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Research Article

Canine Distraction: A Three-Dimensional Evaluation

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Abstract

Background: In orthodontics, tooth crowding and space problems are common, with many patients requiring premolar extraction. Canine distalization is crucial, but traditional methods offer limited tooth movement and anchorage loss. The present study aimed to evaluate the biomechanics of rapid canine distalization in a dental distraction (DD) technique using a readymade distraction device.

Materials and Methods: Seven adult female patients who required the extraction of their bilateral maxillary first premolars as part of their orthodontic treatment plan participated in the study. Distalization of 14 maxillary canines was accomplished using the readymade distraction device, 'PiTractor', once the distraction undermining surgical procedure was completed. Cone-beam computed tomography (CBCT) images were taken before distraction and after a consolidation period to evaluate the three-dimensional (3D) positional changes of the maxillary canines and first molars.

Results: The maxillary canines were distalized by an average of 5.2 mm after 12–19 days, with a significant (mean [SD]) distal tipping (9 [3.8])°, buccal rolling (4.8 [2.4])° and distal rotation (7.3 [5.6])°. However, the maxillary first molars showed insignificant positional changes of (0.5 [0.4]) mm and (0.2 [0.3]) mm for horizontal and vertical anchorage loss, respectively.

Conclusions: The 'PiTractor' distraction device successfully achieved rapid canine distalization with minimal posterior anchorage loss. However, significant combined distal tipping, buccal rolling and distal rotation of the distracted canines were detected.

Keywords: 3D Imaging; Canine Distalization; Cone Beam Computed Tomography; Dental Distraction

Introduction

Crowding of teeth and subsequent space shortage are common orthodontic problems, with many patients requiring tooth extraction, primarily of premolars, despite a long-standing debate over treatment modalities [1-4]. Canine distalization is an essential phase of treatment, but conventional orthodontic techniques can only achieve limited biological tooth movement [5,6]. It can be difficult for orthodontics to regulate the anchoring throughout the canine retraction phase, which frequently lasts 6-8 months [5,6]. Rapid canine distraction, introduced by Liou and Huang in 1998, aims to minimise orthodontic treatment time and control anchorage loss [7]. A technique named 'Dental Distraction' (DD) was devised to stretch the periodontal ligament to enable rapid canine movement in patients requiring first premolar extraction and has been validated for external root resorption, pain, canine vitality and anchorage loss [7-10].

Evidence suggests that canines experience an average inclination of 15° to 20° during distalization, but specific evaluations of three-dimensional (3D) positional changes are absent [7-9]. Maxillofacial structures and landmarks can be measured with precision using cone-beam computed tomography (CBCT) images, which provides accurate linear and angular dimensions [11-15]. Earlier distraction devices were modifications of the original Hyrax expansion device with common limitations [7,8,10]. These were custom-made, bulky, uncomfortable to patients, required extensive laboratory work, had a difficult mode of activation and could not be used simultaneously with fixed appliances [7,8]. Focusing on the biomechanics of canine movement is an important part of the DD learning curve. This study aimed to achieve rapid canine distalization using a readymade distraction device, the 'PiTractor', and to evaluate the 3D biomechanics of the attained maxillary canine movement.

Materials and Methods

Seven adult females aged between 19-24 years were recruited in this study from the outpatient clinic at the Department of Orthodontics, Faculty of Oral and Dental Medicine, Cairo University. Patients were included if they had moderate-to-severe crowding and/or dentoalveolar protrusion, a fully erupted canine well-aligned within the alveolar trough and were scheduled for orthodontic treatment with a treatment plan of bilateral maxillary first premolar extraction.

Before the DD procedure, patients and their parents were fully informed about the treatment plan, which included surgery and other conventional options. Each patient provided informed consent, and the Research Ethics Committee of Cairo University approved the study.

Distraction device adaptation

The canine distraction device used in this study was the ready-made 'PiTractor', a tooth-borne, semi-rigid device made of stainless steel with one-threaded screw and two guidance attachments that incorporate 0.022×0.028-inch rectangular tubes and a screw retaining clip (Figure 1). To begin the distraction procedure, the canines and first molars were banded, and an impression was made with the bands in place. Next, the distractor was attached to the buccal surface of the canines and the first molar bands were affixed to the dental casts. The orientation of the distractor was carefully selected to ensure that the distraction force was parallel to both the occlusal plane and alveolar trough, as viewed from occlusal aspect. These steps were crucial to effectively carry out the distraction procedure (Figure 1).

Surgical procedure

The surgical procedure was performed as described by Liou and Huang [7]. Immediately after extraction of the maxillary first premolars, surgical preparation of the extraction socket began according to the following steps:

- The first premolar socket was deepened to match the maxillary canine root length as estimated from the CBCT images. This was done with a surgical round bone bur (No. 4) in a slow-speed straight handpiece under copious irrigation.
- The reduction of the interseptal bone distal to the canine was performed to reduce the overall thickness to 1-1.5 mm. This step commenced by estimating the thickness of the interseptal bone distal to the canine from the CBCT image. A cylindrical bur held parallel to the long axis of the canine and moved buccopalatally while shaving the interseptal bone. Ten buccopalatal (back and forth) shaving movements were used to reduce the thickness of the interseptal bone by approximately 1 mm (Figure 2).
- Vertical grooves on both the mesiobuccal and mesiopalatal line angles of extraction socket were made using a 1mm fissure carbide bur, addressing undermined margins of the interseptal bone distal to the canine (Figure 3). Although the surgical procedure was performed in the extraction socket, no mucoperiosteal flaps or osteotomies were required on the buccal or palatal alveolar plate of the canine. At the end of surgical preparation, a periapical radiograph with a parallel technique was taken to ensure a full-length uniform reduction of the interseptal bone.

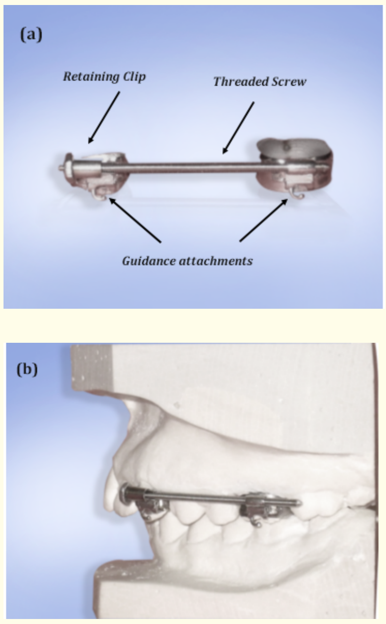

Figure 1: PiTractor' distraction device. (a) Buccal view, (b) Device on the cast.

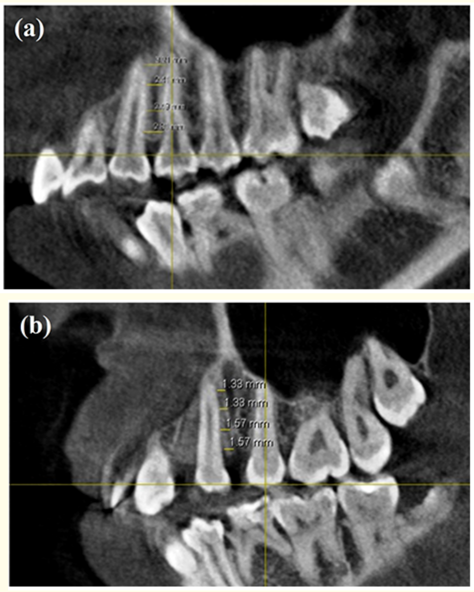

Figure 2: Sagittal multiplanar view showing the width of the interseptal bone distal to maxillary canine. (a) Before, (b) After surgical preparation.

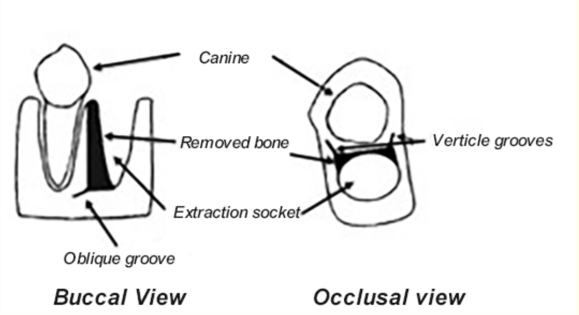

Figure 3: Diagrammatic presentation of the surgical technique for undermining the interseptal bone distal to canine.

Distraction protocol

After the surgical preparation of the extraction socket of each canine was completed, the distraction device was fitted and cemented in place with glass ionomer cement. A continuous 0.016×0.022-inch stainless steel archwire was inserted, connecting the devices on both sides and bypassing the anterior teeth. The patients were instructed to activate the device once every 12 hours for a total activation of approximately 0.72 mm/day. Patients were then monitored at three-day intervals for their compliance with the distractor activation protocol and oral hygiene instructions. The distraction phase ended when the canines were sufficiently distalized according to the proposed treatment plan. After the distraction procedure, the distraction devices were left *in situ* for a consolidation period of another 6 weeks. Then, the distraction devices were removed, and the post-DD CBCT was obtained. After canine distraction, all patients had full-fixed appliances on their upper and lower arches, and all cases were completed and retained.

Cone-beam computed tomography measurements

The CBCT imaging was performed in all patients before DD (pre-DD) and after the consolidation period (post-DD). The CBCT images of the patients were taken with a GALILEOS CBCT scanner (Sirona Dental Systems, Bensheim, Germany). The MIMICS image processing software (Materialise Group,Leven, Belgium) was used to create a comprehensive 3D volumetric image complete with multiplanar projections in the sagittal, coronal, and axial planes. Fourteen landmarks were identified, using which four lines and planes were projected onto each CBCT image, and different measurements were conducted to evaluate the 3D tooth movement (Table 1; Figure 4, and Figure 5) [16,17]. All teeth movements were measured to the nearest 0.1 mm and degree. Furthermore, superimposition of the pre-DD and post-DD CBCT images was done to depict the amount of positional change in the maxillary canine and first molar, and for standardisation purposes, the palatal plane was used (Figure 6). Data representing the periodontal tissue integrity and root resorption of the patients of this study were presented in a previously published study [18].

ANS	Anterior nasal spine
Or	Orbitale
PNS	Posterior nasal spine
PMP	Posterior maxillary point
Ptm	Pterygomaxillary
SPH	Sphenoid-ethmoidal
U3IP	Maxillary canine incisal point
U3RP	Maxillary canine root point
U3MP	Maxillary canine mesial contact point
U3DP	Maxillary canine distal contact point
U6FP	Maxillary first molar furcation point
U6MbCP	Maxillary first molar mesiobuccal cusp point
U6MbRP	Maxillary first molar mesiobuccal root point
U6DbCP	Maxillary first molar distobuccal cusp point

1.1: Three-dimensional cephalometric reference landmarks.

Maxillary plane (MxP)	Established by ANS, PMPr and PMPl points
Frontal plane (FP)	Established by SPH, Ptmr and Ptml points
Maxillary line (MxS)	Formed by connecting ANS and PNS
Frontal line (FL)	Formed by connecting Orr and Orl

1.2: Three-dimensional cephalometric reference lines and planes.

U3 AP	The perpendicular distance from (U3IPr or U3IPl) to the FP
U6 AP	The perpendicular distance from (U6MbCPr or U6MbCPl) to the FP
U6 VP	The perpendicular distance from (U6FPr or U6FPl) to the MxP
U3 MD	The anterior angle between the maxillary canine long axis (U3IP and U3RP) and the MxS
U6 MD	The anterior angle between the maxillary first molar long axis (U6MbCP and U6MbRP) and the MxS
U3 BL	The external angle between the maxillary canine long axis (U3IP and U3RP) and the FL
U6 BL	The external angle between the maxillary first molar long axis (U6MbCP and U6MbRP) and the FL
U3 ROT	The internal angle between the line connecting the U3MP and U3DP and the MxS
U6 ROT	The internal angle between the line connecting the U6MbCP and U6DbCP and the MxS

1.3: Three-dimensional cephalometric measurements.

Table 1: Three-dimensional cephalometric landmarks, lines, planes and measurements.

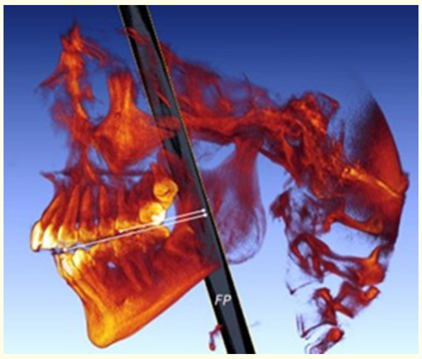

Figure 4: CBCT volumetric image showing the maxillary canine and first molar anteroposterior position measurements about the frontal plane.

Figure 5: CBCT volumetric image showing the maxillary first molar vertical position measurement about the maxillary plane.

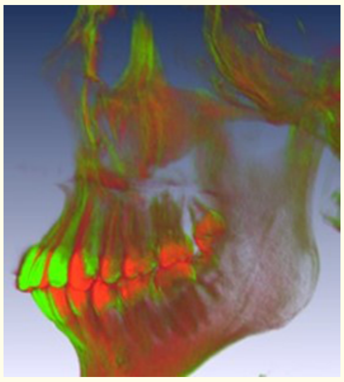

Figure 6: Superimposition of the pre-DD (green) and post-DD (red) CBCT volumetric images at the palatal plane.

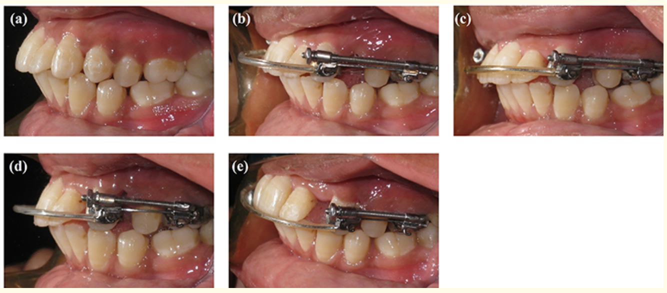

Figure 7: Intra-oral photographs showing the sequence of canine distraction. (a) Before canine DD, (b) Day 2 of canine DD, (c) Day 6 of canine DD, (d) Day 10 of canine DD, (e) Day 16 of canine DD.

Statistical analysis

To analyse the data, IBM's Statistical Package for Scientific Studies (SPSS) version 16.0 for Windows was used. Statistical analysis was conducted using this software package. Descriptive statistics and the significance of differences for the treatment changes were computed using the paired t-test. Seven randomly selected canines were re-measured at 2-week intervals to assess intra- and inter-observer reliability using Cronbach's alpha test.

Results and Discussion

Results

The DD principle was followed to distalize the 14 maxillary canines into the extracted first premolar sockets. The entire process took an average of 14.5 [1.9] days (ranging from 12-19 days) with a rate of 0.36 mm/day (Figure 7). During canine distalization, the maxillary first molars were able to withstand resistance to retraction forces, with minimal horizontal (0.5 [0.4] mm) and vertical (0.2 [0.3] mm) anchorage loss. The distraction procedure was well-tolerated by the patients and no one reported swelling or severe pain. Some patients experienced minimal discomfort following the surgery that improved spontaneously without the need for analgesics.

For the maxillary canines, the results of the pre-DD and post-DD CBCT image analysis revealed a mean (SD) difference in distal crown tipping (U3 MD) of 9 (3.8)°, a buccal rolling (U3 BL) of 4.8 (2.4)° and a distal rotation (U3 ROT) of 7.3 (5.6)°, all of which were statistically significant ($P < 0.001$). For the maxillary first molars, the results revealed a mean (SD) difference in mesial crown tipping (U6 MD) of 0.1 (0.6)°, a buccal rolling (U6 BL) of 0.1 (0.3)° and a mesial rotation (U6 ROT) of 0.2 (0.5)°. Statistically, these results were found to be insignificant ($p > 0.05$). Cronbach's alpha ranged from 0.930 to 0.986 and from 0.885 to 0.944, indicating very good intra- and inter-observer reliability, respectively (Table 2, Figure 5). No external root resorption was evident in the post-DD CBCT images except in one patient, showing moderate root resorption, suggesting that it might be related to other individual predisposing factors rather than the distraction procedure itself. No signs of ankylosis were noticed during the subsequent root uprighting procedure throughout the course of treatment.

Discussion

Although extraction of teeth for orthodontic purposes is sometimes necessary for teeth alignment, the prolonged duration of treatment and the need for extra-oral anchorage provoke patient complaints. The ability to deliver proper treatment for a short du-

Measurements (mm)	Pre-DD		Post-DD		Difference		p-value
	Mean	SD	Mean	SD	Mean	SD	
U3 AP	54.3	4.1	49.1	4.2	5.2	0.6	<0.001*
U3 MD	75	4.6	84	6	9	3.8	<0.001*
U3 BL	83.1	4.4	78.3	5.3	4.8	2.4	<0.001*
U3 ROT	24	11.3	16.7	8.2	7.3	5.6	<0.001*
U6 AP	34.4	3.9	34.9	4	0.5	0.4	NS
U6 VP	12.8	3.8	13	3.9	0.2	0.3	NS
U6 MD	85	5.1	84.9	4.8	0.1	0.6	NS
U6 BL	86.6	2.6	86.5	2.6	0.1	0.3	NS
U6 ROT	18.3	3.1	18.5	3.4	0.2	0.5	NS

Table 2: Descriptive data of the CBCT measurements taken (means, standard deviations and the paired t-test).

*Highly significant ($p \leq 0.001$) NS = $p > 0.05$

AP: Antero-Posterior Position; BL: Buccolingual Inclination; MD: Mesiodistal Angulation; ROT: Rotation; SD: Standard Deviation; VP: Vertical Position

ration is greatly appreciated by patients, particularly adults. Hence, the present study utilised the periodontal ligament distraction technique to rapidly distalize bilateral maxillary canines in seven adult female patients who needed their canines to be fully erupted and well-aligned in the alveolar trough.

In this study, CBCT imaging was used to overcome the limitations of the traditional 2D cephalometric and panoramic projections in the assessment of the mesiodistal and buccolingual tooth angulations, particularly in the premolar and canine regions [19,20]. The GALILEOS scanner was chosen since it is reported to have the lowest radiation dose among the currently available CBCT units [21]. Different well-established skeletal and dental landmarks have been used to set up reference lines and planes [22-24]. In addition, several linear and angular measurements were conducted to evaluate 3D tooth movement using third-party computer software (MIMICS, Materialise Group, Leuven, Belgium).

The present study demonstrated that it was possible to rapidly distalize the maxillary canines at a mean rate of 0.36 mm/day and to achieve a total mean distalization of 5.2 mm over 12-19 days. Previous studies have also shown distalized maxillary canines up to 6.5 mm and mandibular canines up to 6.6 mm over 3 weeks, [7] retracted maxillary canines by 5.3 mm over a mean period of 17.5 days at a rate of 0.3 mm per day, [8] and achieved a canine retraction of 5.75 mm in 3 weeks [9]. Ideally, canine distraction involves the rapid distalization of canines through the extraction socket while the posterior teeth are either still in their lag period or just initiating their mesial movement. According to recent reports, the first molars exhibited minimal movement in almost 73% of cases, with only 27% showing slight movement of less than 0.5 mm [7-9]. The horizontal anchorage loss ranged from 0 to 0.7 mm, with a mean of 0.26 mm, while the mean horizontal and vertical anchorage losses were 0.56 mm and 0.64 mm, respectively [7-9]. However, the findings of current study indicate that first molar movement was minimal, and there was negligible horizontal and vertical anchorage loss.

In the present study, the 3D analysis of the maxillary canine and first molar movement was presented as the changes occurred in the mesiodistal angulation (Tip), buccolingual inclination (Torque) and rotation. For the maxillary canine, the CBCT image analysis revealed significant mean changes in the distal crown tipping, buccal rolling and distal rotation pre- and post-DD. Similar findings were reported earlier, where a mean distal canine tipping ranging from 9.1 to 13.15° was recorded [9,25,26]. The main reason for the potential tipping movement of the canine could be attributed to the bending or fracture of the interseptal bone adjacent to the apex of the canine, which alters the biomechanical configuration of the force distribution system inside the socket by moving the centre of resistance of the canine closer to the apex [7,27,28]. However, our findings indicate that the crown moves more than its root apex, generating less trauma to the pulpal blood vessels and nerve fibres, which is advantageous for pulp vitality.

The insecure connection between the threaded screw and the screw retaining clip of the canine part of the distraction device, which led to a considerable amount of play between the screw and the canine guidance attachment, could be the major contributor to the significant rotation observed in the present study. Correcting the rotation after canine retraction is not a time-consuming process and does not require excessive anchorage demands [29]. The technique used for the maxillary first molars effectively conserved anchorage post-DD as demonstrated by the minimal mean changes in mesial crown tipping, buccal rolling, and mesial rotation. The technique used for the maxillary first molars effectively conserved anchorage post-DD as demonstrated by the minimal mean changes in mesial crown tipping, buccal rolling, and mesial rotation.

As per reports, an ideal canine distraction device should have the following characteristics: controlled force magnitude and vector; ease of fabrication, insertion and activation; an adequate range of action; reasonable cost; not affected by rigorous oral environments; and comfortable to the patient [8]. A study conducted in 2004 found that canine distractors currently on the market were bulky, unidirectional, and not readily available. The study recommended the need for refinement, development, and orientation with fixed appliances in the future [9]. The distraction device used in the present study was a semi-rigid, readymade orthodontic distractor, 'PiTractor'. It successfully achieved rapid canine destabilisation with minimal anchorage loss. No cases of device fracture or failure were observed during the distraction and consolidation phases. In addition, the device was well-tolerated by the patients and there were no complaints of any difficulty in activating the device. To achieve greater success in surgical procedures, it is essential to explore advanced techniques like piezo-surgery and examine their effectiveness in teeth situated near the mandibular dental nerve. Additionally, progress in biomechanical principles and distraction devices is crucial to ensure optimal 3D control of rapid tooth movement. Future studies are necessary to focus on refining surgical techniques and developing innovative solutions to enhance surgical outcomes.

Conclusion

The DD technique may be considered a clinically efficient method for achieving rapid canine distalization with minimal posterior anchorage loss. The 'PiTractor' distraction device successfully achieved rapid canine distalization and has the following advantages: well-tolerated by patients, requires no laboratory work and can be used simultaneously with fixed appliances. The distracted maxillary canines showed statistically significant distal tipping, buccal rolling and distal rotation, whereas the maxillary first molars demonstrated insignificant positional changes.

Conflict of Interest

The authors report no conflict of interest.

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