Journal of Dental Sciences 20 (2025) 1415–1421

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journal homepage: www.e-jds.com

Original Article

Evaluation of the effects for root resorption in orthodontic tooth movement with micro-osteoperforations in mice

Tulonga Ndemuweda [a], Hideki Kitaura [a*], Fumitoshi Ohori [a], Aseel Marahleh [b], Jinghan Ma [a], Ziqiu Fan [a], Angyi Lin [a], Kohei Narita [a], Arata Itou [a], Itaru Mizoguchi [a]

[a] *Division of Orthodontics and Dentofacial Orthopedics, Tohoku University Graduate School of Dentistry, Sendai, Japan*
[b] *Frontier Research Institute for Interdisciplinary Sciences, Tohoku University, Sendai, Japan*

Received 1 February 2025; Final revision received 17 February 2025
Available online 25 February 2025

KEYWORDS
Micro-osteoperforations;
Orthodontics;
Tooth movement;
Odontoclast;
Root resorption

Abstract *Background/purpose:* Orthodontic treatment is one of the most demanding procedures available for both patients and clinicians. The challenges stem from the extended duration to achieve desired results, often necessitating surgical interventions, such as micro-osteoperforations (MOPs). This study aimed to investigate the biological effects and extent of changes resulting from these interventions. Specifically, we evaluated the degree of root resorption during orthodontic tooth movement accelerated by MOPs.
Materials and methods: We assessed the tooth movement rates and root resorption in eight-to ten-week-old male mice. A nickel-titanium (Ni–Ti) closed-coil spring was applied between the maxillary left first molar and maxillary incisors. In the MOPs group, micro-perforations were made on the mesial and palatal surfaces of the left maxillary first molar. Odontoclast formation and root resorption were assessed using histological analysis and scanning electron microscopy.
Results: Tooth movement was greater in the MOPs group. Odontoclast formation was remarkably higher in this group than in the orthodontic tooth movement (OTM) group. Additionally, more extensive root resorption was observed on the mesial surface of the distobuccal root of the left maxillary first molar.
Conclusion: Root resorption significantly increased in mice with MOPs. These findings highlight the need to carefully consider the risk of root resorption in patients undergoing MOPs during orthodontic treatment.

* Corresponding author. Division of Orthodontics and Dentofacial Orthopedics, Tohoku University Graduate School of Dentistry, 4-1 Seiryo-machi, Aoba-ku, Sendai 980-8575, Japan.
E-mail address: hideki.kitaura.b4@tohoku.ac.jp (H. Kitaura).

https://doi.org/10.1016/j.jds.2025.02.017

Introduction

The duration of orthodontic treatment is a major concern, prompting ongoing research into methods to shorten treatment times. Various biological, mechanical, physical, and surgical approaches have been developed,[1] with surgical procedures yielding the most promising results. These surgeries leverage the regional acceleratory phenomenon (RAP), which involves enhanced bone remodeling in response to noxious stimuli.[2] Various techniques have been developed to modulate these biological processes and accelerate orthodontic tooth movement (OTM).

Micro-osteoperforations (MOPs) are a surgical technique involving small perforations in the alveolar bone around teeth to accelerate OTM.[3] Tissue response studies conducted on animal models revealed that MOP induced RAP.[4] Several studies have demonstrated the effectiveness of MOPs in accelerating tooth movement in humans.[3,5,6] Moreover, studies in animals have reported that alveolar bone perforations promote OTM by inducing the expression of inflammatory cytokines,[4,7–10] which promote osteoclast formation, thereby enhancing bone remodeling.[4] In a previous study, we found that MOPs increase the expression of TNF-α and tooth movement depends on TNF-α-responsive stromal cells. This conclusion was derived using a mouse tooth movement model with chimeric mice deficient in TNF receptors.[11]

Root resorption is an unavoidable complication of orthodontic treatment. During OTM, osteoclasts resorb bone on the compression side while osteoblasts form bone on the tension side, enabling tooth movement. However, alongside osteoclast activity, odontoclasts on the root surface also appear, often leading to root resorption. Cytokines such as RANKL[12,13] and TNF-α[14,15] are important for the formation and differentiation of both osteoclasts and odontoclasts during OTM. Root resorption remains an unresolved problem, frequently observed as an undesirable consequence of orthodontic treatment.

Despite the effectiveness of MOPs in accelerating tooth movement, their impact on root resorption remains unclear. This study evaluated root resorption in mice by measuring odontoclast formation and analyzing the resorption area.

Material and methods

Experiment of animals

Male C57BL6/J mice aged eight to ten weeks were purchased from CLEA Japan Inc. (CLEA Japan Inc., Tokyo, Japan). The mice were housed in the animal facility at Tohoku University under controlled conditions with a 12-h light/dark cycle and a temperature range of 21–24 °C. They were fed a granular diet from Oriental Yeast (Oriental Yeast, Tokyo, Japan) to minimize excessive chewing forces during OTM. All animal experiments were conducted in accordance with Tohoku University guidelines. The institutional committee on the ethics of animal experiments approved the study protocol (approval no. 2024DnA-003-03).

Orthodontic tooth movement and micro-osteoperforations experiment

A nickel-titanium (Ni–Ti) closed-coil spring appliance (Tomy, Fukushima, Japan) was prepared for the experiment. Anesthesia was induced by intraperitoneal injection of 0.25 ml of the prepared mixture of midazolam, butorphanol, medetomidine and 7.9 ml of saline solution. Mice were placed in the supine position, and the Ni–Ti appliance was placed between the maxillary left first molar and maxillary incisors. The appliance was secured with a 0.1 mm diameter stainless steel wire, which was hooked between the maxillary left first molar and a hole in the alveolar bone beneath the maxillary incisors using a slow-speed handpiece and a tungsten carbide bur (Fig. 1A). In the MOPs group, we made two points for MOPs. Microperforations were made approximately 1 mm to the mesial and 1 mm palatal to the left maxillary first molar (Fig. 1B). Perforations were approximately 0.5 mm in diameter and 0.25 mm in depth. The Ni–Ti appliance was activated to apply a force of approximately 10 g, as per the manufacturer's instructions. Each experimental group consisted of four mice. The experiment lasted 12 days, after which the mice were sacrificed. To assess tooth movement, impressions of the teeth and maxilla were made using a hydrophilic vinyl polysiloxane material (EXAFAST injection type, GC Co., Tokyo, Japan). The distance of tooth movement in the OTM and MOPs groups was assessed using a stereoscopic microscope (VH-7000, Keyence, Osaka, Japan). The distance between the maxillary left first molar and the maxillary left second molar was measured after 12 days of mechanical loading. A significant increase in tooth movement was observed in the MOPs group (195.18 $\pm$ 32.42 μm) compared to the OTM-only group (122.60 $\pm$ 10.16 μm) (Fig. 1C, D and E).

Histological analysis preparation

Maxillary samples were fixed in 4 % formaldehyde at 4 °C for 24 h and subsequently decalcified in 14 % ethylenediaminetetraacetic acid (EDTA) for 28 days at room temperature. After decalcification, the samples were embedded in paraffin, sectioned at the thickness of 4 μm. The sections were prepared from distobuccal root of the first maxillary molar at five levels: 100, 140, 180, 220, and 260 μm. Sections were stained with tartrate-resistant acid

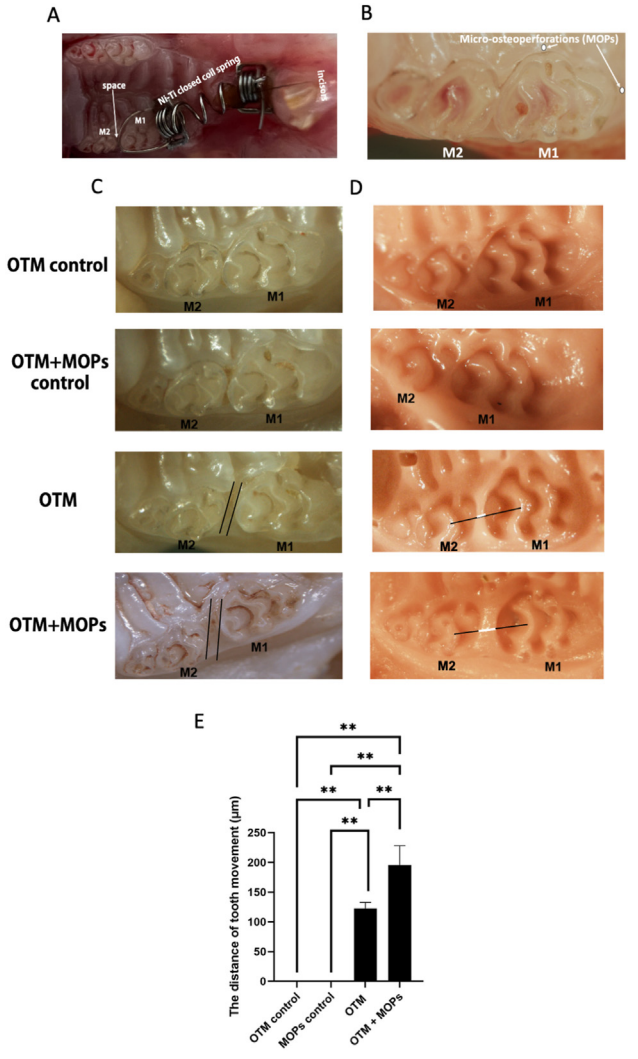

Figure 1 Orthodontic tooth movement and MOPs in mice. (A) An intraoral image of a nickel-titanium closed spring appliance placed between the maxillary left first molar and the maxillary incisors. The appliance hooked between the maxillary left first molar and the hole made in the alveolar bone beneath the maxillary incisors. (B) Intraoral image of tooth movement and the area of micro-osteoperforations (MOPs). One MOP (white dot) was placed 1.0 mm palatal of the maxillary left first molar and another was placed 1.0 mm mesial to the maxillary left first molar. (C) Intraoral image of the tooth movement and measurement of orthodontic tooth movement (OTM) in mice. The double line between the maxillary left first molar (M1) and the maxillary left second molar (M2) was evaluated under a stereoscopic microscope. (D) Image of the impression of tooth movement and measurement of OTM in mice. The white line between the maxillary left first molar (M1) and maxillary left second molar (M2) on the solid line connecting the central fossae of the two molars in silicone impressions was evaluated under a stereoscopic microscope. (E) Graph illustrating the distance of tooth movement after 12 days of experimental loading. The results are given as means ± SD. The ANOVA test was used to determine the statistical significance of differences (**$P < 0.01$). n = 4 for each group.

phosphate (TRAP) solution and counterstained with hematoxylin. The TRAP solution was attained by mixing Fast Red Violet LB Salt (Sigma–Aldrich, St. Louis, MO, USA), N–N dimethylformamide, 0.1 M sodium acetate (pH 5.0), 0.5 M sodium tartaric acid, and naphthol AS-MX Phosphate (Sigma–Aldrich). Odontoclasts were identified as TRAP-positive cells on the root surface using a stereoscopic microscope.

Analysis of the resorption area of the root

Twelve days after orthodontic force loading, the maxillary left first molar was extracted using tissue forceps and a Terumo 25-gauge needle (0.50 × 16 mm). The teeth were treated with 2 % sodium hypochlorite for 10–30 min to remove periodontal ligaments (PDLs). The mesial surface of the distobuccal root was examined using scanning electron microscopy (SEM) (TM-1000, Hitachi, Tokyo, Japan). To standardize specimen orientation, teeth were rotated distopalatally for optimal visualization of the mesial surface of the distal root. The resorbed areas were quantified using ImageJ software (National Institutes of Health, Bethesda, MD, USA).

Statistical analysis

Data are presented as mean ± standard deviation (SD) from independent biological replicates. Statistical analyses were performed using one-way ANOVA and t-tests, with significance set at $P < 0.05$.

Results

Histological analysis of micro-osteoperforations-enhanced odontoclast formation and root resorption during orthodontic tooth movement

Odontoclasts were observed on the mesial side of the distobuccal root in both the OTM and OTM + MOP groups. However, the number of odontoclasts was significantly higher in the OTM + MOPs group (8.0 ± 1.5) than in the OTM-only group (2.67 ± 0.76) (Fig. 2A and B). Root resorption areas were assessed through histological examination. Transverse histological sections revealed a significantly larger root resorption area in the OTM + MOP mice (22.75 % ± 5.74 %) than in the OTM-only mice (11.25 % ± 4.72 %) (Fig. 3A and B).

Scanning electron microscopy analysis of micro-osteoperforation-induced root resorption during orthodontic tooth movement

Root resorption on the mesial side of the distobuccal root was evaluated using SEM. Twelve days after OTM, the resorption area on the mesial side was significantly larger in the OTM + MOP group (22.81 % ± 1.54 %) than in the OTM-only group (10.95 % ± 5.39 %) (Fig. 4A and B).

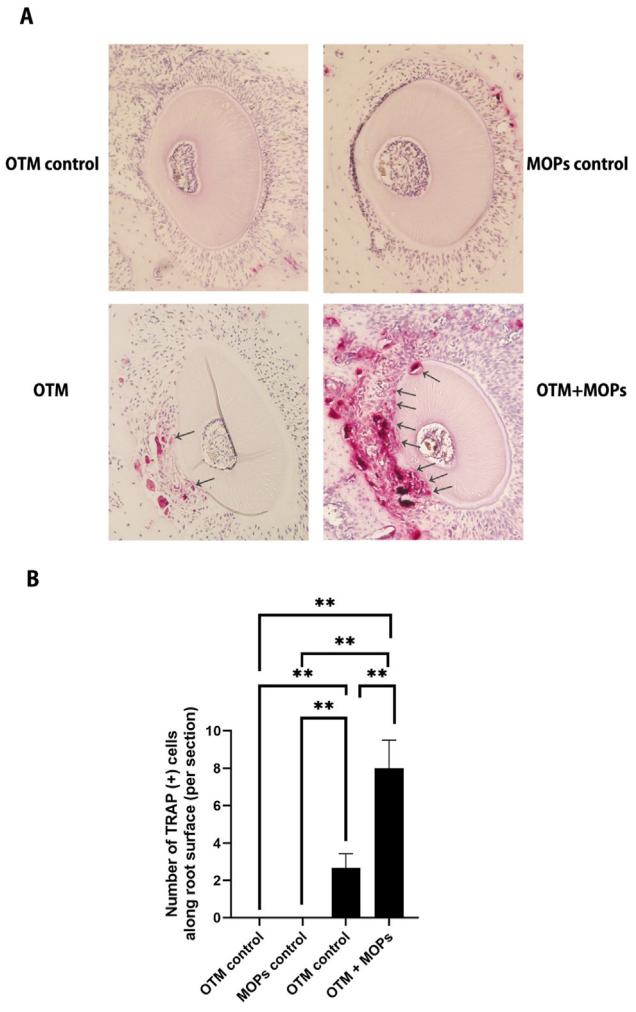

Figure 2 Effect of MOPs on orthodontic tooth movement and histological evaluation of MOPs on orthodontic tooth movement. (A) Image of the tartrate-resistant acid phosphate (TRAP)-stained histological analysis of the horizontal sections of the distobuccal root of the maxillary left first molar evaluated after 12 days of experimental loading with and without micro-osteoperforations (MOPs). The black arrows show odontoclasts along the surface of the distobuccal root. (B) Graph illustrating the number of TRAP-positive cells on the mesial side of the distobuccal root of the maxillary left first molars after orthodontic tooth movement (OTM) and MOPs as indicated per group. The results are given as means ± SD. The ANOVA test was used to determine the statistical significance of differences (**$P < 0.01$). n = 4 for each group.

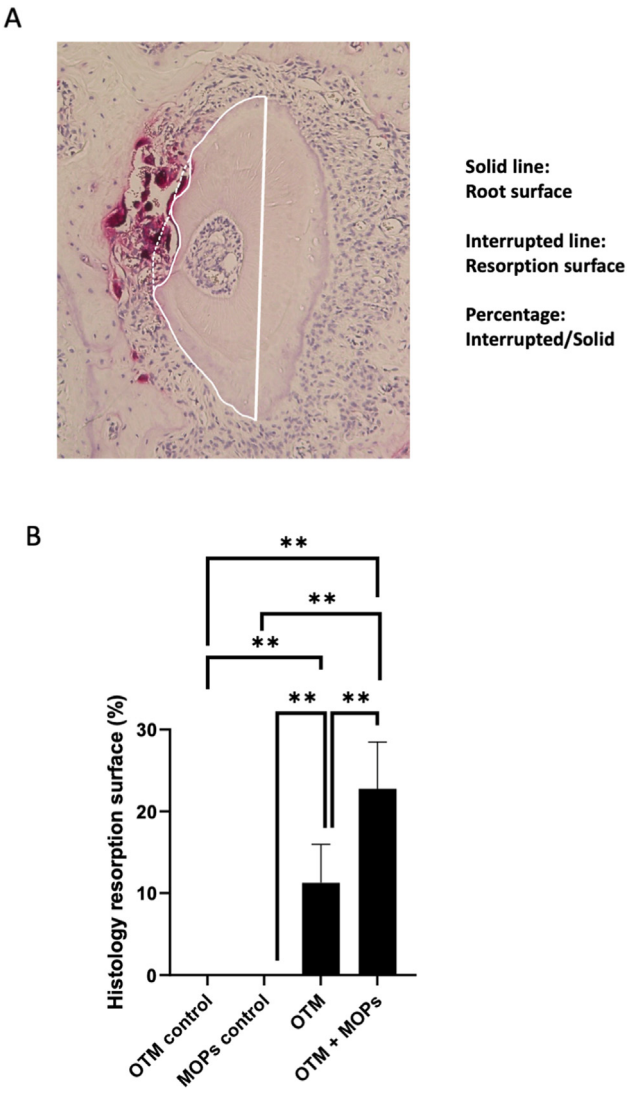

Figure 3 Diagram demonstrating the evaluation of the root resorption surface on the transverse histological sections. (A) Solid line represents the root surface and the interrupted line represents the resorption surface. The root resorption surface was measured by the percentage of interrupted line/solid line. (B) Ratio of the root resorption surface on the histological sections of control orthodontic tooth movement (OTM), control OTM with micro-osteoperforations (MOPs), OTM and OTM with MOPs groups for 12 days. The results are given as means ± SD. The ANOVA test was used to determine the statistical significance of differences (**$P < 0.01$). n = 4 for each group.

Discussion

MOPs have been reported to accelerate OTM in human.[3,5,6] However, their impact on root resorption during OTM remains unclear. In this study, we investigated the effects of MOP on root resorption using an OTM mouse model. A Ni—Ti closed-coil spring was placed between the maxillary left first molar and maxillary incisor to move the first molar mesially in C57BL/6J mice over 12 days. MOPs were drilled into the palatal and mesial sides of the maxillary first molar using a round bur. Root resorption was assessed histologically and via electron microscopy. First, we confirmed that MOPs significantly increased the tooth movement distance. The number and area of odontoclasts were notably higher in the MOPs group than in the non-MOP group. Additionally, the root resorption area was significantly larger in the MOPs group than in the OTM-only group. These findings suggest that MOPs enhance root resorption during tooth movement by promoting odontoclast formation. This study is the first to demonstrate that MOPs significantly increase both root resorption and odontoclast formation in an OTM mouse model.

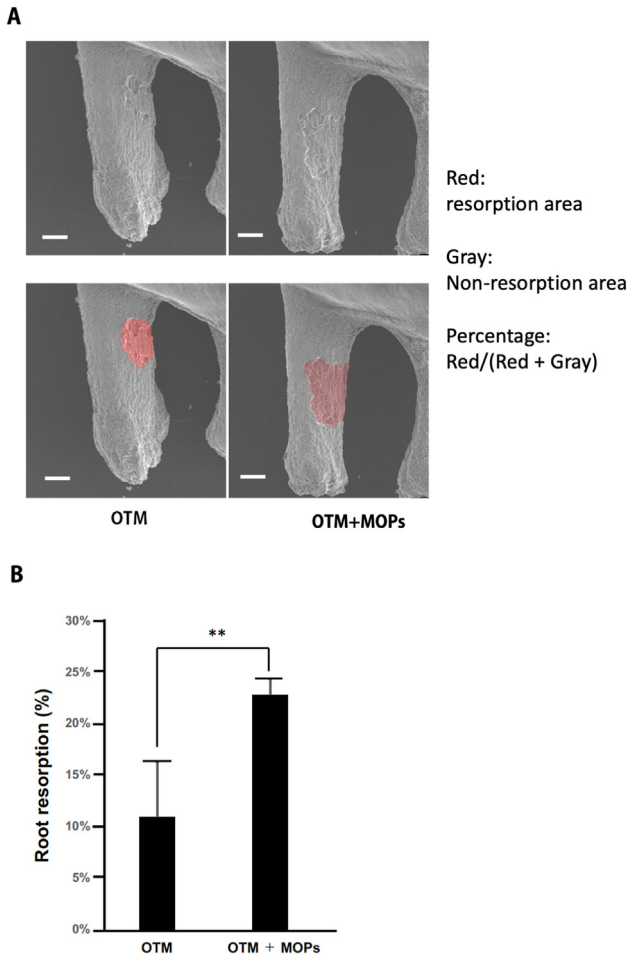

Figure 4 Root resorption of OTM and OTM with MOPs mice. (A) Images of scanning electron micrographs of the distobuccal root of the maxillary left first molar after 12 days in orthodontic tooth movement (OTM) only and OTM with microosteoperforations (MOPs) mice. (B) Ratio of root resorption area on the mesial side of the distobuccal root in OTM only and OTM with MOPs mice. The results are given as means ± SD. The t-test was used to determine the statistical significance of differences (**$P < 0.01$). n = 4 for each group. (Scale bar = 100 μm).

Several clinical studies have demonstrated that MOPs significantly increase the rate of tooth movement compared to control groups.[3,5,6,16,17] In contrast, several reports have shown no accelerated tooth movement in the MOP group.[18,19] Currently, no conclusions have been reached. Furthermore, several animal studies have been shown that MOPs accelerate tooth movement. Animal studies have also similarly shown mixed results. In mouse models, MOPs increased tooth movement compared to controls, and it was demonstrated that MOPs enhanced tooth movement[20] via TNF-α-responsive stromal cells.[11] Studies on rats, rabbits, and beagle dogs have also indicated increased tooth movement following MOPs.[21,7,22] However, other reports on rats and beagle dogs showed that MOPs did not affect distance of tooth movement.[23,24] We believe that the reasons for these discrepancies are the different animal species, different MOPs methods, and different periods of tooth movement. In the present study, we confirmed that MOPs accelerated tooth movement in mice.

C57BL/6 mice are genetically identical within each strain. There are no genetic differences that could affect research results. Therefore, C57BL/6 mice are the most commonly used mouse strain in research. For such reasons, we used C57BL/6 mice for mouse OTM model in this study.

Root resorption is a complex inflammatory process influenced by factors such as mechanical forces, root morphology, alveolar bone, PDL, cementum, and certain known biological messengers.[25] Excessive force is an important factor in root resorption.[26,27] In this study, a force of 10 g led to root resorption pits with odontoclasts formation, consistent with previous reports.[28–30] These results suggest that the orthodontic force applied was excessive for mice. Odontoclast, which resorb tooth roots, share similar mechanisms with osteoclasts in bone resorption.[25,31–33] In the present study, TRAP-positive cells were detected on root surfaces and in the PDL tissue. Prior research suggests that TRAP-positive cells in the PDL are linked to root resorption.[25,34,35] Mice with MOPs in this study exhibited significantly more TRAP-positive cells, indicating that MOP-induced cells may contribute to root resorption.[11]

The differentiation of odontoclasts during OTM is influenced by key cytokines such as RANKL and TNF-α.[12–15] In a previous study, MOPs induced TNF-α expression, promoting odontoclast formation.[11] In this study, increased odontoclast numbers due to MOPs likely contributed to the enhanced root resorption.

While most clinical studies did not find significant root resorption with MOPs,[36–39] one report noted that MOPs caused significant root resorption in maxillary first premolars. In contrast,[40] several animal studies have shown that MOP promote tooth movement without increasing root resorption.[7,10,20] However, our findings indicate that MOPs induced root resorption in mice, likely due to species-specific factors, procedural differences, and tooth movement duration. However, further studies are required to confirm this hypothesis.

In conclusion, although MOPs significantly increased OTM in mice, they also led to increased root resorption. These findings highlight the need for caution regarding the risk of root resorption in clinical applications of MOPs during OTM. Further research is required to understand the factors influencing odontoclast differentiation, and explore potential methods for mitigating root resorption, which could benefit patients undergoing orthodontic treatment.

Declaration of competing interest

The authors have no conflicts of interest relevant to this article.

Acknowledgments

This work was supported in part by JSPS KAKENHI grants from the Japan Society for the Promotion of Science (Nos. 22K10236 to HK and 24K20049 to FO).

References

1. Hoogeveen EJ, Jansma J, Ren Y. Surgically facilitated orthodontic treatment: a systematic review. *Am J Orthod Dentofacial Orthop* 2014;145:S51—64.
2. Frost HM. The regional acceleratory phenomenon: a review. *Henry Ford Hosp Med J* 1983;31:3—9.
3. Alikhani M, Raptis M, Zoldan B, et al. Effect of micro-osteoperforations on the rate of tooth movement. *Am J Orthod Dentofacial Orthop* 2013;144:639—48.
4. Teixeira CC, Khoo E, Tran J, et al. Cytokine expression and accelerated tooth movement. *J Dent Res* 2010;89:1135—41.
5. Attri S, Mittal R, Batra P, et al. Comparison of rate of tooth movement and pain perception during accelerated tooth movement associated with conventional fixed appliances with micro-osteoperforations - a randomised controlled trial. *J Orthod* 2018;45:225—33.
6. Gulduren K, Tumer H, Oz U. Effects of micro-osteoperforations on intraoral miniscrew anchored maxillary molar distalization : a randomized clinical trial. *J Orofac Orthop* 2020;81:126—41.
7. Kim J, Kook YA, Bayome M, et al. Comparison of tooth movement and biological response in corticotomy and micro-osteoperforation in rabbits. *Korean J Orthod* 2019;49:205—13.
8. Huang CY, Lu HP, Yu YF, et al. Comparison of tooth movement and biological response resulting from different force magnitudes combined with osteoperforation in rabbits. *J Appl Oral Sci* 2021;29:e20200734.
9. Sugimori T, Yamaguchi M, Shimizu M, et al. Micro-osteoperforations accelerate orthodontic tooth movement by stimulating periodontal ligament cell cycles. *Am J Orthod Dentofacial Orthop* 2018;154:788—96.
10. Cheung T, Park J, Lee D, et al. Ability of mini-implant-facilitated micro-osteoperforations to accelerate tooth movement in rats. *Am J Orthod Dentofacial Orthop* 2016;150:958—67.
11. Kinjo R, Kitaura H, Ogawa S, et al. Micro-osteoperforations induce TNF-alpha expression and accelerate orthodontic tooth movement via TNF-alpha-responsive stromal cells. *Int J Mol Sci* 2022;23:2968.
12. Yang CY, Jeon HH, Alshabab A, et al. RANKL deletion in periodontal ligament and bone lining cells blocks orthodontic tooth movement. *Int J Oral Sci* 2018;10:3.
13. Tyrovola JB, Spyropoulos MN, Makou M, Perrea D. Root resorption and the OPG/RANKL/RANK system: a mini review. *J Oral Sci* 2008;50:367—76.
14. Kitaura H, Yoshimatsu M, Fujimura Y, et al. An anti-c-Fms antibody inhibits orthodontic tooth movement. *J Dent Res* 2008;87:396—400.
15. Ogawa S, Kitaura H, Kishikawa A, et al. TNF-alpha is responsible for the contribution of stromal cells to osteoclast and odontoclast formation during orthodontic tooth movement. *PLoS One* 2019;14:e0223989.
16. Alfawal AM, Hajeer MY, Ajaj MA, Hamadah O, Brad B. Effectiveness of minimally invasive surgical procedures in the acceleration of tooth movement: a systematic review and meta-analysis. *Prog Orthod* 2016;17:33.
17. Shahabee M, Shafaee H, Abtahi M, Rangrazi A, Bardideh E. Effect of micro-osteoperforation on the rate of orthodontic tooth movement-a systematic review and a meta-analysis. *Eur J Orthod* 2020;42:211—21.
18. Dos Santos CCO, Mecenas P, de Castro Aragon MLS, Normando D. Effects of micro-osteoperforations performed with propel system on tooth movement, pain/quality of life, anchorage loss, and root resorption: a systematic review and meta-analysis. *Prog Orthod* 2020;21:27.
19. Fu T, Liu S, Zhao H, Cao M, Zhang R. Effectiveness and safety of minimally invasive orthodontic tooth movement acceleration: a systematic review and meta-analysis. *J Dent Res* 2019;98:1469—79.
20. Erdenebat T, Lee DJ, Kim SJ, et al. Effect of the number of micro-osteoperforations on the rate of tooth movement and periodontal response in mice. *Front Physiol* 2022;13:837094.
21. Tsai CY, Yang TK, Hsieh HY, Yang LY. Comparison of the effects of micro-osteoperforation and corticision on the rate of orthodontic tooth movement in rats. *Angle Orthod* 2016;86:558—64.
22. Lee JW, Cha JY, Park KH, Kang YG, Kim SJ. Effect of flapless osteoperforation-assisted tooth movement on atrophic alveolar ridge: histomorphometric and gene-enrichment analysis. *Angle Orthod* 2018;88:82—90.
23. Cramer CL, Campbell PM, Opperman LA, Tadlock LP, Buschang PH. Effects of micro-osteoperforations on tooth movement and bone in the beagle maxilla. *Am J Orthod Dentofacial Orthop* 2019;155:681—92.
24. Pedraza JLM, Marquezan M, Nojima LI, Nojima M. Macroscopic and microscopic evaluation of flapless alveolar perforations on experimental tooth movement. *Dental Press J Orthod* 2018;23:73—9.
25. Brezniak N, Wasserstein A. Orthodontically induced inflammatory root resorption. part II: the clinical aspects. *Angle Orthod* 2002;72:180—4.
26. Gonzales C, Hotokezaka H, Yoshimatsu M, et al. Force magnitude and duration effects on amount of tooth movement and root resorption in the rat molar. *Angle Orthod* 2008;78:502—9.
27. Harris DA, Jones AS, Darendeliler MA. Physical properties of root cementum: part 8. volumetric analysis of root resorption craters after application of controlled intrusive light and heavy orthodontic forces: a microcomputed tomography scan study. *Am J Orthod Dentofacial Orthop* 2006;130:639—47.
28. Yoshimatsu M, Kitaura H, Fujimura Y, et al. Inhibitory effects of IL-12 on experimental tooth movement and root resorption in mice. *Arch Oral Biol* 2012;57:36—43.
29. Fujimura Y, Kitaura H, Yoshimatsu M, et al. Influence of bisphosphonates on orthodontic tooth movement in mice. *Eur J Orthod* 2009;31:572—7.
30. Kitaura H, Fujimura Y, Yoshimatsu M, et al. An M-CSF receptor c-Fms antibody inhibits mechanical stress-induced root resorption during orthodontic tooth movement in mice. *Angle Orthod* 2009;79:835—41.
31. Casa MA, Faltin RM, Faltin K, Arana-Chavez VE. Root resorption on torqued human premolars shown by tartrate-resistant acid phosphatase histochemistry and transmission electron microscopy. *Angle Orthod* 2006;76:1015—21.
32. Harokopakis-Hajishengallis E. Physiologic root resorption in primary teeth: molecular and histological events. *J Oral Sci* 2007;49:1—12.
33. Sasaki T. Differentiation and functions of osteoclasts and odontoclasts in mineralized tissue resorption. *Microsc Res Tech* 2003;61:483—95.
34. Brudvik P, Rygh P. Non-clast cells start orthodontic root resorption in the periphery of hyalinized zones. *Eur J Orthod* 1993;15:467—80.
35. Brudvik P, Rygh P. Root resorption beneath the main hyalinized zone. *Eur J Orthod* 1994;16:249—63.
36. Aboalnaga AA, Salah Fayed MM, El-Ashmawi NA, Soliman SA. Effect of micro-osteoperforation on the rate of canine retraction: a split-mouth randomized controlled trial. *Prog Orthod* 2019;20:21.
37. Alqadasi B, Aldhorae K, Halboub E, et al. The effectiveness of micro-osteoperforations during canine retraction: a three-dimensional randomized clinical trial. *J Int Soc Prev Community Dent* 2019;9:637—45.
38. Khlef HN, Hajeer MY, Ajaj MA, et al. The effectiveness of traditional corticotomy vs flapless corticotomy in miniscrew-supported en-masse retraction of maxillary anterior teeth in patients with Class II Division 1 malocclusion: a single-

centered, randomized controlled clinical trial. *Am J Orthod Dentofacial Orthop* 2020;158:e111—20.

39. Shahrin AA, Ghani SHA, Norman NH. Effect of micro-osteoperforations on external apical root resorption: a randomized controlled trial. *Korean J Orthod* 2021;51:86—94.

40. Chan E, Dalci O, Petocz P, Papadopoulou AK, Darendeliler MA. Physical properties of root cementum: part 26. effects of micro-osteoperforations on orthodontic root resorption: a microcomputed tomography study. *Am J Orthod Dentofacial Orthop* 2018;153:204—13.