CLINICAL AND INVESTIGATIVE ORTHODONTICS
https://doi.org/10.1080/27705781.2023.2295615

Heated tobacco smoke components delay tooth movement in a rat model

Yoshitsugu Nakamoto[a], Aki Nishiura[b], Yoshimasa Makita[c], Susumu Tsuda[c], Kenichirou Yasui[a], Shin-ichi Fujiwara[c] and Naoyuki Matsumoto[b]

[a]Graduate School of Dentistry (Orthodontics), Osaka Dental University, Hirakata, Osaka, Japan; [b]Department of Orthodontics, Osaka Dental University, Hirakata, Osaka, Japan; [c]Department of Chemistry, Osaka Dental University, Hirakata, Osaka, Japan

ABSTRACT

Purpose: This study aimed to evaluate the effect of the components of tobacco smoke from heated tobacco products (HTPs), referred to as Tobacco Smoke Components (TSCs), on tooth movement and the number of osteoclasts in rat models.

Materials and Methods: Wistar rats were divided into the following groups: control, distilled water-administered, cigarette TSCs-administered, and HTP TSCs-administered. Tooth movement was experimentally induced within each group using the Waldo method. Measurements were performed for tooth movement and the number of osteoclasts.

Results: Both cigarette and HTP TSCs decreased the number of osteoclasts and delayed the rate of tooth movement. The TSCs of cigarettes were particularly shown to have a stronger effect than the HTPs.

Conclusion: HTP TSCs significantly affected the rate of tooth movement; thus, orthodontists should be aware of the patient's smoking status, as well as smoking method (paper or heated), and encourage smoking cessation during treatment.

ARTICLE HISTORY
Received 7 October 2023
Revised 8 November 2023
Accepted 5 December 2023

KEYWORDS
HTP; tooth movement; osteoclasts; tobacco

Introduction

The number of cigarette smokers worldwide has recently decreased. According to the World Health Organization, the number of male and female cigarette smokers reduced by approximately 10 million between 2018 and 2020. Furthermore, an additional reduction of approximately 27 million was predicted by 2025, leading to a total of 1.299 billion smokers [1].

The use of heat-not-burn tobacco products (HTP) is increasing. The prevalence of HTP users in the Western Pacific Region increased from 0.12% in 2015 to 10.57% in 2020 [2]. Similarly, the prevalence in the European Region increased from 0% in 2016 to 1.15% in 2020 [2]. Based on the Japan 'Society and New Tobacco' Internet Survey, the prevalence of HTP use in Japan increased from 0.2% in 2015 to 11.3% in 2019 among participants aged 15 to 69 years [3].

Cigarette smoke is a toxic and carcinogenic mixture containing over 5,000 different chemicals, including nicotine, tar, carbon monoxide, and ammonia [4], which have various detrimental effects on the human body. It serves as the primary risk factor for lung cancer and chronic obstructive pulmonary disease in the respiratory system [5]. In the circulatory system, it increases the risk of left ventricular hypertrophy, systolic dysfunction, and heart failure [6] while suppressing the immune system [7]. In dentistry, smokers have a significantly higher risk of developing periodontal disease compared with non-smokers, ranging from 2.5 to 6 times. This elevated risk is associated with factors, such as alveolar bone loss and periodontal pocket formation [8,9]. Moreover, smoking delays wound healing and reduces the success rates of bone grafts and dental implant procedures [10].

Regarding orthodontic treatment, the effects of nicotine, a component of cigarette smoke, on tooth movement in rats have been studied [11–13]. However, to investigate the actual effects of smoking, studies must administer a comprehensive mixture of tobacco smoke components (TSCs) rather than just the individual substances present.

Our research group investigated the effects of TSCs from combustible cigarettes on tooth movement in rats. Previous studies revealed that TSCs influence osteoclast progenitors, inhibit osteoclastogenesis, and consequently decrease the speed of experimental tooth movement [14]. Furthermore, smoking discontinuation restores tooth movement speed to pre-smoking levels [15]. HTP differs from cigarettes in composition and combustion method [16,17], and HTP smoke contains less nicotine and carcinogens than cigarette smoke [18,19]. Furthermore, previous studies analysing the smoke components of combustible cigarettes and HTP have shown that while both mainstream smoke types predominantly contain nicotine, HTP mainstream smoke includes higher amounts of glycerol and propylene glycol, highlighting the differences between the

CONTACT Aki Nishiura nishiura@cc.osaka-dent.ac.jp Department of Orthodontics, Osaka Dental University, 8-1, Kuzuhahanazonocho, Hirakata 573-1121, Japan

smoke of combustible cigarettes and HTP [20]. Research on the effects of HTP TSCs on tooth movement is currently lacking, and the impact of these compounds remains unclear. Considering the anticipated increase in the number of HTP users, it is crucial for orthodontists to understand the potential effects of HTP TSCs on tooth movement.

Therefore, this study aimed to investigate the influence of HTP on tooth movement using the Waldo method [21]. A Clear Power Chain II was inserted between the maxillary right first molar (M1) and second molar (M2) of rats, and HTP TSCs were continuously administered.

Materials and methods

Preparation of cigarette and HTP TSCs

Seven Stars cigarettes (JT, Tokyo, Japan) were used as combustible cigarettes (nicotine content of 1.2 mg per cigarette and tar content of 14 mg) [22]. HTPs, such as I-Quit-Ordinary-Smoking (iQOS) loaded with Marlboro Heat Sticks (Philip Morris Inc., New York, USA) were used (containing 1.2 mg of nicotine per stick) [20]. We collected 20 cigarette equivalents of mainstream smoke components following established protocols and extracted the TSCs, as previously described [23]. We diluted the TSCs to a concentration of 0.13%, following previous reports [14,15]. Subsequently, we prepared Seven Stars cigarette and IQOS HTP TSCs.

Method for tooth movement experiment in rats

All the animal experiments were performed strictly in accordance with the Osaka Dental University Animal Experiments Regulations and were approved by the Animal Experiments Committee of the Osaka Dental University (Approval No. 23–02015).

A total of 24 11-week-old male Wistar rats with an average weight of 260 g (260 ± 10 g) were divided into four groups: (1) no treatment (NT) group, administered with distilled water for 28 days and did not undergo any dental procedures ($n = 6$); (2) distilled water (DW) group, administered with distilled water for 28 days and underwent dental procedures ($n = 6$); (3) cigarette TSCs (CT) group, given distilled water containing Seven Stars cigarette TSCs for 28 days and underwent tooth movement procedures ($n = 6$); and (4) HTP TSCs (HT) group, consumed distilled water containing IQOS HTP TSCs for 28 days and then underwent tooth movement procedures ($n = 6$).

The rats were placed in plastic cages under a standard 12-h light-dark cycle and provided ad libitum access to soft food, distilled water, CT, and HT. The intake amounts were recorded as appropriate. Additionally, the presence of cotinine in the urine was confirmed using the ABV-KA0930 Cotinine ELISA Kit, HUM (Abnova, Taipei, Taiwan). On day 15 of the experiment, a combination of three mixed anaesthetic agents (medetomidine hydrochloride, midazolam, and butorphanol tartrate) was administered intraperitoneally to induce general anaesthesia. Using the Waldo method [21], Clear Power Chain II (Ormco, Orange, CA, USA; 0.67 mm thickness) was inserted between the M1 and M2. Additionally, on day 21 of the experiment, Clear Power Chain II was replaced with a Separation Ring (Orthodentaurum, Tokyo, Japan; 1.3 mm thickness). Tooth movements were conducted for a total duration of 14 days (Figures 1 and 2). To prevent loosening and rupture of the elastic rubber, hard

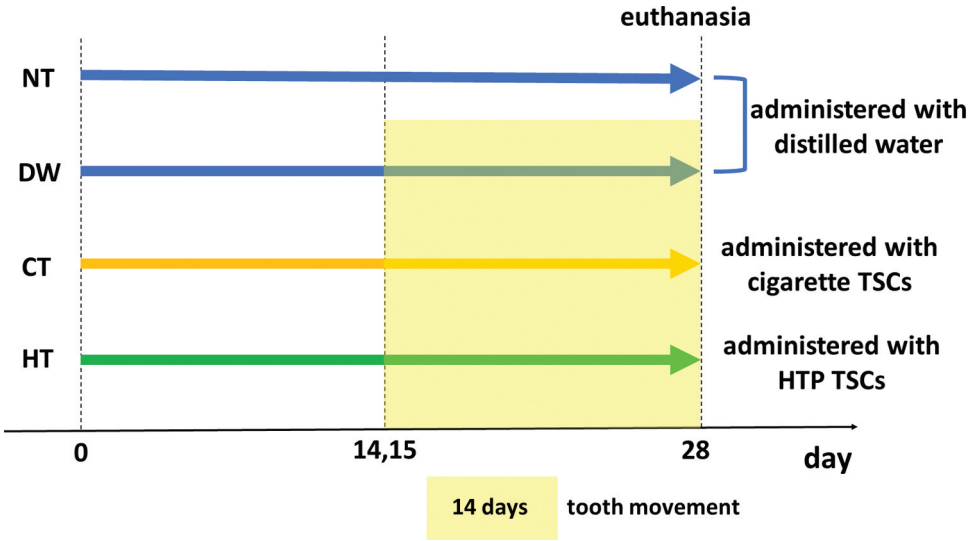

Figure 1. Timeline for the tooth movement experiment in rats. The subjects were divided into four groups: no treatment (NT) group, distilled water (DW) group, cigarette tobacco smoke components (TSCs) (CT) group, and heated tobacco products (HTP) TSCs (HT) group. The respective treatment was administered in each case during 28 consecutive days. In the groups undergoing tooth movement (DW, CT, and HT), experimental tooth movement was performed during 14 days (from day 15 to day 28 after the start of the experiment). The yellow area in the figure represents the period of tooth movement.

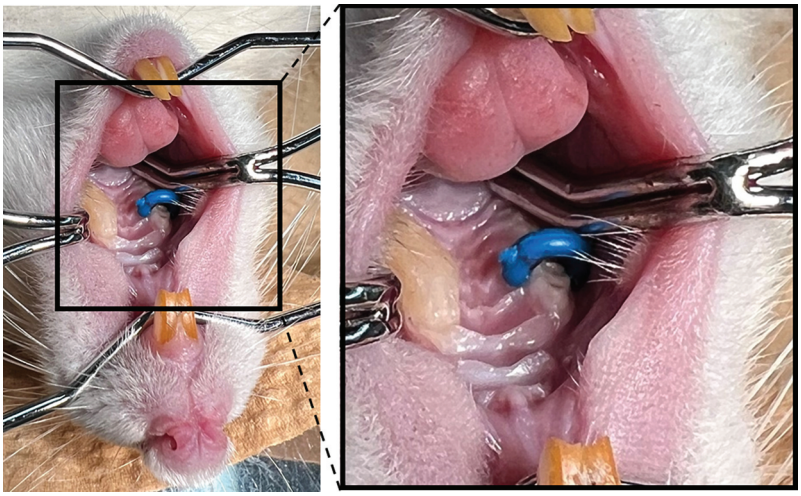

Figure 2. The left image depicts the oral cavity of a rat with a separation ring inserted using the Waldo method. The right image provides a high-magnification view of the image on the left.

composite resin was placed on the occlusal surfaces of the opposite maxillary left first molar (M1) to second molar (M2) at a height of approximately 1.3 mm, and occlusal elevation was performed.

On day 28 after the initiation of the experiment (after tooth movement), euthanasia was performed, and the maxillary bones of the rats were extracted. The extracted bones were fixed in 4% paraformaldehyde-phosphate-buffered saline and subjected to X-ray computed tomography imaging using the SkyScan 1275 system (Bruker, Billerica, Massachusetts, USA). To minimize interindividual variations in measurements, a reference plane was established, encompassing the sagittal section and passing through the proximal root apex of the upper right M1 and distal root apex of M3, as well as the proximal maximal tuberosity of the M1 crown. The tooth movement distance was defined as the perpendicular distance between the line connecting the proximal root axis of M1 on the baseline plane, point of contact of the distal maximal tuberosity of the M1 crown, and line connecting the proximal maximal tuberosity of the M2 crown. This measurement was performed, as depicted in Figure 3.

After computed tomography imaging, the entire rat population was subjected to a 27-day room-temperature decalcification process using a 10% ethylenediaminetetraacetic acid solution (pH 7.0). Subsequently, the specimens were embedded in paraffin, sliced into 3-μm thick sections along the reference plane, and subjected to haematoxylin and eosin and tartrate resistant acid phosphatase (TRAP) staining procedures. Two sections per individual rat were prepared to measure the number of

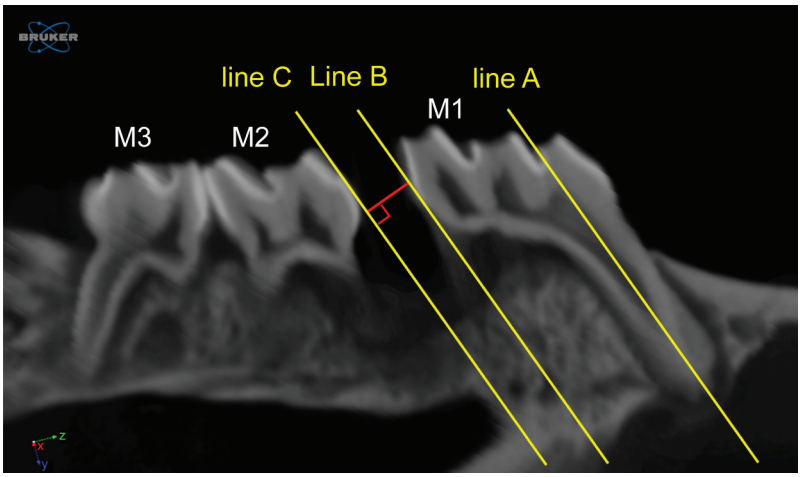

Figure 3. Sagittal cross-sectional view of X-ray μ-computed tomography images. A reference plane was established to include the sagittal plane passing through the mesial root apex of the maxillary right first molar (M1), distal root apex of the third molar (M3), and proximal maximal convexity of the M1 crown. The central axis of the mesial root of M1 on the reference plane is defined as line A. Line B represents a line parallel to line A, tangent to the distal maximal convexity of the M1 crown. Line C represents a line tangent to the proximal maximal convexity of the maxillary right second molar (M2) crown. The perpendicular distance between lines B and C was considered as tooth displacement.

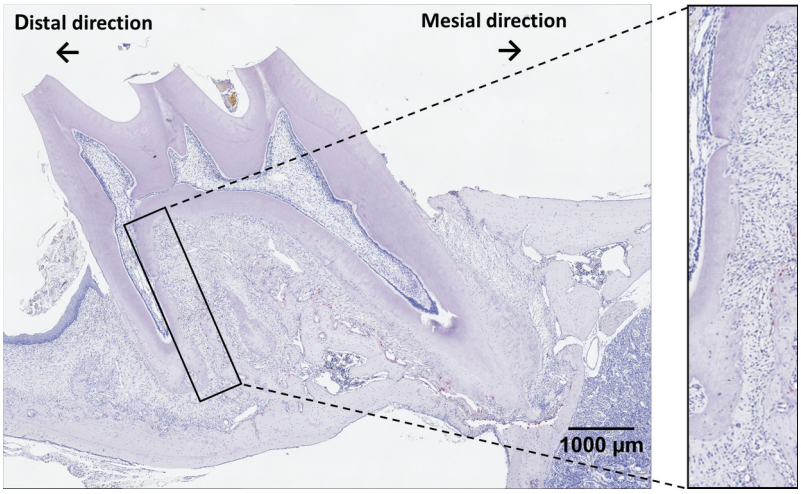

Figure 4. Sagittal section images after experimental tooth movement, stained with tartrate resistant acid phosphatase (TRAP). The area enclosed by a black line within the periodontal tissues between the distal root of M1 and alveolar bone was defined as the region of interest (ROI), where the number of TRAP-positive cells was quantified. The image on the right depicts a high-magnification view of the ROI. The scale bar in the lower right represents 1000 µm. The size of the ROI used to measure the number of TRAP-positive cells was 650 µm wide and 2850 µm long, corresponding to a total area of 1,852,500 µm^2.

TRAP-positive cells; the number of osteoclasts in each section was measured, and the final outcome was considered the average value. Furthermore, the number of TRAP-positive cells (denoted by black squares) within the region of interest (ROI) in the periodontal tissues between the M1 furcation and alveolar bone was quantified, as shown in Figure 4.

Statistical analysis

One-way analysis of variance and Tukey – Kramer methods were used for comparisons among the four groups using GraphPad Prism version 9.5.0 Windows; GraphPad Software, La Jolla California USA, www.graphpad.com.

Results

The daily beverage intake per rat is shown in Figure 5.

Upon comparing the intake levels of the NT, DW, CTs, and HT group, no significant differences were observed in the daily intake amounts among the respective rat groups. A sagittal cross-sectional view of the X-ray computed tomography images is presented in Figure 6(a). We performed experimental tooth movement on M1 using the Waldo method for 14 days. M1 exhibits a slight proximal crown inclination.

Furthermore, alveolar bone resorption was observed in the M1 and M2 groups. In all groups where tooth movement was performed, a significant increase in tooth movement was evident compared with that in the control group, which did not undergo tooth movement (Figure 6(b)). The greatest tooth movement was observed in the NT group, followed by the HT group, whereas the least movement was observed in the CT group. In addition, significant differences were observed among the various groups.

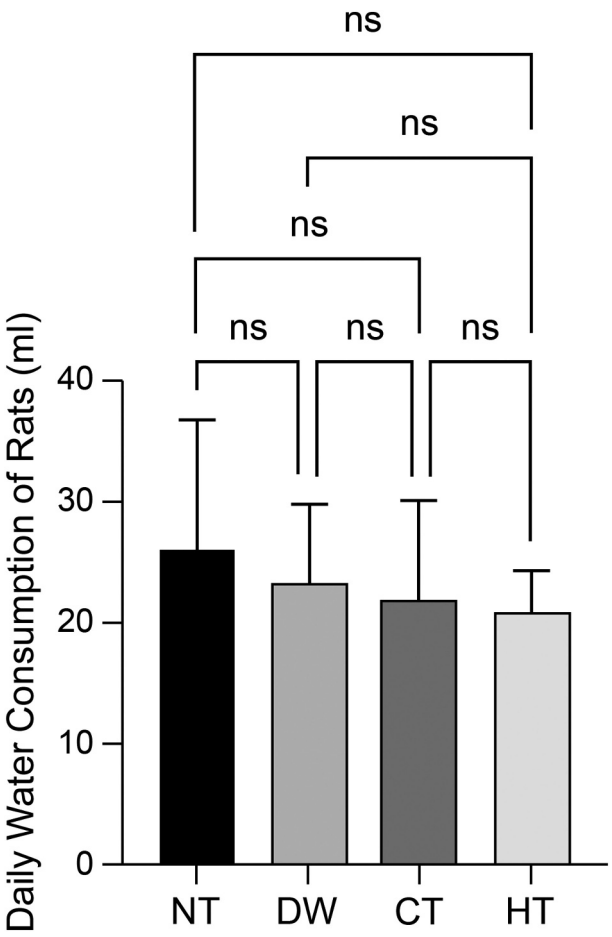

Figure 5. Relationship between beverage intake and each rat group in terms of daily consumption: data presented as mean ± standard deviation (SD) for each group. ns = non-significant ($p > 0.05$).

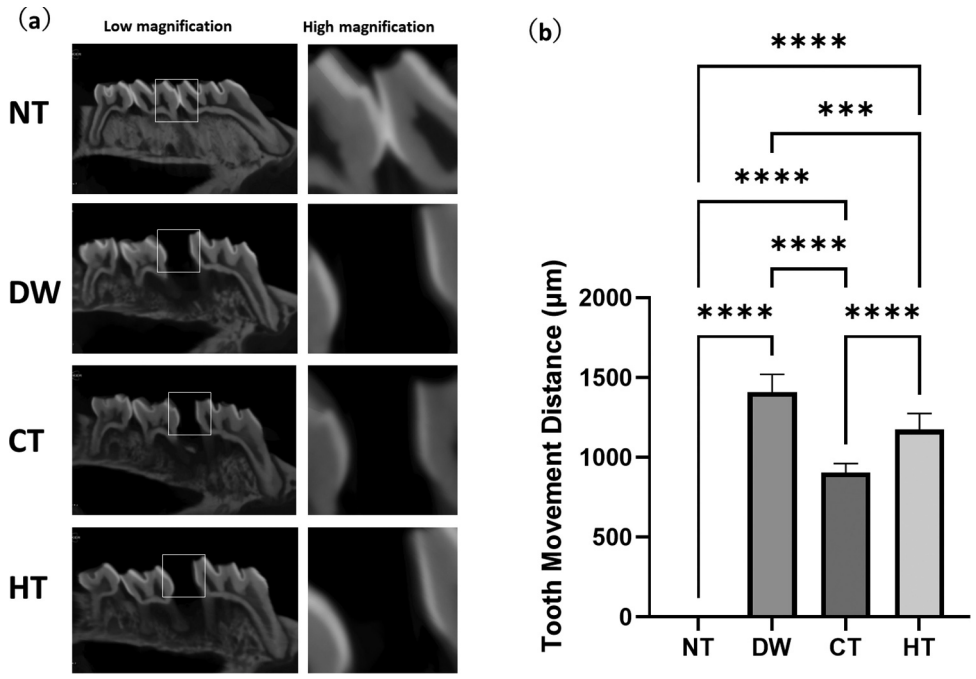

Figure 6. (a) Sagittal cross-sectional view of X-ray μ-computed tomography. White rectangles: enlarged regions at high magnification within the low-magnification view. (b) quantitative data of tooth movement distances and their correlation with each rat group. Data are presented as mean ± standard deviation (SD). *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$, ****$p < 0.0001$; assessed using analysis of variance and the Tukey – Kramer test. $n = 6$.

Figure 7(a) shows TRAP-stained images. TRAP-positive cells (osteoclasts) were absent in the control group, but were observed in the DW, HT, and CT groups on the M1 centrifugal root proximal surface. The number of osteoclasts that was observed within the ROI is shown in Figure 7(b). Both the CT and HT groups exhibited a significant reduction in the number of TRAP-positive cells compared with the DW group. Additionally, the CT group showed a significant decrease in the number of TRAP-positive cells compared with the HT group, as shown in Figure 7.

Discussion

A comparison of the daily beverage intake among the various rat groups revealed no significant differences. Thus, Seven Stars cigarette TSCs were diluted up to 0.13%, and IQOS HTP TSCs did not affect the beverage intake of the rats.

Furthermore, when Seven Stars cigarette and IQOS HTP TSCs were administered for 28 days, and Separation Rings were inserted following the Waldo method for 14 days, the tooth movement distances in the CT and HT groups were significantly smaller than those in the DW group, which did not include Seven Stars cigarette and IQOS HTP TSCs. These results suggest the potential influence of TSCs on tooth movement distance. Furthermore, a significant difference was observed between the HT and CT groups, with the CT group moving the shortest distance. In both the CT and HT groups, a significant decrease in osteoclasts was observed compared with that in the DW group. Additionally, the CT group showed a more significantly reduced number of osteoclasts than the HT group. These findings suggest that TSCs suppress osteoclastogenesis, thereby potentially delaying the rate of tooth movement, supporting the results reported by Nagaie et al. [14].

In Figure 6, CT images showed that the maxillary right first molar (M1) had moved with a proximal tilt. We believe that this was caused by the elastic rubber inserted between the maxillary right first molar (M1) and second molar (M2) using the Waldo method, which pushed the crown of the maxillary first molar (M1) in the proximal direction. Although several different optimal orthodontic forces have been proposed for experimental tooth movement in rats, consensus exists for orthodontic forces between 10 g and 50 g [24,25]. In the Waldo method used in this study, elastic rubber was inserted between the teeth, but the force applied to the teeth was not measured and may have been excessive. Elastic rubber is a product that uses tensile forces for tooth movement; however, the Waldo method uses compressive forces for experimental tooth movement, which makes measurement of the orthodontic force challenging [25]. In studies on tooth movement using NiTi coil springs, which provide an optimal orthodontic force [24], the compression side at the distal root of M1 reportedly appears on 1/3 of the proximal side of the cervical region and 1/3 of the distal side of the apical region. The traction side at the distal root of M1 appears on 1/3 of the mesial side of the apical region and 1/3 of the distal side of the cervical region [26]. In a previous study using the Waldo method, it was reported that

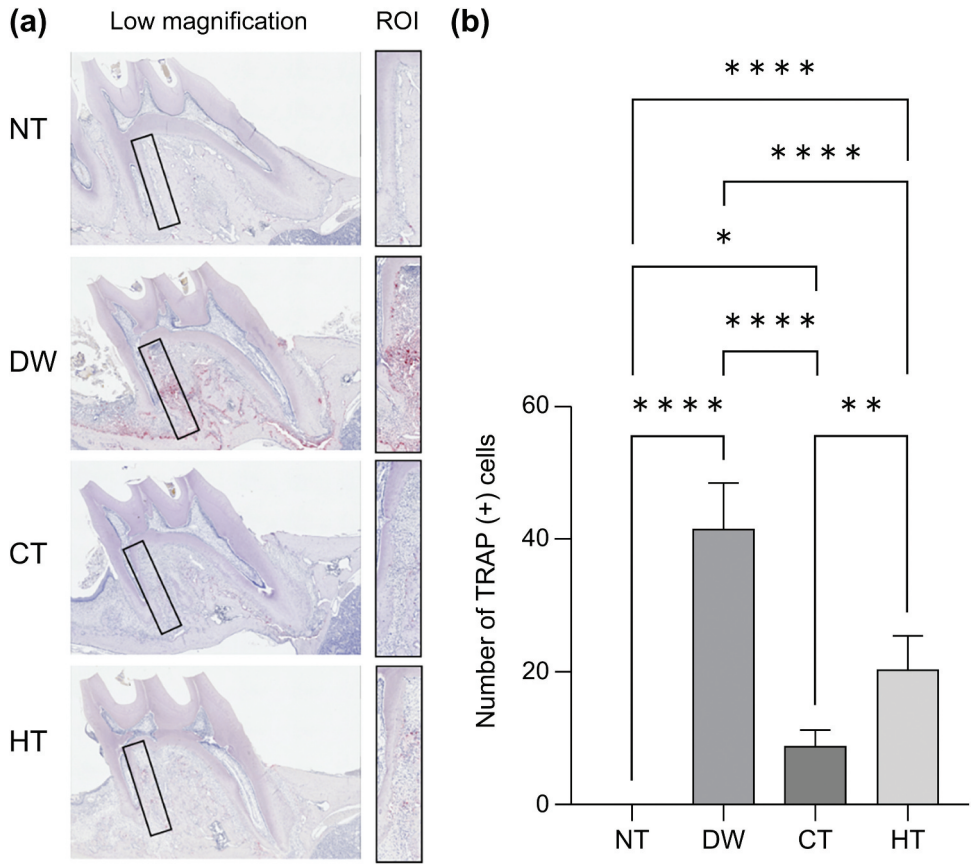

Figure 7. (a) Tartrate resistant acid phosphatase (TRAP) staining images. Black rectangle: region of interest in the periodontal tissue between the centrifugal root surface of the maxillary right first molar and alveolar bone. (b) quantitative data of TRAP-positive cells and their correlation with each rat group. Data are presented as mean ± standard deviation (SD). *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$, ****$p < 0.0001$; assessed using analysis of variance and the Tukey – Kramer post hoc test. $n = 6$.

osteoclasts appeared on the compression side, and the compression side is on the proximal side of the distal root of M1 from the apex to the cervical region [27]. Another study reported that one-third of the area from the root bifurcation to the cervical side was on the compression side in the proximal aspect of the distal root of M1 [28]. If the orthodontic force applied to the tooth is excessive, severe blood flow disturbance on the compressed side can occur and vitreous degeneration can be observed. In extreme cases, contacts of the root of the tooth with the alveolar bone, rupture of blood vessels, anaemia, absence of osteoclasts, inhibition of alveolar bone resorption, and temporary cessation of tooth movement are observed [28]. In this study, TRAP-positive cells were seen in the ROI of the TRAP-stained tissue despite the presence of excessive orthodontic forces. Although this was not an optimal tooth movement environment, TRAP-positive cells were nevertheless observed. Therefore, we believe that the conditions were adequate for the occurrence of tooth movement. Based on previous reports, a wide area of the alveolar bone surface in the direction of pressure may be present on the compression side when the Waldo method is used. Therefore, we selected the sagittal section in this study to measure the number of TRAP-positive cells in the ROI.

Several studies have investigated the effects of nicotine, a major component of cigarette smoke, on tooth movement. Sodagar et al. [11] discovered that nicotine accelerates tooth movement in rats, whereas Bakathir et al. [12] reported that nicotine accelerates tooth movement and leads to imbalanced bone resorption around the moving teeth. However, Araujo et al. [13] reported that nicotine and ethanol did not affect tooth movement speed. When comparing nicotine levels between the Seven Stars cigarette and IQOS HTP TSCs that were used in this study, the Seven Stars cigarette TSCs contained nearly twice the amount of nicotine [23]. However, Seven Stars cigarette TSCs that have higher nicotine levels led to a significantly smaller amount of tooth movement, suggesting that components other than nicotine in TSCs may reduce tooth movement distance. Seven Stars cigarette and IQOS HTP TSCs contain different substances, with Seven Stars cigarette TSCs containing significant amounts of harmful tar-derived components such as polycyclic aromatic hydrocarbons, phenolic compounds, and aldehydes [29]. By contrast, IQOS HTP TSCs have negligible tar content [30,31] and are rich in compounds, such as glycerol and propylene glycol [20]. Although the potential effects of glycerol on glucose and glycerol

homoeostasis within the human body, as well as its effects on the liver, have been established [32,33], its influence on tooth movement remains unexplored in the existing literature. However, considering the adverse effects of tar on bone remodelling [34], tar-derived components may contain substances that inhibit osteoclastogenesis. However, further investigation is required to comprehensively identify these specific constituents. This study aimed to extract the smoke components of heated cigarettes, which have become an alternative to traditional paper cigarettes in recent years, and examine whether or not the smoke components of heated cigarettes affect the tooth migration rates when administered to rats. Since we demonstrated that heated tobacco TSCs slow down tooth movement, we intend to identify the constituents of heated tobacco TSCs and explore their effects on osteoclast differentiation mechanisms in future *in vitro* studies.

Conclusion

When comparing the effects of IQOS and Seven Star cigarette TSCs, mainstream smoke from conventional cigarettes (Seven Star cigarette TSCs) significantly inhibited the rate of tooth movement and led to significantly decreased number of osteoclasts (TRAP-positive cells). Furthermore, substances other than nicotine that are present in the mainstream smoke of both cigarettes and HTPs may inhibit osteoclast regeneration. Based on these results, patients undergoing orthodontic treatment who smoke cigarettes or HTP may experience delayed tooth movement speed, potentially leading to an extended treatment duration. Although the impact of HTP on osteoclasts is smaller compared with that of traditional cigarettes, it still affects tooth movement when compared to that in non-smokers. Therefore, orthodontists should ascertain the smoking status of patients, particularly their smoking methods, before initiating orthodontic treatment. They should explain the potential for extended treatment duration and provide guidance for making efforts to quit smoking. These findings provide insights on the effects of HTP on the human body.

Acknowledgments

We are grateful to all the members of Department of Orthodontics, Osaka Dental University, for their cooperation.We would like to thank Editage (www.editage.com) for English language editing.

Disclosure statement

There are no financial conflicts of interest to disclose

Funding

The author was supported by the Osaka Dental University Research Funds (23-12).

ORCID

Aki Nishiura http://orcid.org/0000-0001-9295-2532

Author contributions

Author 1 contributed to the conception, design, data acquisition, and interpretation, and drafted and critically revised the manuscript.

Author 2 contributed to the conception, design, and interpretation, critically revising the manuscript.

Author 3 contributed to the design, drafted, and critically revised the manuscript.

Author 4 contributed to the design and critically revised the manuscript.

Authors 5, 6, and 7 aided in interpreting the result and critically revised the manuscript.

All authors discussed the results and commented on the manuscript.

Ethical approval

This study was approved by the Ethics Committee of Osaka Dental University (approval number:23–02015).

References

[1] WHO global report on trends in prevalence of tobacco use 2000–2025. 4th ed. Geneva: World Health Organization; 2021.

[2] Sun T, Anandan A, Lim CCW, et al. Global prevalence of heated tobacco product use, 2015–22: a systematic review and meta-analysis. Addiction. 2023;118 (8):1430–1444. doi: 10.1111/add.16199

[3] Hori A, Tabuchi T, Kunugita N. Rapid increase in heated tobacco product (HTP) use from 2015 to 2019: from the Japan "Society and New Tobacco" Internet Survey (JASTIS). Tob Control. 2020;30(4):474–475. doi: 10.1136/tobaccocontrol-2020-055652

[4] Talhout R, Schulz T, Florek E, et al. Hazardous compounds in tobacco smoke. Int J Environ Res Public Health. 2011;8(2):613–628. doi: 10.3390/ijerph8020613

[5] Saha SP, Bhalla DK, TF W Jr, et al. Cigarette smoke and adverse health effects: an overview of research trends and future needs. Int J Angiol. 2007;16(3):77–83. doi: 10.1055/s-0031-1278254

[6] Kamimura D, Cain LR, Mentz RJ, et al. Cigarette smoking and incident heart failure: insights from the Jackson heart study. Circulation. 2018;137(24):2572–2582. doi: 10.1161/CIRCULATIONAHA.117.031912

[7] Sopori ML, Kozak W. Immunomodulatory effects of cigarette smoke. J Neuroimmunol. 1998;83(1–2):148–156. doi: 10.1016/s0165-5728(97)00231-2

[8] Barbour SE, Nakashima K, Zhang JB, et al. Tobacco and smoking: environmental factors that modify the host response (immune system) and have an impact on periodontal health. Crit Rev Oral Biol Med. 1997;8 (4):437–460. doi: 10.1177/10454411970080040501

[9] Obeid P, Bercy P. Effects of smoking on periodontal health: a review. Adv Ther. 2000;17(5):230–237. doi: 10.1007/BF02853162
[10] Levin L, Schwartz-Arad D. The effect of cigarette smoking on dental implants and related surgery. Implant Dent. 2005;14(4):357–361. doi: 10.1097/01.id.0000187956.59276.f8
[11] Sodagar A, Donyavi Z, Arab S, et al. Effect of nicotine on orthodontic tooth movement in rats. Am J Orthod Dentofacial Orthop. 2011;139(3):e261–e265. doi: 10.1016/j.ajodo.2010.08.018
[12] Bakathir MA, Linjawi AI, Omar SS, et al. Effects of nicotine on bone during orthodontic tooth movement in male rats. Histol and immunohistochemical study Saudi Med J. 2016;37(10):1127–1135. doi: 10.15537/smj.2016.10.15159
[13] Araujo CM, Rocha AC, Araujo BMM, et al. Effect of acute administration of nicotine and ethanol on tooth movement in rats. Braz Oral Res. 2018;32:e96. doi: 10.1590/1807-3107bor-2018.vol32.0096
[14] Nagaie M, Nishiura A, Honda Y, et al. A comprehensive mixture of tobacco smoke components retards orthodontic tooth movement via the inhibition of osteoclastogenesis in a rat model. Int J Mol Sci. 2014;15(10):18610–18622. doi: 10.3390/ijms151018610
[15] Matoba H, Nishiura A, Honda Y, et al. Smoking cessation rescues tooth movement delays caused by tobacco smoke components. Orthod Waves. 2021;80(1):17–22. doi: 10.1080/13440241.2020.1867812
[16] Auer R, Concha-Lozano N, Jacot-Sadowski I, et al. Heat-not-burn tobacco cigarettes: smoke by any other name. JAMA Intern Med. 2017;177(7):1050–1052. doi: 10.1001/jamainternmed.2017.1419
[17] Bravo-Gutiérrez OA, Falfán-Valencia R, Ramírez-Venegas A, et al. Lung damage caused by heated tobacco products and electronic nicotine delivery systems: a systematic review. Int J Environ Res Public Health. 2021;18(8):4079. doi: 10.3390/ijerph18084079
[18] Leigh NJ, Tran PL, O'Connor RJ, et al. Cytotoxic effects of heated tobacco products (HTP) on human bronchial epithelial cells. Tob Control. 2018;27(Suppl 1):s26–s29. doi: 10.1136/tobaccocontrol-2018-054317
[19] Znyk M, Jurewicz J, Kaleta D. Exposure to heated tobacco products and adverse health effects, a systematic review. Int J Environ Res Public Health. 2021;18(12):6651. doi: 10.3390/ijerph18126651
[20] Uchiyama S, Noguchi M, Takagi N, et al. Simple determination of gaseous and particulate compounds generated from heated tobacco products. Chem Res Toxicol. 2018;31(7):585–593. doi: 10.1021/acs.chemrestox.8b00024
[21] Waldo CM. Method for the study of tissue response to tooth movement. J Dent Res. 1953;32:690–691.
[22] https://www.jti.co.jp/tobacco/products/sevenstars/index.html.
[23] Nakamoto Y, Makita Y, Tsuda S, et al. Improved collection method for low volatile smoke components produced by heated tobacco products. J Osaka Dent Univ. 2022;56(2):193–196. doi: 10.18905/jodu.56.2_193
[24] Nakano T, Hotokezaka H, Hashimoto M, et al. Effects of different types of tooth movement and force magnitudes on the amount of tooth movement and root resorption in rats. Angle Orthod. 2014;84(6):1079–1085. doi: 10.2319/121913-929.1
[25] Ren Y, Maltha JC, Kuijpers-Jagtman AM. The rat as a model for orthodontic tooth movement–a critical review and a proposed solution. Eur J Orthod. 2004;26(5):483–490. doi: 10.1093/ejo/26.5.483
[26] Sella RC, de Mendonça MR, Cuoghi OA, et al. Histomorphometric evaluation of periodontal compression and tension sides during orthodontic tooth movement in rats. Dental Press J Orthod. 2012;17(3):108–117. doi: 10.1590/S2176-94512012000300021
[27] Ogasawara T, Yoshimine Y, Kiyoshima T, et al. In situ expression of RANKL, RANK, osteoprotegerin and cytokines in osteoclasts of rat periodontal tissue. J Periodontal Res. 2004;39(1):42–49. doi: 10.1111/j.1600-0765.2004.00699.x
[28] Okafuji N, Nakano K, Yamaki T, et al. Experimentally traumatic mechanical stress exposed periodontal tissues. J Japan Assoc Dent Traumatol. 2011;7(1):25–31.
[29] Phillips GF, Waller RE. Yields of tar and other smoke components from UK cigarettes. Food Chem Toxicol. 1991;29(7):469–474. doi: 10.1016/0278-6915(91)90093-m
[30] Kopa PN, Pawliczak R. IQOS – a heat-not-burn (HnB) tobacco product – chemical composition and possible impact on oxidative stress and inflammatory response. A systematic review. Toxicol Mech Methods. 2020;30(2):81–87. doi: 10.1080/15376516.2019.1669245
[31] Borgerding MF, Milhous LA Jr, Hicks RD, et al. Cigarette smoke composition. Part 2. Method for determining major components in smoke of cigarettes that heat instead of burn tobacco. J Assoc Off Anal Chem. 1990;73(4):610–615. doi: 10.1093/jaoac/73.4.610
[32] Diravidamani K, Sivalingam SK, Agarwal V. Drugs influencing orthodontic tooth movement: an overall review. J Pharm Bioallied Sci. 2012;4(Suppl 2):S299–S303. doi: 10.4103/0975-7406.100278
[33] Lechasseur A, Mouchiroud M, Tremblay F, et al. Glycerol contained in vaping liquids affects the liver and aspects of energy homeostasis in a sex-dependent manner. Physiol Rep. 2022;10(2):e15146. doi: 10.14814/phy2.15146
[34] Hamdy RC, Dickerson K, Whalen K. Cigarette smoking and bone health. J Clin Densitom. 2020;23(3):337. doi: 10.1016/j.jocd.2020.06.005