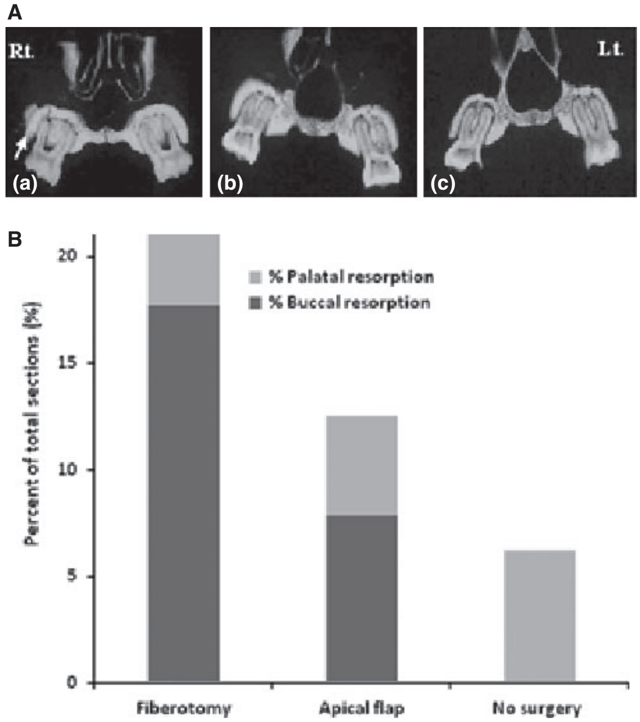

Fig. 3. (a) Radiographs of bucco-lingual sections of the rats' maxilla at T_{30}. (3a) fiberotomy group. Note the alveolar bone resorption on the buccal aspect of the right first maxillary molar (arrow). (3b) No surgery group. (3c) Apical mucoperiosteal flap group. (b) Distribution of alveolar bone resorption in the fiberotomy, apical flap and control experimental groups.% Palatal resorption – percent of sections with resorption on the palatal aspect.% Buccal resorption - percent of sections with resorption on the buccal aspect. The total number of sections (n) was: fiberotomy (group A) n = 68 at T_{30}, apical flap (group B) n = 64 at T_{30}, no surgery (group C) n = 16 at T_{30}. The sections after fiberotomy exhibited significant increase in total and buccal resorptive surfaces in comparison with other experimental groups B and C ($p < 0.05$).

the enhancement of orthodontic tooth movement (16). In the present study, fiberotomy surgery that detaches from root surfaces of the physiologically strained fibrous attachment stimulates significantly the rate of tooth movement in contrast to apical flap surgery that does not detach the dentogingival fibers, or when no surgery is performed. Moreover, during stabilization phase, after removing the orthodontic appliance, only a minimal relapse is observed after fiberotomy, while in other groups, the tooth almost regains its original position. We assume that the genetic positioning of teeth in the dental arch during development of occlusion and their interdental strained fibrous and cellular connectivity establishes a 'positional physical memory of the dentition' (PPMD) (17). Moreover, during eruption of teeth, the dentogingival, dentoperiosteal, and interdental fibrous attachment are established. Figure 4 demonstrates the dentoperiosteal fibers embedded in the cementum and across into the alveolar crest. During fiberotomy,

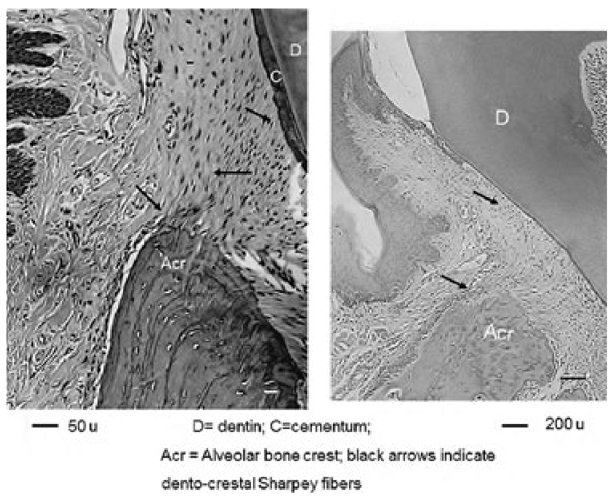

Fig. 4. Histological section (H&E stain) demonstrating the dento-periosteal fibers embedded in the cementum and into the alveolar crest.

the loss of interdental physical connectivity results in a transient loss of PPMD, thus allowing effective rapid change in alignment of teeth achieving a new stable position, without undergoing relapse. Tuncay et al., (18) proposed that enhancement of orthodontic tooth movement after gingival fiberotomy is achieved due to reduction of gingival tissue resistance to orthodontic forces. They assumed that alveolar bone remodeling is largely activated by changes of forces transmitted by the PDL and not fiberotomy (18,19). Here, we found that although fiberotomy has reduced gingival tissue resistance; tooth movement was minimal 30 min after activation of the orthodontic appliance.

In contrast to our findings, the clinicians who developed the periodontally accelerated osteogenic orthodontic tooth movement procedure insist that the contribution of corticotomy in enhancing orthodontic tooth movement is critical (3,19). Sebaoun et al., (4) argues that mucoperiosteum flap surgery without corticotomy does not enhance orthodontic tooth movement as corticotomy does, although he does not present evidence for this argument. Lee et al., (6) describes the effect of corticotomy on remodeling of bone that surrounds and supports teeth as RAP (regional acceleratory phenomenon), consisting of a resorptive phase of the inner trabecular bone, which is mostly alveolar bone. As the authors have not included in their studies a mucoperiosteum flap or fiberotomy without corticotomy, their observations on the resorptive phase and accelerated tooth movement could be attributed to the effects of detachment of the gingival fibers from the root surfaces. It is important to note that elevating an apical mucoperiosteal flap that does not detach the marginal gingiva from root surfaces, does not affect significantly alveolar bone resorption and does not enhance tooth movement.

The present experiments clearly show that there was no significant difference in tooth movement pattern, amount, or rate during the active phase between the no surgery and the apical flap groups. Roberts et al.,(1) stated that the resorptive activity mediated by osteoclasts is the limiting factor in the rate of tooth movement in which the periodontal ligament (PDL) plays a crucial role. Nobuto et al., (10) demonstrated that when mucoperiosteal flap is elevated, a burst of angiogenesis of the PDL vascular plexus surrounded by many osteoclasts is invading the alveolar bone surface and subsequently resorbs it. In our earlier study, we found that mucoperiosteum flap surgery stimulated maximal alveolar bone resorption 3 weeks after surgery, but then a bone formation phase took place which recovered the bone loss 3–6 month later (7).

Collectively, our findings suggest that the osteoclastic activity that resorbs the periodontal surface of the alveolar bone in response to fiberotomy is the key in accelerating the kinetics of tooth movement after application of an orthodontic force. It should be noted that fiberotomy stimulates mostly bone resorption on the periodontal surfaces of the alveolar bone, while the apical flap may affect the outer surfaces of the alveolar and basal bone.

Conclusions

The present study demonstrated that detachment of the marginal gingiva from the root surfaces, also termed as fiberotomy, enhances alveolar bone remodeling, while apical flap does not. When orthodontic forces and detachment of the marginal gingiva are simultaneously applied an accelerated tooth movement and diminished relapse is achieved.

Clinical relevance

Mucoperiosteum flap elevation and selective decortication have been advocated to achieve periodontally accelerated osteogenic orthodontic tooth movement (PAOO) due to extensive bone remodeling. We have shown that detachment of the marginal gingiva during mucoperiosteum flap surgery caused strain relaxation of gingival fibroblasts that stimulated alveolar bone remodeling on its periodontal aspect. In fact, disruption of marginal gingiva from root surfaces is sufficient to accelerate tooth movement and minimize relapse, in a rat model. We suggest that detachment of the dentogingival fibers (fiberotomy) is most effective in accelerating orthodontic treatment and reducing relapse.

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