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Effect of Mini-implant assisted Micro-osteoperforation on the rate of orthodontic tooth movement—A randomized clinical trial

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Abstract

OBJECTIVE: To evaluate the effectiveness of micro-osteoperforation (MOP) over a 56-day period and to determine the influence of number of perforations on the rate of canine retraction. In addition, the amount of pain and discomfort caused by the MOP was evaluated.

TRIAL DESIGN: A single-center, split-mouth, triple-blind, randomized, controlled trial.

METHODS: 22 patients (18–30 years) who need fixed orthodontic treatment were recruited and randomly assigned to MOP1 and MOP2 groups. The recruited patients were divided into two groups with 1:1 allocation ratio. Randomization for the determination of experimental side and number of perforations was done using sealed envelopes. On each patient, the other side of mouth worked as control side with no MOPs. 4 months after first premolar extraction, patients in MOP1 received 3MOPs on the buccal surface of alveolar bone, whereas patients in MOP2 received three buccal and three palatal MOPs in the experimental side. The amount of canine retraction was measured every 28 days at two intervals on both sides of mouth. Pain perception was measured after 1 hr, 24 hr, 72 hr, 7 days, and 28 days of procedure.

RESULTS: Result of the intra-examiner reliability using ICC is more than 0.97 ($P < 0.001$), indicating excellent repeatability and reliability of the measurements. The baseline characteristics between groups were similar ($P > 0.05$). A statistically significant difference in the rate of canine retraction on the MOP side was observed at the end of 56 days, amounting to two folds more than that of the control side. No significant difference was seen between MOP1 and MOP2 groups ($P > 0.05$). Mild-to-moderate pain was experienced only in first 72 hours of procedure.

CONCLUSION: The study recommends that MOP procedure has substantial potential to be used as an adjunct to the routine mechanotherapy for accelerating tooth movement, as it may reduce treatment time by half in the first four weeks after the MOP procedure.

TRIAL REGISTRATION: Clinical trial registry of India (CTRI/2022/12/048181).

Keywords:

Micro-osteoperforation, orthodontic tooth movement, regional acceleratory phenomenon, VAS

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Introduction

Orthodontic treatment with its many advantages has a serious concern about prolonged treatment time. Discomfort and social inhibitions are major concerns among people seeking orthodontic treatment. This results in opting for less optimal options of veneers and implants.[1] Reducing treatment time decreases the risk of caries, periodontal diseases, and root resorption and increases patient satisfaction.[2]

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Many attempts have been made to reduce the treatment time. These can be broadly classified as surgical and non-surgical methods. Non-surgical methods include the use of limited orthodontic treatment, medication,[3] low-intensity lasers.[4] Surgical methods include micro-osteoperforation,[1] piezocision,[5] and corticotomies.[6]

Irrespective of the method employed, the rate of tooth movement is governed by the biological response to orthodontic forces. Frost introduced the term regional acceleratory phenomenon (RAP) in which bone injury induces acceleration in the biological processes such as metabolism, turnover, modeling, remodeling, healing, and inflammation of the bone.[7,8] There is an increase in inflammatory markers (cytokines and chemokines) in response to orthodontic forces.[9] These directly or indirectly through the prostaglandin E2 and the RANK/RANKL pathways help in the differentiation and recruitment of osteoclasts.[10,11] Thus, we can presume that these inflammatory markers increase the rate of orthodontic tooth movement.

Micro-osteoperforation (MOP) is one of the least invasive techniques used in orthodontic treatment. Multiple perforations in the cortical bone have been reported to increase the inflammatory markers and thus increase the rate of orthodontic tooth movement.[1,12] Although there are contradictory reports[13], a better understanding of the procedure and its effects is desirable. Micro-osteoperforations can be done using a PROPEL device or modified using mini-implants. Transmucosal holes in cortical bone are made to trigger bone remodeling changes for faster tooth movement. MOP creates predictable orthodontic treatment results, improves finishes with braces, and reduces or eliminates refinements with clear aligner therapy.[1]

Although there is much literature on the effects of selective decortication on tooth movement, only a few clinical studies have investigated the effects of MOPs on accelerating tooth movement. Studies by Alikhani *et al*.,[1] Feizbakhsh *et al*.[12] stated that the rate of tooth movement associated with MOP increased by 2 to 3 folds with no side effects. Exploring biological bone response seems exciting from a scientific perspective. There is a lack of evidence supporting such new ideas.[12] The heterogeneity and relativity of the parameters (especially the number, frequency, and depth of MOPs) tested in previous studies make it impossible to establish clear guidelines for the use of MOPs. Therefore, we designed a clinical study to gain a better understanding of the effectiveness of MOPs.

Objectives and Hypotheses

The present split-mouth, triple-blind, randomized controlled trial was designed to evaluate the effect of MOP over 56 days and to determine the influence of the number of perforations on the rate of canine retraction. Also, the level of pain and discomfort was accessed using the visual analogue scale.

The study group was divided into two, where three MOPs were done in the MOP1 group and six MOPs were done in the MOP2 group. The null hypothesis was that an increase in the number of perforations (from three buccal perforations to three buccal and three palatal perforations) does not accelerate the rate of canine retraction compared to the control side and the group receiving fewer perforations.

Materials and Method

Trial design

A single-center, split-mouth, parallel-arm, triple-blind, randomized controlled clinical trial performed with a 1:1 allocation ratio in the Dept. of Orthodontics and Dentofacial Orthopedics, Hazaribag College of Dental Sciences and Hospital, Jharkhand.

Protocol registration

The trial was registered at the Clinical Trial Registry of India (CTRI/2022/12/048181). No methodological changes were made after trial initiation. Ethical clearance was obtained from the Institute Ethics Committee for Hazaribag College of Dental Sciences and Hospital (HCDSHIEC/2021/011).

Participants and eligibility criteria

A detailed informed written consent form was signed by each patient and the patient's parents or guardians, who were willing to participate in the study. Patients with Angle's Class II Div1 malocclusion (indicated for bilateral maxillary first premolar extraction) or Class I Bimaxillary protrusion (indicated for all first premolar extraction) between ages 18–30 years were included in the study. Subjects with a history of systemic or periodontal disease, gingivitis or active caries, smoking, or undergoing any long-term medications were excluded from the study. Subjects with a history of previous orthodontic treatment, craniofacial anomalies, pregnancy, and long-term use of any systemic medication were excluded from the study.

Sample size calculation

In a previous study,[1] 30% increase in the rate of orthodontic tooth movement with one-time micro-osteoperforation, as reported by Alikhani *et al*.,[1] the sample size was calculated with 95% significance and 80% power. Furthermore, on account of using a mini-screw as an anchor unit, the amount of canine movement on one side could be considered completely independent from the contralateral side. Accordingly, a sample size of ten patients per group was calculated.

However, to achieve a more accurate estimation and compensate for the potential dropout during the research, the sample size was increased to 11 patients per group. A total of 41 patients were evaluated for eligibility out of which 22 patients fulfilled the inclusion criteria. (Illustrated in CONSORT Guidelines Figure 1)

Randomization

Participants were divided into two groups MOP1 and MOP2. It was decided that three micro-osteoperforations will be done in MOP1 group and six in MOP2 group. The participants for each group and the experimental side for each participant were selected randomly using sealed envelopes. At the start of the study, the participants were asked to pick a sealed envelope that determined the number of micro-osteoperforations to be done (3 or 6). After that, the patient was asked to pick another sealed envelope determining the experimental side (right or left) for that particular participant.

Blinding

This study was a triple-blind study where the patient, operator, and the investigator were all blinded to prevent any sort of bias. Patients were blinded by doing equal number of insertions on the buccal surface (in the MOP1 group) or buccal and palatal surfaces (in the MOP2 group) only in the gingival tissue on the control side. MOP interventions were performed by the first author such that the orthodontist was blinded to the experimental side. No perforation on the cortical bone of the control side was created. All the models and measurements were coded. In addition, the second author, responsible for the measurements, and the statistician were blinded to the coding of the study models. No information about the experimental side or the experimental group was disclosed to the investigators.

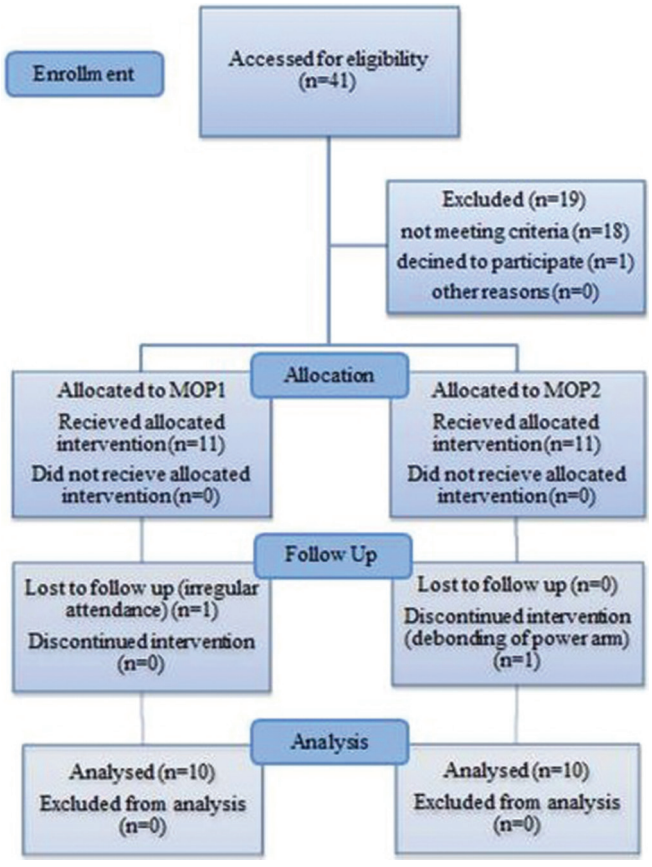

Figure 1: Consort flow diagram (2010)

Orthodontic appliance

As part of the initial phase, before the orthodontic treatment, the periodontal condition of all patients was assessed by the same periodontist. The patients were referred to the same surgeon for the simultaneous extraction of both maxillary first premolars. All the subjects were bonded with Pre-adjusted Edgewise Mechanotherapy (MBT prescription; 0.022 slot). Following the extraction of maxillary first premolars, initial alignment was done. Segmental retraction of 13 and 23 was done on 0.019 × 0.025 inch stainless steel wire which was left *in situ* for four weeks before the commencement of retraction. This period enabled full arch-wire passivity before the retraction. A power arm was made using 0.019 × 0.025-in. SS wire, based on the estimated center of rotation, bonded just mesial to the canine bracket on the buccal surface.

Micro-osteoperforation technique and canine retraction procedure

Modified MOPs were performed under local anesthesia (2% lidocaine with 1:100,000 epinephrine) and with standard asepsis. No flap was raised. The soft tissue thickness was measured using a needle with a stopper before performing each modified MOP. A rubber stopper was used to standardize the depth of penetration of the mini-screw implant. Each perforation was 1.5 mm wide and 6 mm deep in the bone.

Three MOPs were created on the buccal surface of the alveolar process on the experimental side of the MOP1 group [Figure 2]. In the MOP2 group, three MOPs on the buccal surface and three MOPs on the palatal surface were created [Figure 3]. MOPs were done directly through the alveolar mucosa in the middle of the distance between the distal surface of the canine and the mesial surface of the second premolar at the extraction site, in the vertical direction and 3 mm apart. The first MOP was given 5 mm away from the free gingival margin. Concurrently, local anesthesia was applied on the control sides and extremely shallow insertions were made corresponding to those of the experimental sides, but only in the gingival tissue.

Bilateral canine retraction was achieved by using pre-calibrated 150 gm NiTi closed coil springs connected from a temporary anchorage device (1.5 × 8 mm) placed between the maxillary second premolar and the first molar and loaded immediately [Figure 4]. The participants were instructed to avoid the use of anti-inflammatory medication. At each visit, the force produced by the coil was checked and the appliances were monitored for any deformation or change in position due to chewing.

Measurement of rate tooth movement

All the measurements were performed on the dental casts. Alginate impressions were taken at the beginning of the study, immediately before canine retraction (T0), 28th day, and 56th day after the commencement of canine retraction (T1 and T2, respectively) to monitor the rate of tooth movement. The impressions were immediately poured up with type V dental stone. The casts were labeled with the patient›s name and stored. Vertical lines were drawn on the cast over the palatal surface of the lateral incisor and canine from the middle of the incisal edge to 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 [Figure 5]. All cast measurements were made using a digital vernier caliper with an accuracy of 0.01 mm.[1]

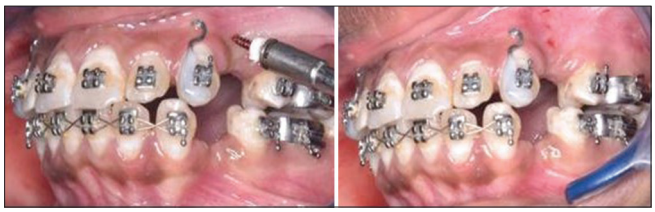

Figure 2: MOP procedure on the buccal side using mini-implant (MOP1)

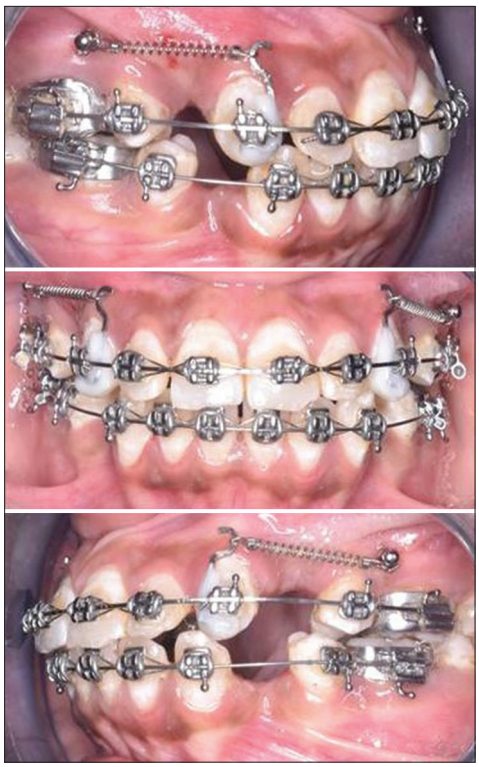

Figure 4: Closed coil NI-Ti spring stretched between the power arm and the mini-implant for canine retraction

All measurements were done by a single observer. For the evaluation of the intra-observer error, ten study models were randomly chosen and measured twice within a two-week interval. The intra-observer reliability was assessed using intra-class correlation coefficient (ICC).

Assessment of pain and discomfort levels

The participants were asked to assess their level of discomfort on the day of canine retraction, and subsequently at 1 hour, 24 hours, 72 hours, 7 days, and 28 days after canine retraction with a visual analogue scale. The patients were instructed to choose a number (from 0 to 10) that best describes their pain: 0 would mean "no pain" and 10 would mean "worst" possible pain.

Statistical analysis

Statistical Package for Social Sciences [SPSS] for Windows Version 22.0 Released 2013. Armonk, NY: IBM Corp., was used to perform statistical analyses.

Descriptive statistics

Descriptive analysis of all the explanatory and outcome parameters was done using frequency and proportions

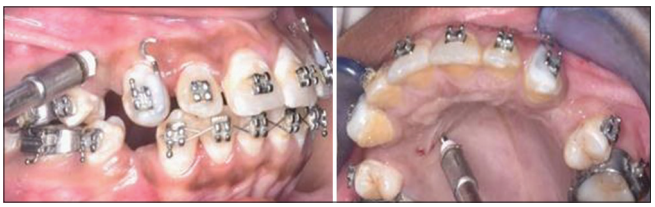

Figure 3: MOP procedure on the buccal and palatal side using mini-implant (MOP2)

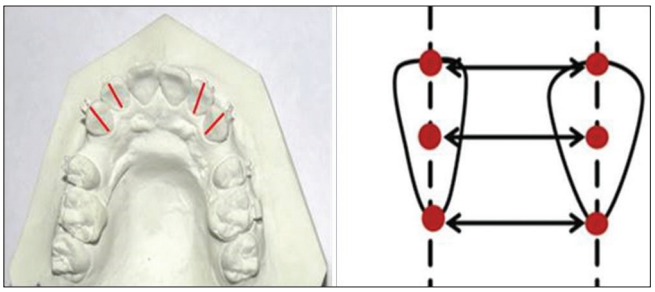

Figure 5: Canine retraction was measured on the casts by drawing lines on the midline of the lateral incisor and the canine at three points: incisal, middle, and cervical thirds of the crowns

for categorical variables, whereas mean and SD for continuous variables.

Inferential statistics

Independent Student's *t*-test was used to compare the mean rate of tooth movement and canine retraction in MOP1 and MOP2 between the experimental and control sides in various regions at different time intervals and also on the experimental side between MOP1 and MOP2 groups. Mann–Whitney test was used to compare the mean difference in the rate of tooth movement and canine retraction in MOP1 and MOP2 between the experimental and control sides in various regions at different time intervals and also on the experimental side between MOP1 and MOP2 groups. Similarly, the mean VAS scores for pain were also compared between two sides in MOP1 and MOP2 at different time intervals and between MOP1 and MOP2 on the experimental side. The level of significance was set at $P < 0.05$.

Results

Participant flow

Following the MOP procedure, one patient in the MOP1 group and one patient in the MOP2 group were excluded from the study due to either debonding of the power arm on the canine or irregular attendance.

Baseline data

A sample of 20 patients between the ages of 18–30 years was included in the study.

The error in the method

All measurements on the study models were done by a single examiner. To evaluate the intra-examiner reliability, ten study models were randomly chosen and measured twice within a 2-week interval. The intra-examiner reliability was assessed using the intraclass correlation coefficient (ICC). The result of the intra-examiner reliability using ICC was 0.97 ($P < 0.001$), indicating excellent repeatability and reliability of the measurements.

Primary outcome

Descriptive data (mean and SD) of the amount of canine retraction in various parts of the tooth are summarized in Table 1. The mean value of the canine movement was greater on the experimental side than on the control side. Comparison between the experimental and control side using an independent *t*-test showed a statistically significant difference in the rate of canine retraction in the middle and cervical place of both T1 and T2 time points for MOP1 and only in the incisal part of the tooth for T2 time point of MOP2 ($P \leq 0.05$) in Table 1.

Descriptive statistics of overall canine retraction (average of incisal, middle, and cervical parts) are summarized in Table 2. The mean value of canine retraction was greater on the experimental side than on the control side with a statistically significant difference noted in 28 and 56 days for MOP1 and 56 days for MOP2 ($P \leq 0.05$) in Table 2.

Comparison of the difference in the mean rate of canine retraction for the individual side at different times revealed a statistically significant difference for

Table 1: Comparison of mean rate of canine retraction at different time intervals at the incisal, middle, and cervical parts of the tooth in experimental and control side using independent *t*-test for MOP1 and MOP2

Group	Time interval	Region	Experimental		Control		Mean Diff	*P*
			Mean	SD	Mean	SD		
MOP 1	Day 1 (T0)	Incisal	8.091	0.551	8.182	1.383	-0.091	0.85
		Middle	7.599	0.501	7.693	0.797	-0.094	0.76
		Cervical	6.970	0.778	6.676	0.864	0.294	0.43
	Day 28 (T1)	Incisal	9.227	0.516	8.664	1.218	0.563	0.20
		Middle	8.624	0.517	7.952	0.747	0.672	0.03*
		Cervical	7.740	0.752	7.008	0.873	0.732	0.04*
	Day 56 (T2)	Incisal	9.918	0.710	9.213	1.170	0.705	0.12
		Middle	9.199	0.574	8.459	0.626	0.740	0.01*
		Cervical	8.319	0.671	7.385	0.763	0.934	0.009*
MOP2	Day 1 (T0)	Incisal	7.983	0.341	8.332	0.742	-0.349	0.19
		Middle	7.187	0.392	7.644	0.599	-0.457	0.07
		Cervical	6.300	0.483	6.527	0.759	-0.227	0.44
	Day 28 (T1)	Incisal	9.282	0.415	8.755	0.748	0.527	0.07
		Middle	8.149	0.433	8.027	0.752	0.122	0.66
		Cervical	7.103	0.365	6.849	0.807	0.254	0.38
	Day 56 (T2)	Incisal	9.964	0.402	9.225	0.728	0.739	0.01*
		Middle	8.717	0.436	8.319	0.836	0.398	0.20
		Cervical	7.647	0.439	7.171	0.977	0.476	0.18

**Statistically significant*

MOPs ($P \leq 0.05$) and control side ($P \leq 0.05$) between any two-time points except between P0 vs P1 in control side of MOP1 and MOP2 ($P > 0.05$) in Table 3.

The difference in the mean rate of tooth movement at different time intervals (T1-T0, T2-T1, and T2-T0) was greater on the experimental side as compared to the control side during the entire study period on all three parts of the tooth. A comparison of the difference in the mean rate of canine retraction between the experimental side and control side was done using Mann–Whitney U test. A statistically significant difference was seen in all parts of the tooth in T1-T0 and T2-T0 ($P \leq 0.05$) but only in the cervical part in T2-T1 in MOP1 and only the middle part in T2-T1 in MOP2 ($P \leq 0.05$) Table 4.

It was observed that there was a 2.5-fold increase in the first 28 days and a 2-fold increase in 56 days in the rate of tooth movement on the experimental side in MOP1 and a 2.15-fold increase in the first 28 days and a 2-fold increase in 56 days in the rate of tooth movement on the experimental side in MOP2 group. The difference in mean rate of canine retraction was statistically significant ($P \leq 0.05$) in 0-28 and 0-56 and non-significant ($P > 0.05$) between 28 and 56 days of the MOP1 and during the entire study period in MOP2 ($P \leq 0.05$) in Table 5.

Interestingly, there was no significant difference ($P > 0.05$) in the rate of canine retraction between the two groups during the entire study period as well as for all three parts of the teeth (incisal, middle, and cervical) in Tables 6 and 7.

Secondary outcome

Data analysis [Table 8] indicated that till 72 hours after the beginning of canine retraction both the control and experimental side reported higher levels of pain compared with the levels before retraction, this was statistically significant ($P \leq 0.05$). In all the study groups, pain significantly decreases after 72 hours. However, the comparison of mean VAS scores for pain between the experimental and control sides at different time intervals was not statistically significant ($P > 0.05$). The patient reported local discomfort at the site of the MOP procedure that was bearable, and no medication was needed [Table 9].

Discussion

The present study aimed to evaluate the effect of MOP on the rate of orthodontic tooth movement during canine retraction over 2 months. We also investigated whether an increase in the number of perforations could increase the rate of canine retraction. In addition, we evaluated the pain and discomfort of the patients during the treatment. A total of 20 patients participated and were randomly assigned to two equal groups.

To evaluate the effect of MOP on the rate of orthodontic tooth movement during canine retraction, we utilized the split-mouth study design. The main advantage of

Table 2: Comparison of mean rate of overall canine retraction of experimental and control side at different time intervals using independent Student's *t*-test for MOP1 and MOP2

Group	Time interval	Experimental		Control		Mean Diff	*P*
		Mean	SD	Mean	SD		
MOP1	Day 1 (T0)	7.550	0.515	7.515	0.859	0.035	0.91
	Day 28 (T1)	8.528	0.484	7.861	0.844	0.667	0.04*
	Day 56 (T2)	9.141	0.515	8.349	0.752	0.792	0.01*
MOP2	Day 1 (T0)	7.146	0.284	7.498	0.618	-0.352	0.12
	Day 28 (T1)	8.180	0.287	7.867	0.684	0.313	0.20
	Day 56 (T2)	8.773	0.284	8.241	0.767	0.532	0.04*

**Statistically significant*

Table 3: Comparison of mean difference in the rate of tooth movement at different time intervals on experimental and control side in various regions using Friedman's test followed by Wilcoxon signed rank *post hoc* test in MOP1 and MOP2

Group	Region	Side	T1-T0		T2-T1		T2-T0		*P*	WSR *Post hoc* Test		
			Mean	SD	Mean	SD	Mean	SD		P0 vs P1	P1 vs P2	P0 vs P2
MOP1	Incisal	Experimental	1.14	0.26	0.69	0.39	1.83	0.49	<0.001*	0.04*	0.005*	0.005*
		Control	0.48	0.35	0.55	0.30	1.03	0.61	<0.001*	0.29	0.005*	0.005*
	Middle	Experimental	1.03	0.25	0.58	0.34	1.60	0.33	<0.001*	0.04*	0.005*	0.005*
		Control	0.26	0.23	0.51	0.26	0.77	0.41	<0.001*	0.02*	0.005*	0.005*
	Cervical	Experimental	0.77	0.17	0.58	0.17	1.35	0.17	<0.001*	0.04*	0.005*	0.005*
		Control	0.33	0.30	0.38	0.26	0.71	0.44	<0.001*	0.58	0.005*	0.005*
MOP2	Incisal	Experimental	1.30	0.29	0.68	0.18	1.98	0.32	<0.001*	0.005*	0.005*	0.005*
		Control	0.42	0.34	0.47	0.33	0.89	0.19	0.001*	0.66	0.005*	0.005*
	Middle	Experimental	0.96	0.24	0.57	0.21	1.53	0.28	<0.001*	0.02*	0.005*	0.005*
		Control	0.38	0.25	0.29	0.19	0.68	0.28	0.001*	0.42	0.005*	0.005*
	Cervical	Experimental	0.80	0.25	0.54	0.24	1.35	0.36	<0.001*	0.04*	0.005*	0.005*
		Control	0.32	0.28	0.32	0.23	0.64	0.35	0.001*	1.00	0.005*	0.005*

** - Statistically Significant. Note: P0: T1 -T0, P1: T2 - T1 and amp; P2: T2 -T0. WSR - Wilcoxon Signed Rank Test*

Table 4: Comparison of difference in mean rate of tooth movement at different time intervals between experimental and control side at incisal, middle, and cervical part of tooth using Mann–Whitney test for MOP1 and MOP2

Group	Time interval	Region	Experimental		Control		Mean Diff	*P*
			Mean	SD	Mean	SD		
MOP1	T1-T0	Incisal	1.136	0.258	0.482	0.346	0.654	0.001*
		Middle	1.025	0.245	0.259	0.228	0.766	<0.001*
		Cervical	0.770	0.173	0.332	0.304	0.438	0.005*
	T2-T1	Incisal	0.691	0.392	0.549	0.303	0.142	0.60
		Middle	0.575	0.343	0.507	0.260	0.068	0.88
		Cervical	0.579	0.174	0.377	0.258	0.202	0.03*
	T2-T0	Incisal	1.827	0.487	1.031	0.613	0.796	0.009*
		Middle	1.600	0.331	0.766	0.410	0.834	<0.001*
		Cervical	1.349	0.167	0.709	0.439	0.640	0.004*
MOP2	T1-T0	Incisal	1.299	0.290	0.423	0.341	0.876	<0.001*
		Middle	0.962	0.235	0.383	0.250	0.579	<0.001*
		Cervical	0.803	0.254	0.322	0.281	0.481	0.004*
	T2-T1	Incisal	0.682	0.183	0.470	0.330	0.212	0.16
		Middle	0.568	0.208	0.292	0.194	0.276	0.01*
		Cervical	0.544	0.238	0.322	0.234	0.222	0.06
	T2-T0	Incisal	1.981	0.317	0.893	0.187	1.088	<0.001*
		Middle	1.530	0.278	0.675	0.284	0.855	<0.001*
		Cervical	1.347	0.364	0.644	0.345	0.703	0.001*

**Statistically significant*

Table 5: Comparison of difference in overall mean canine retraction between experimental and control side at different time intervals using independent Student's *t*-test for MOP1 and MOP2

Group	Time interval	Experimental		Control		Mean Diff	*P*
		Mean	SD	Mean	SD		
MOP1	T1-T0	0.978	0.087	0.346	0.214	0.632	<0.001*
	T2-T1	0.613	0.202	0.488	0.223	0.125	0.33
	T2-T0	1.591	0.223	0.834	0.378	0.757	<0.001*
MOP2	T1-T0	1.034	0.125	0.369	0.176	0.665	<0.001*
	T2-T1	0.593	0.100	0.374	0.155	0.219	0.002*
	T2-T0	1.627	0.132	0.743	0.193	0.884	<0.001*

**Statistically significant*

Table 6: Comparison of difference in the mean rate of tooth movement at different time intervals for experimental side between MOP1 and MOP2 at incisal, middle, and cervical points using Mann–Whitney test

Time interval	Region	MOP1		MOP2		Mean Diff	*P*
		Mean	SD	Mean	SD		
T1-T0	Incisal	1.136	0.258	1.299	0.290	-0.163	0.24
	Middle	1.025	0.245	0.962	0.235	0.063	0.65
	Cervical	0.770	0.173	0.803	0.254	-0.033	0.91
T2-T1	Incisal	0.691	0.392	0.682	0.183	0.009	0.65
	Middle	0.575	0.343	0.568	0.208	0.007	0.54
	Cervical	0.579	0.174	0.544	0.238	0.035	0.85
T2-T0	Incisal	1.827	0.487	1.981	0.317	-0.154	0.45
	Middle	1.600	0.331	1.530	0.278	0.070	0.60
	Cervical	1.349	0.167	1.347	0.364	0.002	1.00

**Statistically significant*

this design was that it reduced biological variables and therefore required a lower sample size.[14] Randomization and blinding were done to remove the risk of information bias and conflict of interest throughout the study.

Many factors could affect the rate of tooth movement and were considered during the study design. It has been shown that the forces of occlusion is one such confounding factor.[15] To rule out the effect of occlusion in this study, we selected patients with similar severities of malocclusion. Primary leveling and alignment was done to reduce occlusal interferences. Patients with crossbite or deviation during closure caused by occlusal interference were excluded. MOPs were randomly done to eliminate the possibility of uneven occlusal forces that may occur as a result of the unilateral chewing habit. Occlusal interferences during canine retraction were checked, but none was found that required occlusal adjustment.

Another major factor affecting the rate of tooth movement is the type of movement.[16] In this study, an attempt was made to achieve bodily movement, by sliding the canine on 0.019 × 0.025 SS wire using a power arm designed so that the force passes through the center of resistance. However, complete bodily movement was not achieved and an insignificant degree of tipping was involved in both study groups. A previous study argued that the tipping movement reported in MOP studies resulted in a false-positive increase in the rate of tooth movement.[17] We found no significant difference in the amount of tipping between the groups, and thus, it could not be responsible for the accelerated tooth movement.

The researchers argued that the maxillary lateral incisors could not be a reliable reference point due to their potential movement during canine retraction. We used these teeth as a reference since we believed ligation of the four incisors could prevent potential undesired movement. In addition, wire ligature was used to reduce the amount of friction during canine retraction in all subjects.

Another confounding variable is age. The rate of tooth movement is faster in younger patients.[18,19] This effect has been attributed to the rate of osteoclastic activity, recruitment, and bone density. To rule out this effect, adult patients between 18 and 30 years were considered in the study.

Gender can be another confounding factor. Animal studies showed sex hormones affected the rate of orthodontic tooth movement.[20,21] However, human studies have not shown any such significant difference between men and women.[18] Thus, in this study the number of male and female subjects was not taken into consideration.

Poor periodontal health, systemic diseases, and the use of certain medications can affect the rate of tooth movement significantly. Proper oral hygiene and exclusion criteria were taken into consideration to reduce the effect of these variables.

Table 7: Comparison of difference in the mean of overall canine retraction on experimental side between MOP1 and MOP2 at different time intervals using independent Student's *t*-test

Time interval	MOP1		MOP2		Mean Diff	*P*
	Mean	SD	Mean	SD		
T1-T0	0.978	0.087	1.034	0.125	-0.056	0.26
T2-T1	0.613	0.202	0.593	0.100	0.020	0.82
T2-T0	1.591	0.223	1.627	0.132	-0.036	0.94

**Statistically significant*

Malocclusion requiring bilateral extraction of upper first premolars with maximum anchorage was selected, to allow investigation of the long-term effect of RAP following the MOP procedure which usually lasts for 2–3 months on average.

Timing of tooth extractions can influence the rate of tooth movement by increasing the activity of inflammatory markers, which could give ambiguous results for the effect of micro-osteoperforations. Therefore, a three-month time interval between premolar extraction and canine retraction commencement was scheduled.[22]

The use of TADs with stoppers to perform the MOPs allowed standardization of the width and depth of the perforation. The mini-implant used was attached with a stopper to calibrate a depth of 6 mm. The average gingival and cortical bone thickness is 1.29–1.35 mm[23] and 1.12–1.22 mm[24], respectively. This perforation of 6 mm would go 3–3.5 mm in the medullary bone. Unlike shorter duration studies of 28 days, this study was conducted for 56 days to evaluate the effect of MOP. According to the histological observations of the sequential events in periosteal repair by Wilderman *et al.*,[23] it takes 3 months for the mature periosteum to be evident in the operated surgical areas.

Achieving the highest rate of tooth movement with minimal iatrogenic side effects is the common goal of orthodontists with a good understanding of "optimal" force magnitude.[25] A force of 150 g was employed in the present study, similar to the force applied by many other authors, ranging from 100 g to 200 g, for canine retraction.[25,26] Boester and Johnston[27] found that a retraction force of 150 g resulted in the highest canine retraction rate. Ren *et al*.[28] found no conclusive evidence regarding the optimal force level.

Yang *et al*.[29] showed that the maximum stress encountered during canine retraction was focused on its cervix at

Table 8: Comparison of mean VAS scores for pain at different time intervals in experimental and control sides using Friedman's test followed by Wilcoxon signed rank *post hoc* test in MOP1 and MOP2

MOP	Groups	Time	*n*	Mean	SD	*P*[a]	Sig. Diff	*P*[b]
MOP1	Experimental	1 hr.	10	3.10	1.60	<0.001*	1 h vs 24 h	0.004*
		24 hrs.	10	1.10	0.88		1 h vs 72 h	0.004*
		72 hrs.	10	0.00	0.00		24 vs 72 h	0.008*
	Control	1 hr.	10	2.00	1.94	<0.001*	1 h vs 24 h	0.06
		24 hrs.	10	0.80	0.92		1 h vs 72 h	0.02*
		72 hrs.	10	0.10	0.32		24 vs 72 h	0.02*
MOP2	Experimental	1 hr.	10	3.40	1.84	<0.001*	1 h vs 24 h	0.01*
		24 hrs.	10	1.60	1.17		1 h vs 72 h	0.005*
		72 hrs.	10	0.00	0.00		24 vs 72 h	0.007*
	Control	1 hr.	10	3.30	1.49	<0.001*	1 h vs 24 h	0.007*
		24 hrs.	10	0.80	0.92		1 h vs 72 h	0.005*
		72 hrs.	10	0.00	0.00		24 vs 72 h	0.04*

* - *Statistically Significant*. Note: [a]*P* value derived by Friedman's Test; [b]*P* value derived by Wilcoxon signed rank *post hoc* test

Table 9: Comparison of mean VAS scores for pain between experimental and control sides at different time intervals using Mann–Whitney test in MOP1 and MOP2

Groups	Time	Experimental		Control		Mean Diff	*P*
		Mean	SD	Mean	SD		
MOP1	1 hour	3.10	1.60	2.00	1.94	1.10	0.14
	24 hours	1.10	0.88	0.80	0.92	0.30	0.33
	72 hours	0.00	0.00	0.10	0.32	-0.10	0.32
	7 Days	0.00	0.00	0.00	0.00	0.00	.
	28 Days	0.00	0.00	0.00	0.00	0.00	.
MOP2	1 hour	3.40	1.84	3.30	1.49	0.10	0.75
	24 hours	1.60	1.17	0.80	0.92	0.80	0.12
	72 hours	0.00	0.00	0.00	0.00	0.00	.
	7 Days	0.00	0.00	0.00	0.00	0.00	.

the distolabial side and added that distal corticotomy had similar biomechanical effects as a continuous circumscribing cut around the canine root. Based on their assumptions, the MOPs were only performed distal to the canine and vertically distributed along the cervical two-thirds of the canine root length.

In line with the previous studies, our results showed a significant increase in the mean rate of canine retraction compared to the contralateral side in both groups at the T1 and T2 interval. Our results align with the results of Alikhani *et al*.[1] and Sivarajan *et al*.[30] who advocated that MOPs increased the rate of canine retraction compared to the control group. However, another split-mouth clinical trial study found no significant effect of MOP on the rate of tooth movement over 3 months.[17] The latter study uses indirect measurements performed in digital models. Moreover, different reference points were used to measure the amount of canine movement.

Nevertheless, the difference in canine retraction rate fluctuation with time on both sides was interesting in the present study. Where the MOP side showed a more steady rate of OTM than the control side along the observation period. Movement of the canine in the control side typically showed alternating series of increased and decreased retraction rates corresponding to tipping and uprighting of the canine.

Reitan[31] emphasized that during canine retraction, the tooth acted as a two-armed lever, with the applied force concentrated at the alveolar crest, where the areas of hyalinization are concentrated. MOPs performed distal to the cervical two-thirds of the canine root have probably decreased the resistance offered by the alveolar crest allowing greater root movement. However, the canine cusp tips moved a greater distance than the apices on both sides, indicating that canine retraction was mostly due to controlled tipping movement.

Our study result showed a statistically significant difference in the rate of canine movement both on the experimental side and the control side, amounting to a 2.5-fold increase in the MOP side during the first 28 days (T0-T1) and a 2-fold increase in 56 days (T0-T2). Our finding was similar to animal studies by, Teixeira *et al*.[32] He reported that 28 days after three MOPs, the rate of tooth movement increased 2.13 times in experimental rats. Baloul *et al*.[33] mentioned that after 10 MOPs via flap elevation in rats, tooth movement was 1.3 times faster on day 42. Cho *et al*.[34] also demonstrated an increased rate of movement in their experimental group.

In 2015, Patterson *et al*.[35] published a systematic review and concluded that corticotomy could increase the rate of tooth movement during orthodontic treatment. Tsai *et al*.[36] showed that the rate of tooth movement after corticision in the buccal cortex was increased by 1.54 times after 3 weeks and 1.11 times after 6 weeks. They found that the rate of tooth movement in their study was lower than in previous studies, such as Teixeira *et al*.,[32] Baloul *et al*.[33], and also Cho *et al*.[34] They concluded that the amount of RAP is directly related to the magnitude of the corticotomy, which means that the more severe corticotomy, the higher the rate of tooth movement.[36]

There was a significant increase in the rate of canine retraction in the MOP2 group compared to the MOP1 group at all time intervals. This finding may be credited to the greater surgical trauma that stimulated a higher expression of inflammatory markers and osteoclast activity, which in turn increased the rate of tooth movement.[7,37,38] Interestingly, there was no significant difference between the experimental side and the contralateral control group at the T1-T2 time interval in the MOP1 group. This could be explained by the transient nature of RAP which weakened over time.[7,39]

Alikhani *et al*.[1] by using three MOPs in the buccal cortex of extracted human first premolars for canine retraction reported that in their experimental group, the rate of tooth movement was 2.3 times higher than in the control group. Our study alone showed a 2.5 times increase in tooth movement after MOPs during the first 28 days.

The study of Alikhani *et al*.[1] and our study confirms the conclusion of Tsai *et al*.[36] which means that by using three buccal MOPs (MOP1) without elevating a flap, the rate of tooth movement is lower than using three buccal and three palatal MOPs (MOP2). However, because the difference is non-significant it seems that using just three MOPs provides favorable acceleration in tooth movement.

In our study, the rate of canine movement was 2-fold more on the experimental side than the control side after

56 days (T0-T2). But this difference was not observed during the 28 to 56 days interval (T1-T2) of the study. The peak movement of the canine on the experimental side was reduced to a similar rate as that of the control side by 28–56 days.

The trend is an effect of regional acceleratory phenomenon (RAP) that begins within a few days of surgery and typically peaks at 1–2 months reported by Yaffe *et al*.[40] It sequentially facilitates tooth movement by amplifying the naturally coupled bone remodeling machinery activated by the orthodontic forces. Micro-osteoperforation attributed to the flapless controlled micro trauma of osseous tissue results in fine-tuning of the expression of inflammatory cytokines and chemokines by eliciting the RAP[1]

One of the unanswered questions about MOP is the frequency of application. Based on the results of the present study, it is wise to use it after every 56 days.

The effect of repeated MOPs on the rate of tooth movement has been reported by various authors with different results. The clinical trial by Attri *et al*.[41] evaluated the effect of repeated MOP (distal to canine) every 28 days on en masse retraction that showed a significant increase in tooth movement, although the effect of RAP on incisors is debatable. In contradiction to this study, Haliloglu-Ozkan *et al*.[42] showed that repeating the procedure monthly does not appear to show a major advance in tooth movement. A similar clinical trial by Sivarajan *et al*.[30] concluded that increased canine retraction achieved using MOP over 16 weeks is unlikely to be clinically significant based on the above finding.

Our results were in line with the study conducted by Babanouri *et al*.[43] which was conducted over a 3-month period. A significant increase in the rate of tooth movement was observed in their study for both MOP1 and MOP2 groups for the experimental side at all time intervals except the third month (T3) owing to the decrease of the activity of inflammatory markers with time. They also reported a significant increase in the rate of tooth movement in the MOP2 compared to MOP1.

The results of the present study, as well as other studies,[43,44] clearly indicate that MOPs accelerate the orthodontic tooth movement until four to six weeks after induction of trauma. The reason behind the accelerating effect of MOPs might be that microtrauma induces alveolar bone inflammation, which leads to an increase in cellular activity, thereby increasing the bone turnover rate, causing a decrease in bone density, thus increasing orthodontic tooth movement. Thereafter, as the healing process progresses, bone remodeling returns to its initial pace, and there is regaining of the bone density to the pre-MOPs level.

Pain and discomfort are typical antagonistic impacts related to orthodontic treatment.[45] Past examinations have demonstrated that 70% to 95% of orthodontic patients experience pain.[46,47] This pain could be an explanation behind the attrition of subjects seeking orthodontic treatment; past investigations have demonstrated that 8% and even up to 30% of orthodontic patients discontinue treatment as a result of pain and discomfort.[45]

According to our study findings, the pain level was higher in the MOP group in the first 24 to 72 hours after the procedure; however, it was not statistically significant. The patient reported mild discomfort locally at the site of MOPs for the first 24 hours after the intervention which gradually faded away.

The finding of the present study was following the earlier studies. Three studies with PROPEL system (Alikhani *et al*.,[1] Attri *et al*.,[41] Puetter *et al*.[48]) and three with mini-screw (Alkebsi *et al*.,[17] Babanouri *et al*.[43] and Alqadasi *et al*.[49]) also found the difference between pain reported by the patient in the control and experimental group.

Since the retraction force was applied immediately after the MOP procedure, probably, the patient could not differentiate between orthodontic pain and the pain caused by MOP. In addition, gingival insertions on the contralateral side were given for blinding purposes and the results for VAS pain scores between the two sides are questionable.

Micro-osteoperforations are a comfortable, safe, and effective procedure for accelerating tooth movement and could result in shorter orthodontic treatments. Although RAP can be induced in patients, if retraction is initiated immediately after canine extraction, the role of MOP comes into play for adult patients whose extraction has been done long before the initiation of retraction. It can also be considered in edentulous patients with poor bone quality, where space closure is a treatment option that can be adopted in routine clinical practice with no distress to the patient.

Conclusion

Micro-osteoperforation increases the rate of canine retraction by 2-folds at the end of 56 days and could be effective in our daily orthodontic practice for decreasing treatment time. Although the increase in the number of perforations increases the rate of tooth movement since it is not statistically significant, only three MOPs

would be enough for efficient results. The patient reported only mild pain and discomfort locally at the site of MOPs. Little to no pain was experienced after 72 hours. Micro-osteoperforation is a simple, comfortable, minimally invasive, and effective procedure to accelerate tooth movement and reduce the treatment period.

Limitation

The current study did not evaluate the effect of different sites and repetition of MOP on the rate, type of tooth movement effect on overall treatment duration, periodontal status, and root resorption. Also, the assessment of inflammatory markers, the degree of rotation of teeth, and its effect on orthodontic tooth movement were not accessed in the current study.

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Conflicts of interest

There are no conflicts of interest.

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