ORIGINAL RESEARCH

Effect of Frequency of Micro-osteoperforation on Miniscrew-supported Canine Retraction: A Single-centered, Split-mouth Randomized Controlled Trial

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Abstract

Aim: The present study aimed at evaluating the increase in the rate of tooth movement by increasing the number and frequency of micro-osteoperforations (MOPs).

Materials and methods: The study was a single-center, split-mouth, randomized controlled trial. A total of 20 patients were included in the study who had fully erupted maxillary canines with class I molar canine relationship and a bimaxillary protrusion that required the removal of both maxillary and mandibular first premolars. Out of 80 samples, the experimental and controlled groups were randomly assigned. The experimental group received five MOPs in the extracted site of the first premolar before retraction, at 28th day and 56th day. The control group received no MOPs. The rate of tooth movement was measured on 28th, 56th, and 84th day on both the experimental and control sides.

Results: In maxillary dentition, the canine on the MOP side moved by 0.65 ± 0.21 mm, 0.74 ± 0.23 mm, and 0.87 ± 0.27 mm during 28th, 56th, and 84th day, respectively, whereas in control side the rate of tooth movement was 0.37 ± 0.09 mm, 0.43 ± 0.11 mm, and 0.47 ± 0.11 mm during 28th, 56th and 84th day, respectively, which was statistically significant (p-value = 0.000).

In mandibular dentition, the canine on the MOP site has moved by 0.57 ± 0.12 mm, 0.68 ± 0.21 mm, and 0.67 ± 0.10 mm during 28th, 56th, and 84th day, respectively, whereas in control side the rate of the tooth movement was 0.34 ± 0.08 mm, 0.40 ± 0.15 mm, and 0.40 ± 0.13 mm during 28th, 56th, and 84th day, respectively, which was statistically significant.

Conclusion: Micro-osteoperforations effectively increased the rate of tooth movement. Overall, MOPs increased the rate of canine retraction by 2-fold when compared with the control group.

Clinical significance: Micro-osteoperforation is a proven methodology to increase the rate of tooth movement and decrease the treatment time. However, it is important to repeat the procedure during every activation to increase its effectiveness.

Keywords: Accelerated orthodontics, Canine retraction, Micro-osteoperforation, Rapid tooth movement.

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Introduction

Orthodontic tooth movement is a biological phenomenon, which is initiated by a physical force that is being exerted on the tooth and is mediated by biochemical changes occurring at the cellular level. The rate of tooth movement is restricted to a particular level, which controls the treatment time and is influenced by bone turnover, bone density, and the degree of hyalinization of the PDL.[1] One of the major drawbacks of orthodontic treatment in patient perspective is the longer orthodontic treatment time. The average time of orthodontic treatment lasts for 2 years,[2] and patient expects a duration of time between 6 and 12 months.[3] Orthodontists and researchers had made a lot of innovations and efforts to accelerate tooth movement thereby reducing the treatment time. The methods to accelerate orthodontic tooth movement can be broadly classified into pharmacological, physical, and surgical methods. Of these, surgical methods of accelerating tooth movement had been found to produce definitive results compared to other methods of acceleration. Corticotomy technique introduced by Kole in 1959 involved reflection of periosteal flap to expose the underlying bone followed by interdental cuts through the cortical bone and a connecting subapical horizontal cuts.[4] Later, Suya modified this technique by replacing apical horizontal cuts by thinning of cortical bone

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instead of a complete cut.[5] However, surgical procedures became more familiar with orthodontist after the invent of Wilckodontics by the Wilcko brothers in the year 2008, which involved cortical bone perforations along with placement of alveolar bone graft.[6] This was also known as periodontally accelerated osteogenic orthodontics. Later on, corticision and piezocision were also reported to fasten tooth movement.[7,8] All these surgical methods were based on regional acceleratory phenomenon by Frost who reported that regional bone density is removed by noxious stimuli thereby accelerating tooth movement.[9]

Micro-osteoperforations are also a type of surgical means of accelerating tooth movement, which involved transmucosal bone puncture without flap elevation. This technique was earlier introduced by Murphy.[10] However, human trials were done by Alikhani et al. after their invention of propel device and reported increase in rate of tooth movement by 2- to 3-fold.[11] But Alkebsi et al. found that there were no difference between the two groups.[12]

To date, we have very little and contradictory literature evidence based on MOPs, with early data derived from animal models and few clinical trials in humans producing results that are for and against the technique. Additional research is needed for a better understanding of the clinical effectiveness of MOP in orthodontics.

Based on the above findings, this *in vivo* clinical trial was designed to evaluate the increase in the rate of tooth movement by increasing the number of MOPs. This study also aimed to check, if there is any increase in the rate of orthodontic tooth movement by increasing the frequency of MOPs and also to find out any possible difference in the rate of tooth movement in between maxilla and mandible. The current study investigated MOP using mini-implant supported canine retraction with fixed appliances. This split-mouth randomized trial focused on canine retraction within the maxilla and mandible following the extraction of the first premolar teeth, and the effects of multiple MOP carried out at specific time points during 28th, 56th, and 84th day of observation.

Materials and Methods

A randomized single center, split mouth study was approved by the institutional review board and ethical committee (IRB/EC Ref No: 2016 -MDS-BR.V-SUD-11/APDCH).

Sample Selection

The sample size was selected based on a type I error frequency of 5% and the power of the statistical test set at 90% (P 5 0.9, b 5 0.1) using our animal studies as a guide to detect at least a 50% difference in the rate of tooth movement.

A total of 20 patients (who satisfied inclusion and exclusion criteria) were included in the study who had fully erupted maxillary canines with class I molar canine relationship and bimaxillary protrusion that required the removal of both maxillary and mandibular first premolars.

The inclusion and exclusion criteria are as follows:

Inclusion criteria

- Patient in permanent dentition between age-group of 15 and 25 years
- Class I bimaxillary protrusion, fully erupted maxillary canine with closed apex
- Cases requiring extraction of both maxillary and mandibular first premolars
- Patients with periodontally sound dentition
- Patients with sound general health

Conflict of interest: None

Ethics: The present study was approved by the institutional review board and ethical committee, Adhiparasakthi Dental College and Hospital, Melmaruvathur, Chengalpattu, Tamil Nadu, India.

Exclusion criteria

- Long-term use of antibiotics, phenytoin, cyclosporine, anti-inflammatory drugs, systemic corticosteroids, and calcium channel blockers
- Skeletal class II tendency and ANB >2°
- Skeletal class III tendency and ANB <2°
- Cases requiring orthognathic surgery
- History of systemic and medical illness
- Contraindication of extraction
- Previous history of orthodontic treatment
- Poor oral hygiene
- Smoking
- Nickel allergy

Methodology

In total, 80 samples were obtained out of which 40 (20 control and 20 experimental) were in maxilla and 40 (20 control and 20 experimental) were in mandible, respectively.

Patients who met the selection criteria and completed an informed consent form were randomly assigned to one of the study groups. The experimental group received MOPs on either the right or left side based on random allocation to eliminate the possibility of uneven occlusal forces because of habitual occlusion predominantly on one side. The control group received no MOPs.

The subjects and the orthodontist performing the experiment were aware of the group assignment and the investigator performing the measurements and data analysis that were blinded from the group assignments.

Treatment was initiated by bonding the fixed appliance in both arches with MBT 0.022 prescription (DENTAURUM EQUILIBRIUM 2) and with an auxiliary vertical slot in the maxillary and mandibular canine brackets [American orthodontics (AO), Fig. 1].

Patients were referred for extraction of the maxillary and mandibular first premolar to the same surgeon to decrease variability.

The aligning and leveling were done using the following sequence of 0.016 NiTi, 0.017*0.25 NiTi, and 0.019*0.025 NiTi wires. After which 0.019*0.025 SS arch wire was placed for a period of 4 weeks and then alginate impressions were taken as a record before retraction phase. At this retraction stage, 19*25 SS arch wire was placed in both maxillary and mandibular arch. A serpentine hook (Fig. 1) was fabricated using 16*16 SS wire, and this hook was inserted into vertical slot of canine (Fig. 1) so that the applied force was close to the center of resistance. A temporary anchorage device (1.5 mm × 9 mm) (Fig. 2) was placed between second premolar and first molar on the buccal aspect, 6 mm from the interdental papilla.[13] On the experimental site, local anesthesia (2% lidocaine with 1:10,0000 epinephrine) was infiltrated in the first premolar region.

Micro-osteoperforations was performed without any flap elevation with a hand-held device [temporary anchorage device (TAD, 1.5 mm × 9 mm)] loaded in the implant driver (SK SURGICALS, INDIA) (Fig. 6) with a rubber stopper placed at a depth of 3 mm so that each perforation was of 3 mm in depth and 1.5 mm in width (Fig. 3). Two MOPs were performed distal to canine and three in the middle of the extraction socket before retraction. The MOPs in the center of socket were placed at a height of 5, 10,

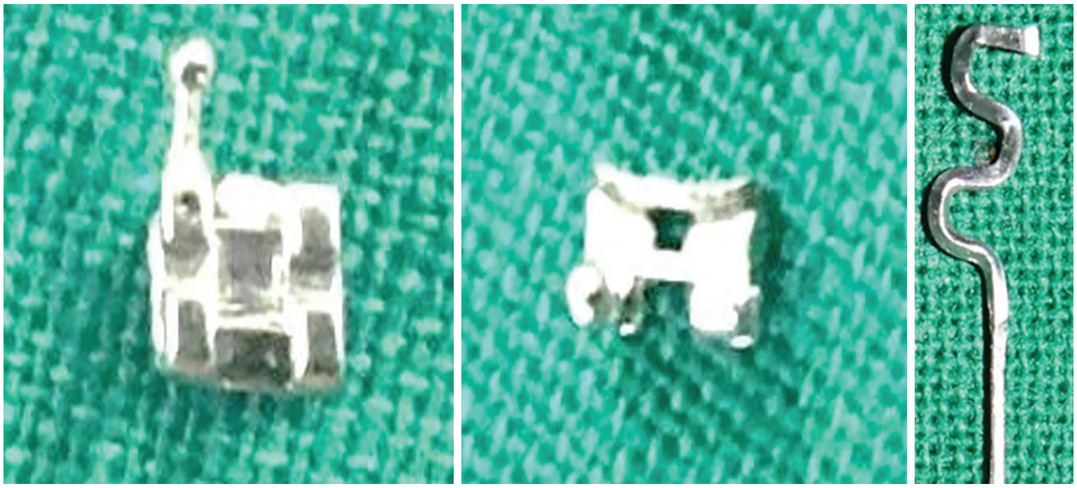

Fig. 1: Canine brackets with vertical slot (AO) and serpentine hook

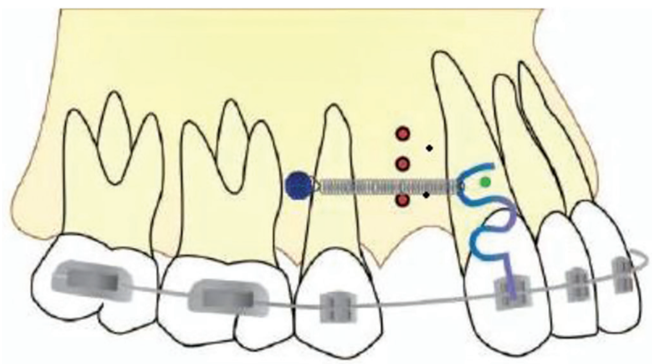

Fig. 2: Schematic representation of TAD placement and MOP

Fig. 3: MOP performed on the experimental site

Fig. 4: Canine retraction on the experimental and control site

and 15 mm from the alveolar crest, respectively, and two MOPs were placed at a height of 7 and 12 mm distal to canine, whereas the control site did not receive any MOPs. A NiTi closed coil spring was placed between TAD and the serpentine hook (Fig. 3). A 100 gm of force was applied for individual canine retraction (Figs 3 and 4) and was measured using Dontrix gauge on both experimental and control sides.[11] At each visit, the force produced by the coil was checked, and appliances were monitored for any deformation or change in the position because of mastication.

On the experimental side, at 28th and 56th day, two MOPs were performed distal to canine and three MOPs at the center of extraction space, and no MOPs were performed in the control side. Alginate impressions were taken at the beginning of the study, immediately before canine retract on, and at 28th, 56th, and 84th day after canine retraction began to monitor the rate of tooth movement in both arches. The impressions were poured immediately with Orthokal. The casts were labeled with the patient's number and date and stored. Vertical lines were drawn on the cast over the palatal surface of the canine from the middle of the cervical line. The distance between the canine and the lateral incisor was assessed before and after canine retraction at three points: incisal, middle, and cervical thirds of the crowns (Fig. 5). All the cast measurements were made using an electronic digital caliper with an accuracy of 0.01 mm (Fig. 6). The obtained measurements were tabulated and given for statistical analysis.

Statistical Analysis

Data were tabulated in an Excel sheet and analyzed using SPSS statistical software (version 22). The data were assessed for normality using Shapiro–Wilk test, which revealed that the data were non-normal in distribution. Hence, nonparametric test (Mann–Whitney *U* test) was employed to detect the significant difference between MOP group and control group. The same

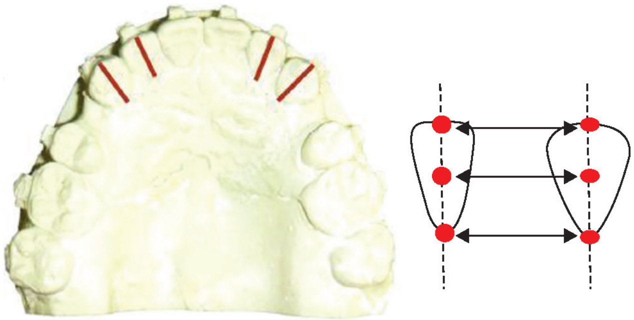

Fig. 5: Schematic representation of measuring tooth movement

Fig. 6: Measurement of canine retraction on model

test was employed to detect the significant difference between maxillary and mandibular jaws.

Results

The amount of canine retraction on both experimental and control side, which was calculated from the model on 28th, 56th, and 84th day, was sent for statistical analyses. The data were assessed using SPSS statistical software (version 22). In order to assess the normality of distribution, Kolmogorov–Smirnov and Shapiro–Wilk test were done. The results indicated that the data were non-normal in distribution. Therefore, Mann–Whitney *U* test was performed (Table 1).

In this test, *p*-value ≤0.005 was considered significant (Table 2). In maxillary dentition, canine on MOP side moved by 0.65 ± 0.21 mm, 0.74 ± 0.23 mm, and 0.87 ± 0.27 mm during 28th, 56th, and 84th day, respectively, whereas in control side the rate of tooth movement was 0.37 ± 0.09 mm, 0.43 ± 0.11 mm, and 0.47 ± 0.11 mm during 28th, 56th, and 84th day, respectively (Table 2 and Figs 2 to 4), which was statistically significant (*p*-value = 0.000, Table 2).

In mandibular dentition, canine on MOP site has moved by 0.57 ± 0.12 mm, 0.68 ± 0.21 mm, and 0.67 ± 0.10 mm during 28th, 56th, and 84th day, respectively, whereas in control side the rate of tooth movement was 0.34 ± 0.08 mm, 0.40 ± 0.15 mm, and 0.40 ± 0.13 mm during 28th, 56th, and 84th day, respectively (Table 1 and Figs 5 and 6), which was statistically significant (*p*-value = 0.000, Table 2).

When comparing the rate of tooth movement between maxilla and mandible in the experimental (MOP) site, the canine moved by 0.65 ± 0.21 mm, 0.74 ± 0.23 mm, and 0.87 ± 0.27 mm during 28th, 56th, and 84th day, respectively, whereas in mandible the canine moved by 0.57 ± 0.12 mm, 0.68 ± 0.21 mm, and 0.67 ± 0.10 mm during 28th, 56th, and 84th day respectively (Table 2).

Table 1: Mann–Whitney *U* test—comparison of control and experimental (MOP) site

Groups	*Max 28th day*	*Max 56th day*	*Max 84th day*	*Mand 28th day*	*Mand 56th day*	*Mand 84th day*
MOP	0.6521	0.7374	0.8589	0.5679	0.6763	0.6705
Mean						
Std. dev.	0.20558	0.23154	0.26868	0.11970	0.20597	0.10368
N	20	20	20	20	20	20
CONTROL						
Mean	0.3700	0.4274	0.4742	0.3416	0.4011	0.4026
Std. dev.	0.08825	0.10852	0.07932	0.8315	0.14594	0.12727
N	20	20	20	20	20	20

Table 2: Tests of significance for intergroup comparison between experimental (MOP) side and control side

	Max 28th day	*Max 56th day*	*Max 84th day*	*Mand 28th day*	*Mand 56th day*	*Mand 84th day*
Mann–Whitney	16.500	14.500	2.500	4.500	30.000	19.500
Wilcoxon *W*	206.500	204.500	192.500	194.500	220.000	209.500
Z	−4.793	−4.850	−5.201	−5.146	−4.397	−4.704
Asymp. sig (two-tailed)	0	0	0	0	0	0
Exact sig [2 × (one-tailed sig)]	0	0	0	0	0	0

Table 3: Tests of significance for intergroup comparison between maxillary and mandibular arch on the experimental (MOP) side

	MOP 28th day	*MOP 56th day*	*MOP 84th day*
Mann–Whitney	145.500	152.500	82.500
Wilcoxon *W*	335.500	342.500	272.500
Z	−1.023	−818	−2.864
Asymp. Sig (two-tailed)	0.306	0.413	0.004
Exact sig [2 × (one-tailed sig)]	0.311	0.418	0.003

The difference between MOP side in maxilla and mandible on 28th and 56th day was 0.08 and 0.06 mm, respectively, which was statistically not significant ($p > 0.05$), whereas in 84th day, the difference was 0.19 mm, which was statistically significant ($p \leq 0.05$, Table 3).

Experimental (MOP) side in the maxillary arch showed 2-fold increase in the rate of tooth movement when compared with control side (Table 1).

Experimental (MOP) side in the mandibular arch showed 2-fold increase in the rate of tooth movement when compared with control side. Therefore, overall rate of tooth movement in experimental (MOP) side showed a 2-fold increase when compared to control side (Table 1).

Discussion

The present study aimed at evaluating the rate of mini-implant assisted individual canine retraction through MOPs by varying the frequency of MOPs at 28th, 56th, and 84th day after force application. The normal activation of orthodontic tooth movement is done every 28th day, and hence the rate of tooth movement was assessed on 28th, 56th, and 84th day, respectively. The results were compared with the control group in order to estimate the effect of MOPs in accelerated tooth movement. A split mouth randomized controlled study was selected so as to avoid bias related to biologic variations in subjects.

It has been shown that the forces of occlusion can affect the rate of tooth movement significantly by Alikhani et al.[11] To rule out the effect of occlusion in this study, we selected patients with similar severities of malocclusion. Patients with crossbite or deviation during closure caused by occlusal interference were not included in this study. In addition, to eliminate the possibility of uneven occlusal forces from habitual occlusion predominately on one side, MOPs were randomly assigned to the left or right side of each patient. Furthermore, the canines were selected because they were free from occlusal interferences.

Alkebsi et al.[12] in their randomized controlled clinical trial found that three MOPs advocated by previous researchers were not effective for accelerating orthodontic tooth movement in the first 3 months. In our study, we decided to incorporate five MOPs, three MOPs in the center of extraction socket, and 2 MOPs just distal to the canine. The MOPs in the center of socket were placed at a height of 5, 10, and 15 mm from the alveolar crest, respectively, and two MOPs were placed at a height of 7 and 12 mm distal to canine.

In their study, Alkebsi et al.[12] calculated the space between the second premolar and canine to estimate space closure. The disadvantage in such case is that the mesial movement of the second premolar might give a false reading. Therefore, in our study, we have measured the space created between canine and lateral incisor that estimated the true retraction of canine and avoided bias reading due to mesial movement of premolar.

We decided to repeat the MOPs on 28th and 56th day to find out any net increase in the rate of tooth movement by repeating the MOPs. We increased the frequency of MOPs so as to replenish the undifferentiated mesenchymal cells at the site of perforation due to limited duration of RAP.[14]

Another major factor affecting the rate of tooth movement is the type of movement. In this study, an attempt was made to achieve bodily movement through application of the force closer to the center of resistance of the tooth. This was achieved by individual canine retraction using calibrated 100 gm of NiTi closing coil spring (9 mm) (Fig. 6) connected from a (TAD, 1.5 mm × 9 mm) (Fig. 6) placed between the second premolar and molar on the buccal aspect to a custom made serpentine hook (Fig. 3) in the vertical slot of canine brackets made with 16*16 ss.

In our study, alginate impressions were taken at the beginning of the study, then immediately before canine retraction, and also on 28th, 56th, and 84th day after canine retraction began. In order to monitor the rate of tooth movement in both the arches, the distance between the canine and the lateral incisor was assessed before and after canine retraction at three points: incisal, middle, and cervical thirds of the crowns. All the cast measurements were made using an electronic digital caliper with an accuracy of 0.01 mm. Both intraobserver and inter-observer errors were evaluated. For the evaluation of the intra-observer error, 10 models were measured twice at least 2 weeks later. For the interobserver error, a second investigator measured the same set of models twice, and the mean values of the two measurements by each investigator were compared. This was done to minimize the errors of measurements as advocated by Houston.[15]

Wilcko et al.[6] in their study proved that age can play a significant role in the rate of tooth movement. This effect has been related to bone density or rate of osteoclast recruitment/activation. To eliminate the effect of age on the rate of tooth movement, only adults between 15 and 25 years were selected for this study, and the average age in both the groups was similar.

Another confounding variable that can affect the rate of tooth movement is the levels of sex hormones in women throughout the estrous cycle.[16,17] Unfortunately, we could not eliminate this variable because of the limited number of men willing to participate in this study.

Poor oral hygiene, periodontal disease, alveolar bone loss, systemic diseases, and consumption of anti-inflammatory medications can affect the rate of tooth movement significantly.[18] To reduce these variables, monitoring of patients was done to maintain excellent oral hygiene and clear exclusion criteria was followed. The patients were expected to comply with the instructions regarding strict attention to oral hygiene measures and keeping the follow-up visits.

In our study, we extracted the first premolars in both the arches before aligning and levelling to rule out the bias that extractions can change the rate of tooth movement by increasing the activity of inflammatory markers as suggested by Hasler et al.[19]

It is well known that, in most orthodontic extraction patients, anchorage reinforcement is of prime importance from the study done by Thiruvenkatachari et al.[20] Effective and reliable anchorage will dramatically improve the results of treatment. In this study, mini-screw implants were used as skeletal anchorage during canine retraction because of their simpler placement technique and the possibility of eliminating the reliance on patient compliance.

Assessment of miniscrew mobility after loading showed no mobility during canine retraction except for four miniscrews. One screw became lose 1 month after loading and the other three screws 1.5 months after loading. These miniscrews were immediately repositioned between the maxillary first and second molars, and canine retraction was resumed. These findings showed that the success rate of miniscrews in this study was approximately 93%, which is in accordance with previous reports by Chen et al.[13]

The miniscrews selected had a diameter of 1.5 mm and a length of 9 mm. The rationale was to optimize the mechanical retention of the screws and eliminate any risks of root proximity or contact that might contribute to failure during treatment. The placement site of the miniscrews, between the maxillary second premolar and the first molar buccally, was selected based on the recommendations of Marissa et al.[21] who advocated this site as bone stock for safe miniscrew placement in the maxillary arch. The miniscrews that were placed without flap surgery have higher success rates with less pain and discomfort than those placed with flap surgery, and these findings are in accordance with the that of Kuroda et al.[22]

Shpack et al.[23] concluded that retraction of maxillary canine into the first premolar extraction site using nickel-titanium closed coil springs occurred faster. Therefore, nickel-titanium closing coil spring (9 mm) was used for retraction to permit constant force application. Pain and discomfort caused by the MOPs were not different from the control group mentioned in the previous study (Alikhani et al).[11] This indicates that this procedure can be adopted in the routine clinical practice with no distress for the patient. This discomfort caused by a small injection can be bypassed by using a strong anesthetic.

In this project, root resorption was not investigated, any long-term effect of MOPs on root resorption would be difficult to study because many variables can contribute to root resorption; the longer the study, the more difficult it would be to control those variables.

This was the first study to determine the effect of MOPs on the rate of tooth movement by varying the number and the frequency of humans. We have shown that MOPs were an effective, comfortable, and safe procedure that accelerate tooth movement significantly and could result in shorter orthodontic treatment time.

Conclusion

Our study successfully evaluated the rate of tooth movement using MOP by increasing the frequency on every 28th day for a period of 84 days and as a result the rate of tooth movement increased significantly.

It is concluded from this study that:

- Overall, MOPs increased the rate of canine retraction by 2-fold when compared with the control group. From the statistical analysis, MOP site in the maxillary arch showed 2-fold increase when compared with the control side, and the MOP site in the mandibular arch showed 2-fold increase after increasing the frequency on 28th, 56th, and 84th day, which is statistically significant.
- When MOP was repeated for three times, maxillary canine showed more accelerated tooth movement than mandibular canine, which was statistically significant. Conclusively, MOPs could reduce orthodontic treatment time by 62%.

Therefore, MOPs can be incorporated into routine orthodontic mechanics and at different stages of treatment, facilitating alignment and root movement, stimulating bone remodeling in areas of deficient alveolar bone, and reducing the stress on anchor units. Hence, MOPs offer a practical, minimally invasive, and safe procedure that can be repeated as needed to maximize the biological response to orthodontic forces.

Further studies must be done by increasing the frequency and varying site, for example, by involving mesial side of canine. Then, histological studies can be done not only to assess the role of inflammatory cell as rate limiting factor in accelerated tooth movement but also to evaluate the trabecular pattern of the maxillary and mandibular arch for the variation in the rate of tooth movement between the arches.

Availability of Data and Materials

Data of the present study will not be shared because the same data and materials will be used in further publications where the analysis of rate of tooth movement for complete canine retraction is assessed.

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References

1. Krishnan V, Davidovitch Z. Cellular, molecular, and tissue-level reactions to orthodontic force. Am J Orthod Dentofacial Orthop 2006;129:469.e1-32. DOI: 10.1016/j.ajodo.2005.10.007.
2. Tsichlaki A, Chin SY, Pandis N, et al. How long does treatment with fixed orthodontic appliances last? A systematic review. Am J Orthod Dentofacial Orthop 2016;149:308–318. DOI: 10.1016/j.ajodo.2015.09.020.
3. Uribe F, Padala S, Allareddy V, et al. Patients', parents', and orthodontists' perceptions of the need for and costs of additional procedures to reduce treatment time. Am J Orthod Dentofacial Orthop 2014;145:S65–73. DOI: 10.1016/j.ajodo.2013.12.015.
4. Kole H. Surgical operations of the alveolar ridge to correct occlusal abnormalities. Oral Surg Oral Med Oral Pathol 1959;12:515–529. DOI: 10.1016/0030-4220(59)90177-x.
5. Suya H. Corticotomy in orthodontics. In: Hosl E, Baldauf A, eds. Mechanical and biological basis in orthodontic therapy. Heidelberg, Germany: Huthig Buch Verlag; 1991. pp. 207–26.
6. Wilcko MT, Wilcko WM, Pulver JJ, et al. Accelerated osteogenic orthodontics technique: a 1-stage surgically facilitated rapid orthodontic technique with alveolar augmentation. J Oral Maxillofac Surg 2009;67:2149–2159. DOI: 10.1016/j.joms.2009.04.095.
7. Kim SJ, Park YG, Kang SG. Effects of corticision on paradental remodeling in orthodontic tooth movement. Angle Orthod 2009;79: 284–291. DOI: 10.2319/020308-60.1.
8. Dibart S, Sebaoun JD, Surmenian J. Piezocision: a minimally invasive, periodontally accelerated orthodontic tooth movement procedure. Compend Contin Educ Dent 2009;30:342–4: 346, 348–350. PMID:19715011.
9. Frost HM. The regional acceleratory phenomenon: a review. Henry Ford Hosp Med J 1983;31:3–9. PMID:6345475.
10. Murphy NC. *In vivo* tissue engineering for orthodontists: a modest first step. In: Davidovitch Z, Mah J, Suthanarak S, editors. Biological

mechanisms of tooth eruption, resorption, and movement. Los Angeles: University of Southern California; 2006, pp. 385–410.
11. Alikhani M, Raptis M, Zoldan B, et al. Effect of micro-osteoperforations on the rate of tooth movement. Am J Orthod Dentofacial Orthop 2013;144:639–648. DOI: 10.1016/j.ajodo.2013.06.017.
12. Alkebsi A, Al-Maaitah E, Al-Shorman H, et al. Three-dimensional assessment of the effect of microosteoperforations on the rate of tooth movement during canine retraction in adults with Class II malocclusion: a randomized controlled clinical trial. Am J Orthod Dentofacial Orthop 2018;153(6):771–785. DOI:10.1016/j.ajodo.2017.11.026
13. Chen CH, Chang CS, Hsieh CH, et al. The use of microimplants in orthodontic anchorage. J Oral Maxillofac Surg 2006;64(8):1209–1213. DOI: 10.1016/j.joms.2006.04.016.
14. Dibart S, Keser E, Nelson D. Piezocision assisted orthodontics: past, present, and future. Semin Orthod 2015;21(3):170–175. DOI: 10.1053/J.SODO.2015.06.003.
15. Houston WJB. The analysis of errors in orthodontic measurements. Am J Orthod. 1983; 83(5):382–90.
16. Alikhani M, Alansari S, Sangsuwon C, et al. Micro-osteoperforat ions: minimally invasive accelerated tooth movement. Semin Orthod 2015;21(3):162–169. DOI: 10.1016/0002-9416(83)90322-6.
17. Haruyama N, Igarashi K, Saeki S, et al. Estrous-cycle-dependent variation. J Dent Res 2002;406–410. DOI: 10.1177/154405910208100610.
18. Bartzela T, Türp JC, Motschall E, et al. Medication effects on the rate of orthodontic tooth movement: A systematic literature review. Am J Orthod Dentofac Orthop 2009;135(1):16–26. DOI: 10.1016/j.ajodo.2008.08.016.
19. Hasler R, Schmid G, Ingervall B, Gebauer U. A clinical comparison of the rate of maxillary canine retraction into healed and recent extraction sites – A pilot study. Eur J Orthod 1997;19(6):711–719. DOI: 10.1093/ejo/19.6.711.
20. Thiruvenkatachari B, Ammayappan P, Kandaswamy R. Comparison of rate of canine retraction with conventional molar anchorage and titanium implant anchorage. Am J Orthod Dentofacial Orthoped 2008;134(1):30–35. DOI: 10.1016/j.ajodo.2006.05.044.
21. Schnelle MA, Beck FM, Jaynes RM, et al. A radiographic evaluation of the availability of bone for placement of miniscrews. *Angle Orthod* 2004;74(6):832–837. DOI:10.1043/0003-3219(2004)074<0832:AREOTA>2.0.CO;2.
22. Kuroda S, Hichijo N, Sato M, et al. Long-term stability of maxillary group distalization with interradicular miniscrews in a patient with a Class II Division 2 malocclusion. Am J Orthod Dentofacial Orthoped 2016;149(6):912–922. DOI: 10.1016/j.ajodo.2015.07.045.
23. Shpack N, Davidovitch M, Sarne O, et al. Duration and anchorage management of canine retraction with bodily versus tipping mechanics. Angle Orthod 2008;78(1):95–100. DOI: 10.2319/011707-24.1.