TURKISH JOURNAL OF
ORTHODONTICS

DOI: 10.4274/TurkJOrthod.2023.2022.172

Original Article

# Effect of Aligning Forces by Two Preadjusted Edgewise Techniques on a Buccally Positioned Maxillary Canine at Varying Vertical Displacements: A Finite Element Study

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**Cite this article as:** Mathew S, Batra P, Arora N, Kumar Singh A, Kannan S, Talwar A. Effect of Aligning Forces by Two Preadjusted Edgewise Techniques on a Buccally Positioned Maxillary Canine at Varying Vertical Displacements: A Finite Element Study. *Turk J Orthod.* 2024; 37(2): 122-129

**Main Points**

- The most optimal displacement for engaging a vertically displaced canine in continuous mechanics is up to 4 mm from the occlusal plane.
- The piggyback method is more efficient with less counter effects on adjacent teeth compared to the continuous archwire.
- Maximum occlusal movement was observed at a 2 mm vertical displacement, which decreased progressively as the vertical displacement increased.

## ABSTRACT

**Objective:** To evaluate the effect of continuous arch and piggyback mechanics in a straight wire appliance (SWA) for the alignment of buccal and variably vertically positioned maxillary canines.

**Methods:** A three-dimensional finite element model with near-normal occlusion and buccal and vertically displaced maxillary canines was used. Two groups were created to simulate two commonly used SWAs techniques, continuous archwire (Group 1) and piggyback models (Group 2). Each group had three subgroups with varying vertical displacement of the canine from 2 to 6 mm from the occlusal plane. The displacement and stress distribution were noted in each group.

**Results:** As the vertical displacement increased in Group 1, the concentration of von Mises stress increased progressively at the incisal third (0.36, 0.41 and 0.44 MPa) at 2, 4, and 6 mm, respectively, with decreased maximum occlusal movement in the vertical plane with respect to the canine. Group 2 exhibited a similar pattern but greater occlusal movement of the canine compared with Group 1.

**Conclusion:** A vertical displacement of 4 mm is the optimal level at which continuous arch mechanics should be considered. For displacements beyond 4 mm, the piggyback wire technique is a suitable alternative.

**Keywords:** Biomechanics, canine impaction, evidence-based practice, finite element analysis (FEM), force

## INTRODUCTION

Ectopic, or vertically displaced teeth are one of the most commonly encountered orthodontic problems. This vertical displacement can occur in both anterior and posterior teeth; the most commonly occurring vertical displacement is in the permanent maxillary canine, with 1-2% prevalence in the general population.[1,2] The

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**Received:** November 29, 2022 **Accepted:** April 27, 2023 **Publication Date:** June 30, 2024

prevalence rate of ectopic eruptions in the Indian population was reported to be 5.5%.[3] Orthodontic tooth movement is a biological reaction of periodontal tissue to orthodontic force. The force applied to the teeth must be precisely controlled to generate the desired outcome.[4] A multibracket appliance with a continuous archwire produces a complex force system that is statically indeterminate.[5] The use of the continuous archwire technique for highly displaced canines may cause harmful or unwanted movement in the adjacent reactionary units. The adjacent teeth may intrude, they may tip, an occlusal cant may develop, there may be a lateral open bite, and the patient's arch form may distort due to these detrimental effects.[6,7] The piggyback technique, or a nickel titanium (NiTi) overlay serves as an alternative to the continuous archwire method. The piggyback technique utilizes a rigid base archwire, which is usually a high-tensile stainless steel wire, and NiTi overlay wire.[6] Orthodontic research can use finite element analysis (FEA) as a powerful tool to overcome clinical limitations in *in vivo* studies and investigate the displacement pattern and stress distribution. It is particularly suited to analyzing the complex force system produced by multibrackets and continuous archwire systems.[7-10] There are lacunae in the existing literature comparing the efficiency of the two methods and the optimal level of displacement of the vertically positioned canine when continuous arch mechanics should be considered efficient treatment mechanics. Therefore, the purpose of the present study was to compare the biomechanical characteristics of two different clinical techniques for correcting a vertically displaced canine, as well as to evaluate the displacement and stress pattern generated at different levels of vertical displacement.

## METHODS

The finite element model (FEM) was constructed using cone-beam computed tomography (CBCT) (digital imaging and communications in medicine) images of a 25-year-old patient with a near-normal occlusion with a vertically displaced maxillary canine from the archives of the Oral Medicine and Radiology Department, Manav Rachna Dental College, and exported to create a three-dimensional FEA model of the maxillary arch. CBCT details: 90 kVp, 12 mA, exposure time of 29 s, slice thickness of 0.3 mm, and FOV of 16x8 cm. Manav Rachna Dental College institutional ethical approval (ref. no.: MRDC/IEC/2019/525, date: December 26, 2019) was obtained before starting the study.

### Construction of the Model and Preprocessing

Volumetric data from the CBCT files was used to create a virtual model consisting of the maxillary bone and teeth. The boundaries of the maxilla were differentiated in each CBCT slice, and the geometries of the cortical and cancellous bone were segmented from the scan using image processing software (MIMICS, Version 21.0, Materialize, Leuven, Belgium). Further segmentation of each tooth was performed individually. The periodontal ligament (PDL) was modeled as uniformly thick at 0.25 mm around the teeth, with a cortical bone thickness of 1 mm around the alveolar process, and the remaining volume as cancellous bone following the tooth contour 1.0 mm below the cementoenamel junction (CEJ). MBT brackets (low profile Victory series) with 0.022" x 0.028" slots along with 0.012-inch NiTi and 0.018 stainless steel archwire beam elements (straight ovoid archforms) were geometrically modeled in HyperMesh (version 13.0, Altair Engineering Inc., Michigan, USA). Validation of the model was further carried out to evaluate element qualities like warpage, aspect ratio, and local re-meshing to improve the overall mesh quality of the model. The right maxillary canine was displaced buccally and vertically at heights of 2, 4, and 6 mm from the occlusal plane to simulate a buccally erupted ectopic canine.

The teeth, alveolar bone, PDL, brackets, and archwire were assumed to be isotropic and homogeneous linear elastic bodies, and Young's modulus and Poisson's ratio were determined for each component based on available literature (Table 1).[11-13] The alveolar bone was constrained at the nasal floor side in all directions, and each tooth was displaced within the periodontal space and made contact with adjacent teeth at contact points as individual elements. The boundary conditions were applied at maxillary sinus floor (Figures 1, 2).

Two clinical simulations were modeled in the FEM: Group 1 (modeled with a single 0.012" NiTi continuous straight ovoid

**Table 1.** Material properties used for modelling the structures

| Material | Young's modulus (MPa) | Poisson's ratio |
|---|---|---|
| Teeth | $4.0\times10^{4}$ | 0.3 |
| PDL | $5.0\times10^{-2}$ | 0.45 |
| Cortical bone | $1.4\times10^{4}$ | 0.26 |
| Cancellous bone | $1.37\times10^{3}$ | 0.3 |
| Stainless steel | $2.0\times10^{5}$ | 0.3 |
| Nickel titanium | $1.2\times10^{5}$ | 0.3 |

PDL, periodontal ligament

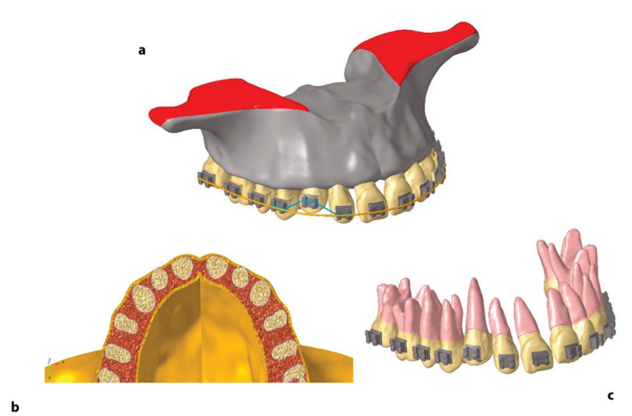


**Figure 1. a)** Boundary condition placed on the floor of the maxillary sinus (represented in red color) **b)** Segregation of the different parts of the model. Golden yellow=cortical bone. Dark brown=Medullary bone. Violet=PDL. Ivory=Teeth **c)** Finite element model including tooth, PDL, and bracket
PDL, periodontal ligament

form archwire) and Group 2 (modeled with a 0.018" SS straight ovoid form base wire with straight 0.012" NiTi in piggyback). In both groups, the wires were modeled in straight ovoid arch form and displaced in the region of the maxillary canine to engage in the bracket of the ectopically positioned canine (Figure 2). Hence, six models simulating varying heights of the maxillary canine (2 mm, 4 mm, and 6 mm from the occlusal plane) with two techniques were analyzed. Von Mises stress and normal stress were evaluated with varying amounts of deflection in the NiTi arch wire. Various simulations at three displacements (2 mm, 4 mm, and 6 mm) generated forces in the range of 80-100 gm.

A mesh convergence test was performed to understand the response for different mesh sizes, and the total number of elements was kept at 34, 65 and 350 (Figure 3). The mesh element was taken from test run 4, as from this point the tested parameter showed convergence. A standard coordinate system was constructed with the X-axis representing the buccolingual direction, the Y-axis representing the anteroposterior direction, and the Z-axis representing the occlusogingival direction. The buccal, anterior, and occlusal directions were defined as negative values (-x, -y, and -z directions), respectively. The displacement of the coronal tips (midpoints of the incisal edges of the lateral incisors, cusp tip of the canine, buccal cusp tips of the premolars, root apices, and mesial and distal contact points of the teeth involved) was calculated. Initial tooth displacement on each tooth was recorded at 4 points (mesial, distal, incisal, and root apex) to simulate orthodontic tooth movement based on the postulation that initial tooth displacement is a forecaster of long-term orthodontic movement.[14]

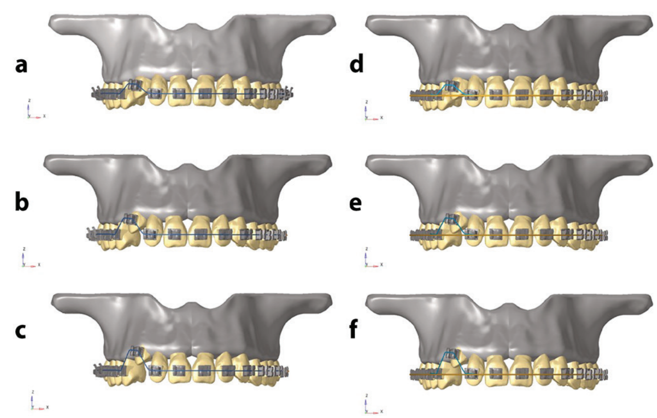


**Figure 2. a-c)** FEM models for different vertical displacements of maxillary canine Group 1 (Continuous arch wire technique) with 2 mm, 4 mm and 6 mm displacement; **d-f)** Group 2 (with 0.018" SS base wire and 0.012" NiTi piggyback or overlay) with 2, 4, and 6 mm displacements
FEM, finite element model; NiTi, nickel titanium

### Statistical Analysis

The input models were processed, and the FEA solver calculated the results for the FEM. The amount of displacement, stress, and strain developed was recorded as the output. The finite element solver used to perform the simulation was OptiStruct version 2020 (Altair Engineering Inc, Troy, Michigan, United States).

## RESULTS

The amount of stress and displacement of the maxillary canine and adjacent teeth (premolar and lateral incisor) and PDL in Groups 1 and 2 were analyzed and tabulated (Table 2, Figures 4 and 5). The maximum von Mises stress in the PDL (0.0204 MPa) was recorded at 2 mm displacement, which decreased as the displacement height increased (0.008 MPa at 6 mm displacement). A similar reduction in stress was also noted in the stress pattern on the teeth (lateral incisors, canines, and 1[st] premolars) in both groups, with Group 2 showing significantly

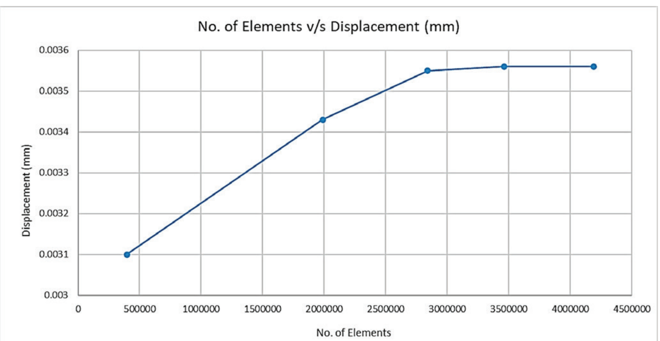


**Figure 3.** Number of nodes and displacement used during the mesh convergence test

**Table 2.** Maximum stress values on PDL and teeth (MPa)

| | Height of displacement | PDL | | Teeth | | |
|---|---|---|---|---|---|---|
| | | Maximum tension stress | Maximum compressive stress | Lateral incisors | Canine | First premolar |
| Group 1 | 2 mm | 0.02043 | 0.01106 | 0.1169 | 0.3042 | 0.1221 |
| | 4 mm | 0.01042 | 0.00967 | 0.0944 | 0.3615 | 0.1689 |
| | 6 mm | 0.00841 | 0.00823 | 0.0476 | 0.4356 | 0.0816 |
| Group 2 | 2 mm | 0.02035 | 0.01108 | 0.1004 | 0.2984 | 0.1083 |
| | 4 mm | 0.01050 | 0.00898 | 0.0326 | 0.4487 | 0.0796 |
| | 6 mm | 0.00843 | 0.00814 | 0.0479 | 0.4278 | 0.0812 |

Group 1 (modeled with a single 0.012" NiTi continuous straight ovoid form archwire) and Group 2 (modeled with a 0.018" SS straight ovoid form base wire with straight 0.012" NiTi in piggyback)
PDL, periodontal ligament

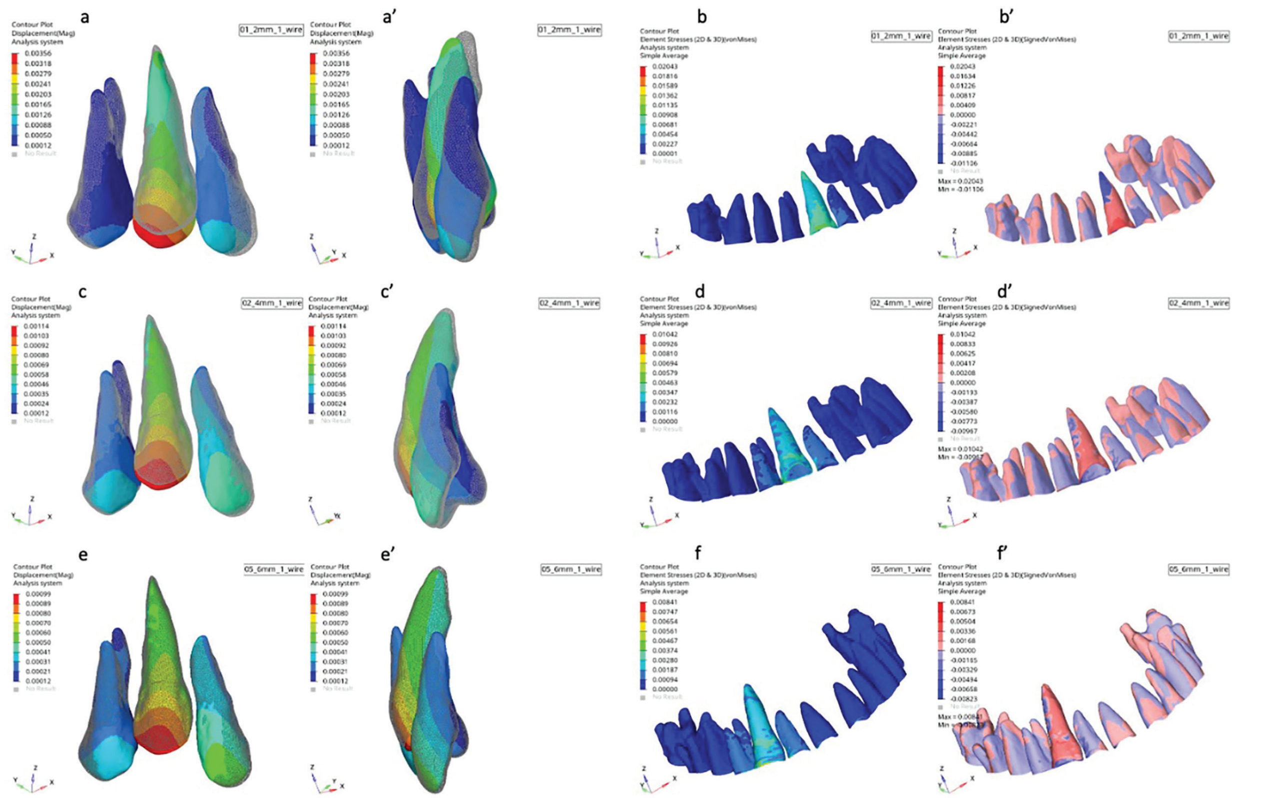

**Figure 4.** Representation of the total displacement and von Mises stress produced on teeth and PDL in Group 1 at; a, a', b, b') 2 mm displacement height of the canine; c, c', d, d') 4 mm displacement height of the canine; e, e', f, f') 6 mm displacement height of the canine
PDL, periodontal ligament

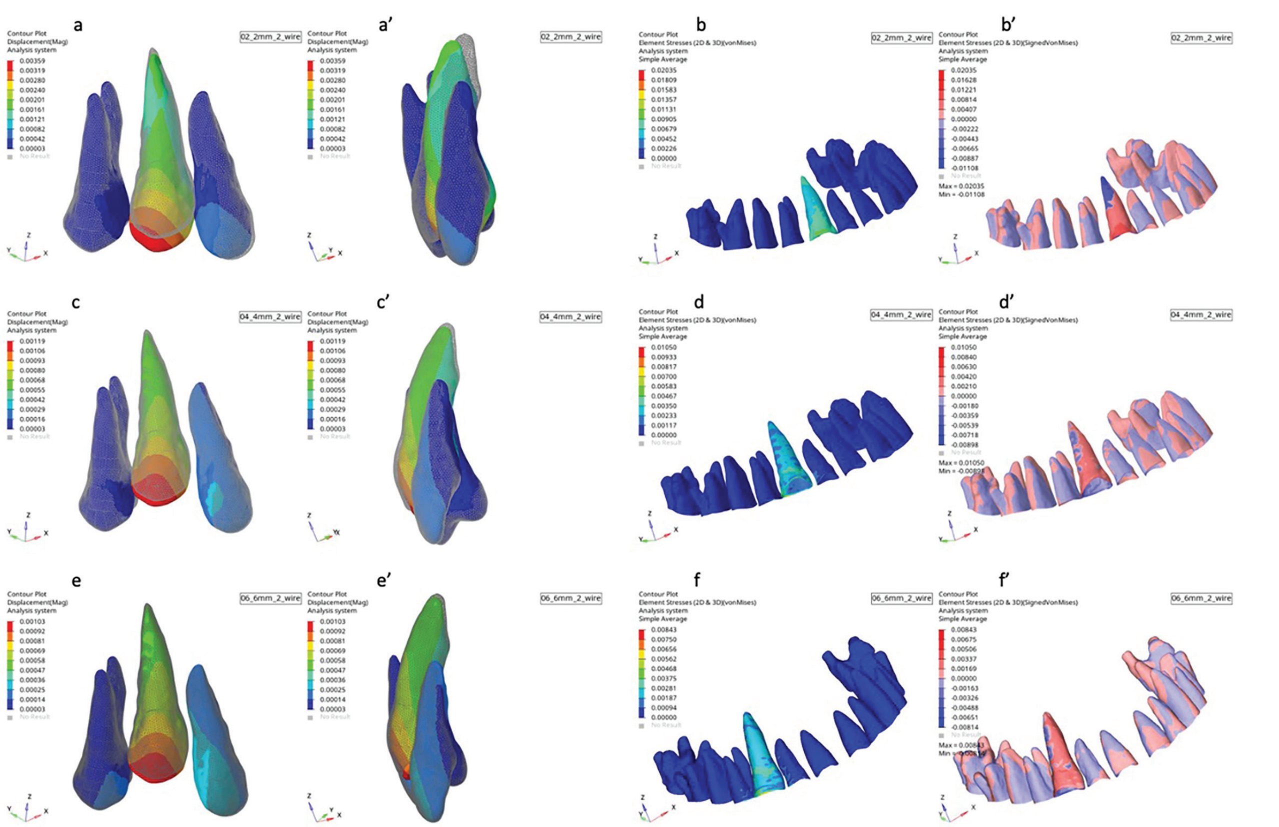

**Figure 5.** Representation of the total displacement and von Mises stress produced on teeth and pdl in Group 2 at; a, a', b, b') 2 mm displacement height of the canine; c, c', d, d') 4 mm displacement height of the canine e, e', f, f') 6 mm displacement height of the canine

**Table 3.** Displacement of teeth (lateral incisors, canine and 1st premolars) along the X, Y, and Z axis

| | Height of displacement | Lateral incisor | | | | Canine | | | | First premolar | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Mesial point | Distal point | Incisal point | Root apex | Mesial point | Distal point | Incisal point | Root apex | Mesial point | Distal point | Incisal point | Root apex |
| **Along Z-axis (Occluso-gingival direction) (in mm)** | | | | | | | | | | | | | |
| Group 1 | 2 mm | 0.00019 | 0.00042 | 0.00032 | 0.00021 | -0.00166 | -0.00196 | -0.00276 | -0.00005 | 0.00030 | 0.00013 | 0.00029 | 0.00013 |
| | 4 mm | 0.00027 | 0.00024 | 0.00032 | 0.00016 | -0.00058 | -0.00070 | -0.00101 | -0.00025 | 0.00027 | 0.00016 | 0.00031 | 0.00015 |
| | 6 mm | 0.00020 | 0.00023 | 0.00027 | 0.00018 | -0.00056 | -0.00067 | -0.00088 | -0.00022 | 0.00027 | 0.00015 | 0.00029 | 0.00015 |
| Group 2 | 2 mm | 0.00002 | 0.00012 | 0.00007 | 0.00007 | -0.00167 | -0.00198 | -0.00278 | -0.00005 | 0.00012 | 0.00004 | 0.00011 | 0.00005 |
| | 4 mm | 0.00008 | 0.00003 | 0.00008 | 0.00005 | -0.0006 | -0.00072 | -0.00104 | -0.00025 | 0.00011 | 0.00005 | 0.00012 | 0.00006 |
| | 6 mm | 0.00004 | 0.00003 | 0.00005 | 0.00006 | -0.00058 | -0.00069 | -0.00091 | -0.00023 | 0.00011 | 0.00005 | 0.00011 | 0.00006 |
| **Along X-axis (Bucco-lingual direction) (in mm)** | | | | | | | | | | | | | |
| Group 1 | 2 mm | -0.0006 | -0.00051 | -0.0009 | 0.0004 | 0.00026 | 0.00122 | 0.00138 | -0.0011 | 0.00016 | 0.00010 | 0.00011 | 0.00006 |
| | 4 mm | -0.0003 | -0.00014 | -0.0004 | 0.00014 | -0.00013 | 0.00013 | 0.00028 | -0.0003 | 0.00004 | -0.00008 | -0.00005 | 0.00009 |
| | 6 mm | -0.0003 | -0.00014 | -0.0004 | 0.00015 | -0.00005 | 0.00018 | 0.00021 | -0.0003 | 0.00005 | -0.00004 | -0.00001 | 0.00008 |
| Group 2 | 2 mm | -0.0003 | -0.00022 | -0.0004 | 0.00022 | 0.00027 | 0.00123 | 0.0014 | -0.0011 | 0.00012 | 0.00003 | 0.0001 | 0.00004 |
| | 4 mm | -0.0001 | -0.00002 | -0.0002 | 0.00007 | -0.00011 | 0.00015 | 0.00031 | -0.0003 | 0.00006 | 0.00001 | 0.00003 | 0.00005 |
| | 6 mm | -0.0001 | -0.00001 | -0.0002 | 0.00007 | -0.00004 | 0.00019 | 0.00023 | -0.0003 | 0.00007 | 0.00002 | 0.00005 | 0.00005 |
| **Along Y-axis (Antero-posterior direction) (in mm)** | | | | | | | | | | | | | |
| Group 1 | 2 mm | 0.00015 | 0.00051 | 0.00028 | -0.00028 | 0.00004 | 0.00006 | 0.00158 | -0.0013 | -0.00013 | -0.0003 | -0.00045 | 0.00026 |
| | 4 mm | 0.00004 | 0.00031 | 0.00003 | -0.00022 | 0.00009 | 0.00006 | 0.00046 | -0.0004 | -0.00007 | -0.00017 | -0.00031 | 0.00013 |
| | 6 mm | 0.00007 | 0.00036 | 0.00016 | -0.00021 | 0.00011 | 0.00012 | 0.00036 | -0.0004 | -0.00007 | -0.00014 | -0.00028 | 0.00013 |
| Group 2 | 2 mm | 0.00016 | 0.00039 | 0.00027 | -0.00017 | 0.00005 | 0.00009 | 0.00160 | -0.0013 | -0.00001 | -0.00011 | -0.00017 | 0.00016 |
| | 4 mm | 0.00004 | 0.00027 | 0.00012 | -0.00013 | 0.00010 | 0.00012 | 0.00048 | -0.0004 | 0.00002 | -0.00004 | -0.00010 | 0.00008 |
| | 6 mm | 0.00001 | 0.00029 | 0.00019 | -0.00013 | 0.00013 | 0.00014 | 0.00038 | -0.0004 | 0.00001 | -0.00003 | -0.00009 | 0.00008 |

Group 1 (modeled with a single 0.012" NiTi continuous straight ovoid form archwire) and Group 2 (modeled with a 0.018" SS straight ovoid form base wire with straight 0.012" NiTi in piggyback)

reduced stresses on both adjacent teeth at 4 mm displacement (0.032 and 0.079 MPa on the lateral incisor and 1st premolar).

Directional changes along the occlusogingival direction (Z-axis) showed extrusion of the maxillary canine, with the maximum extrusive movement of the incisal point observed at a vertical height of 2 mm in both groups. However, Group 2 exhibited larger occlusal displacement of the canine at all three levels of vertical displacement. The total amount of extrusion of the maxillary canine decreased as the vertical height increased from 2 mm to 6 mm. Similarly, the reactionary forces acting on the lateral incisors and first premolar resulted in intrusive action on both teeth. There was a relative distal tipping of the lateral incisors, with more intrusive movement of the distal point compared with the mesial point. This discrepancy was greater in Group 1. A similar pattern was observed in the maxillary first premolar, showing a mesial tipping movement with more intrusive movement on the mesial point as compared to the distal point, with the relative difference being greater in Group 1. A summary of the movement along the Z-axis (occlusogingival direction) is shown in Table 3.

In the anteroposterior plane (Y-axis), the adjacent maxillary lateral incisor and first premolar in both groups showed distal and mesial movement of the crown. Among the different vertical displacements, the 4 mm model showed the least amount of reactionary forces, with the maximum effect observed with the 6 mm model in both groups. Similarly, Group 2 showed decreased reactionary forces on the adjacent teeth in all three models (2 mm, 4 mm, and 6 mm) compared with Group 1. The ectopically positioned canine showed uniform extrusive movement of the teeth in both groups (Table 3).

In the buccolingual direction (X-axis), the incisal tip of the canine showed palatal crown movement with buccal root movement of the root apex in both models. Similarly, the lateral incisor and premolar reported similar movements with the maximum displacement being 2 mm. A summary of the maximum values observed in the two groups is presented in Table 3.

The stress patterns observed on the canine and adjacent teeth in the continuous archwire technique (Group 1) increased proportionally with vertical displacement. The highest stress concentration on the canine was on the incisal third of the crown at 2 mm (0.36 MPa) which progressively increased toward the middle third of the crown (0.41 and 0.44 MPa) at 4 mm and 6 mm, respectively. The lateral incisor showed the least stress concentration at 2 mm of displacement at the distal surface of the incisal third (0.11 MPa) of the crown, which progressively increased until the distal surface of the cervical third of the root at 6 mm of displacement (0.18 MPa). The first premolar also showed a similar pattern, increaseing from the mesial surface of the incisal third of the crown at 2 mm (0.09 MPa) to the middle third (0.18 MPa) at 6 mm displacement. The maximum stress observed for the lateral incisor and first premolar was in the 4 mm displacement model, 0.20 MPa and 0.19 MPa. Table 2 summarizes the maximum von mises stress on the teeth (lateral incisor, canine and premolar). Both the piggyback technique and the continuous archwire technique displayed similar stress patterns on all teeth. Tensile and compressive stresses were concentrated on the PDL near the CEJ and apices of the lateral incisor, canine, and first premolar as vertical displacement accompanied tipping movements. The maximum tensile and compressive stresses generally followed the vertical displacement (Figures 4 and 5).

## DISCUSSION

A vertically displaced canine is a common orthodontic problem due to its timing of eruption in the arch, reduced arch perimeter, and over-retained deciduous teeth.[2,15] The present study investigates the optimal modality and level of vertical displacement at which an ectopically positioned canine should be engaged in straight wire mechanics with minimum counter effects on adjacent teeth. The engagement of a continuous arch wire on vertically displaced canines results in intrusive and tipping forces on adjacent teeth. It can also result in canting of the occlusal plane due to the indeterminate nature of the forces.[16] Nanda et al.[17] described that full arch engagement of a highly displaced canine without a lacebark can lead to flaring of incisors (rowboat effect) and extrusion of the anterior teeth. The piggyback technique is often used to address this problem, aligning the displaced canine with a flexible wire while a rigid archwire supports the other teeth from these unwanted forces.[6]

In the present model, vertical forces (80-100 gms) on the ectopically placed maxillary canine were simulated by the deflection of a straight ovoid NiTi wire. The force magnitude was verified in accordance with by Theodorou et al.'s[18] systematic review, which recommends a force magnitude between 50 and 100 g for optimal orthodontic tooth movement with minimal adverse effects.The canine displacement in the piggyback model provided a marginally larger extrusive movement on the canine. However, extrusive forces decreased as the height of the canine displacement increased, with the largest displacement observed at 2 mm in both groups (Table 3). Previous studies by Kim et al.,[11] and Bacetti et al.,[19], have shown similar results. This decrease in the canine displacement with increased height can be attributed to binding at the bracket-wire interface due to increased deflection of the flexible wire. This indicates that the available force is not proportional to the vertical displacement of the canine.

Furthermore, the continuous archwire model showed variations in the amount of intrusion in adjacent teeth at different heights (Table 3). The largest intrusion effect in the lateral incisor was seen in the 2 mm model, followed by the 6 mm model, with the least intrusion in the 4 mm model. For the first premolar, the 2 mm model produced the least amount of intrusion, while the 4 mm and 6 mm displacement models produced similar amounts of intrusion. These results were contrary to Kim's[11] findings, which showed a steady increase in intrusion of adjacent teeth with vertical displacement. This difference could be due to the incorporation of the buccal inclination of the canine. The lateral incisor showed a greater intrusive effect than the first premolar at all three heights of displacement, which concurs with the results of Kim[11] and Wu[12] , correlating with differences in the root surface area of the lateral incisor and first premolar. In the piggyback group, a similar pattern of intrusion effect on the adjacent teeth was observed, but the amount of intrusion was significantly lower than in the continuous archwire group (Table 3). 

In the antero-posterior direction (Y-axis), both the techniques showed a similar pattern. The continuous archwire technique exhibited the highest reactionary moments at the 2 mm displacement model, followed by the 6 and 4 mm models, with the lateral incisor and first premolars tipping toward the vertically displaced canine (Table 3). Kim et al.,[11] Wu et al.[12] and Fok et al.,[20], reported similar results, concluding that reactionary forces from vertically displaced canines caused distal tipping of the lateral incisors and anterior tipping of the first premolar. However, Kim et al.[11] further reported that increased vertical displacement of the canine led to increased reactionary forces on the adjacent teeth, which contrastd with the present study's findings. This variation may be due to the differences in parameters, because the height of canine displacement was measured only up to 3 mm. The Piggyback group showed reduced reactionary moments in the adjacent teeth compared with the continuous archwire model. The canine showed equal displacement of the mesial and distal points at all levels of displacement, suggesting a uniform extrusive tendency.

In the buccolingual direction (X-axis), Group 1 displayed uncontrolled tipping in both the canine and adjacent teeth. Fok et al.[20] reported a buccal force acting on the entire segment of the continuous arch when engaged on a highly displaced canine. The lateral incisor reported the greatest amount of uncontrolled tipping with palatal root movement at 2 mm, followed by 6 mm and the least in the 4 mm displacement model. The first premolar showed the highest amount of tipping at 4 mm, followed by 6 mm and the least at 2 mm (Table 3). Similar movement was observed in the first premolar but with comparatively less displacement than in the lateral. This uncontrolled tipping could result in a lateral open bite, a common side effect reported when engaging a continuous archwire in highly displaced canines.[6,7] In Group 2, the canine reported a similar pattern of uncontrolled tipping as in Group 1 model, but the amount of palatal root movement in the adjacent teeth was significantly reduced. The lateral incisor experienced half the amount of palatal root movement when compared with Group 1, with 2 mm showing the highest amount, followed by both the 4 mm and 6 mm models. The first premolar also showed less palatal root movement, with 2 mm having the least and both 4 mm and 6 mm reporting similar amounts.

Evaluating the stress pattern on individual teeth in both groups, the maximum von Mises stress in the PDL decreased as the displacement height increased. This result is accurate as the displacement also decreased with increased height. Similar reductions in maximum von Mises stress were observed in the PDL of both groups, with Group 2 showing significantly reduced stress on both adjacent teeth. Individual compressive and tensile stresses produced by the canine and adjacent teeth were also measured. The canines experienced generalized tensile stress, except for the buccal surface at the apical third, which experienced increased compressive stress due to the buccal root movement in both groups. Wilson et al.[21] reported a similar finding with extrusive forceapplied to the canine. Rudolph[13] and Penedo[22] found that compressive stress on the adjacent teeth was similar to that observed in this study, with compressive stress at the root surface and localized tensile stress on the buccal surface of the apical third of the PDL, suggesting palatal root movement.



The present study concluded that the continuous archwire does not have harmful effects on adjacent teeth as long as the vertical displacement is within 2 mm. The piggyback technique serves as an alternative with reduced reactionary effects and should be used for vertical displacements up to 4 mm. For displacements greater than 4 mm, alternative methods of extrusion, such as segment mechanics and vertical elastics, should be explored with further finite element studies.

### Study Limitations

The study had a few limitations, including approximation in the material behaviors and geometry of the tissue like PDL, which was modeled as linear elastic with uniform thickness. Clinically, the PDL exhibits nonlinear, anisotropic, viscoelastic properties with an hourglass shape structure, which may affect the stress value and distribution patterns.

## CONCLUSION

This study derived the following conclusions:

• The vertical forces generated for the extrusion of vertically displaced canines are transferred to adjacent teeth as reactionary forces, causing distal tipping of the lateral incisors and mesial tipping of the first premolars.

• The optimal level of engagement of a vertically displaced canine with continuous arch mechanics is at a vertical displacement of 4 mm.

• Piggyback mechanics serves as a superior treatment modality with significantly reduced counter effects on adjacent teeth during the extrusion of vertically displaced canines.

• Less tooth movement of the canine is observed in continuous arch mechanics when the vertical displacement exceeds 4 mm.

### Ethics

**Ethics Committee Approval:** Manav Rachna Dental College institutional ethical clearance (ref. no: MRDC/IEC/2019/525, date: 26.12.2019) was obtained before starting the study.

**Informed Consent:** Written informed consent was obtained from the patient who agreed to take part in the study.

**Author Contributions:** Concept - S.K., Design - P.B., S.K., A.T., Supervision - P.B., N.A., A.K.S., A.T., Fundings - S.M., Data Collection and/or Processing - S.M., N.A., Analysis and/or Interpretation - A.T., Literature Review - S.M., P.B., N.A., A.K.S., Writing - S.M., N.A., A.K.S., Critical Review - P.B., A.T.

**Conflict of Interest:** The authors have no conflicts of interest to declare.

**Financial Disclosure**: The authors declare that this study has received no financial support.

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