Original Article

Effects of Inverting Bracket on Maxillary Central Incisors with Increased Collum Angle in Class II Division 2 Malocclusion Cases: A Finite Element Analysis

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ABSTRACT

Purpose: Maxillary central incisor teeth present morphological variations in different malocclusions. The collum angles of maxillary central incisors in Class II, division 2 and Class III malocclusions are significantly higher than the other groups of malocclusions. The higher prevalence of root resorption seen in central incisors with increased column angle after orthodontic treatment, warranted the need to study the stress patterns over these teeth during intrusion. In this study, FEM has been used to evaluate and compare the effect of normal bracket and inverted bracket positioning on stress distribution in PDL and root displacement of maxillary central incisors with 11° collum angles during application of intrusion force.

Methods: FEM models of maxillary central incisor with normal collum angle (6°) and a high collum angle (11°)–representing the class II division 2 teeth were modeled. MBT prescription brackets were used to study the effect of positive or negative (invertion of bracket) torque on maxillary central incisors with high column angle. Each of the samples was loaded with intrusive force (0.5 N) perpendicular to the ideal position of bracket. The results were compared with the maxillary central incisor with normal column angle bonded with positive torque (+17°) MBT bracket.

Results: The calculated stress in the inverted bracket model was lesser and extended over a smaller area, as compared to normally positioned bracket in the teeth with increased collum angle. Also, better intrusion was achieved as compared to the conventional bracket placement which exerts positive torque resulting in root impingement frequently seen with such teeth.

Conclusion: The results of this study warn against the use of high positive torque prescription brackets , for Angle Class II division 2 subjects with increased collum angle. The orthodontic treatment must be tailored with respect to the biologic variations presented by the individual patient.

Keywords: Class II Div 2 Malocclusion, Root Resorption, FEM,Torque.

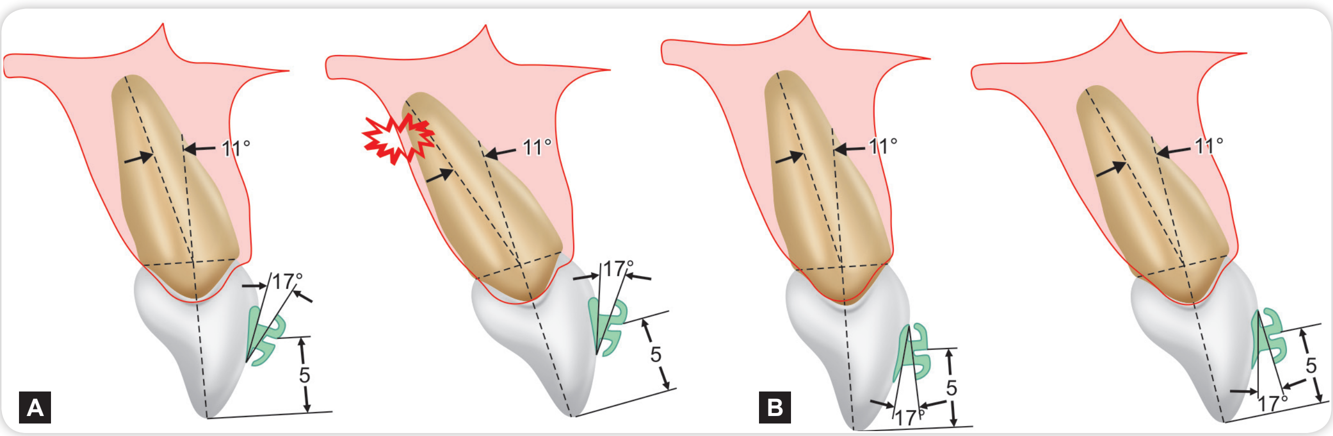
INTRODUCTION

Class II, division 2 malocclusions are associated with straight and pleasant profiles along with the presence of deckbis appearance of incisors to high lower lipline.[1] The collum angles of maxillary central incisors (CI_{CA}) in Class II, division 2 malocclusion are significantly higher compared to other types of malocclusions. Pronounced Collum angle gives rise to a deep overbite because maxillary and mandibular incisors can erupt past one another as suggested by Korkhaus and Andreasen.[2] Due to pleasant profiles and high lipline, nonextraction mechanics is opted for these patients wherein alignment and intrusion of the teeth are the important steps of the treatment mechanics. Initial alignment of the retroclined central incisors using round NiTi wires results in uncontrolled tipping causing labial crown.[3,4] Positive built-in torque (as high as +22°) of the bracket which gets expressed by full size working wires, along with the moments generated during intrusion of these teeth with increased collum angle, further worsens the root position, causing its impingement over the cortical plate.[5,6] Deviant root angulations confound intended axial loads during intrusion and may cause the roots to encroach on the lingual cortical plate. The extent of root resorption depends on the magnitude of the moment and on the duration of the applied force. Time periods of 3–4 weeks may be long enough to cause severe root resorption.[6] Theoretically, if a counterbalancing moment could be applied to keep the root from going into palatal cortical bone during alignment and intrusion, then probably the roots can be maintained within medullary bone (Figs 1A and B). Thus, in the present study, we chose to evaluate and compare the effect of positive and negative root torque on the maxillary central incisor with increased collum angle during alignment and intrusion. A counterbalancing moment can be applied on these teeth either by inverting the central incisor bracket or by incorporating negative torque in the archwire (Figs 1A and B). Inverting the brackets of an in-standing lateral incisor is a recommended procedure in orthodontic mechanotherapy to torque the roots labially i.e. away from palatal cortical plate and into the medullary bone. Thus, the same method when employed for the maxillary central incisor with increased collum angle should help to keep the root apices in medullary bone, and bring about true intrusion.

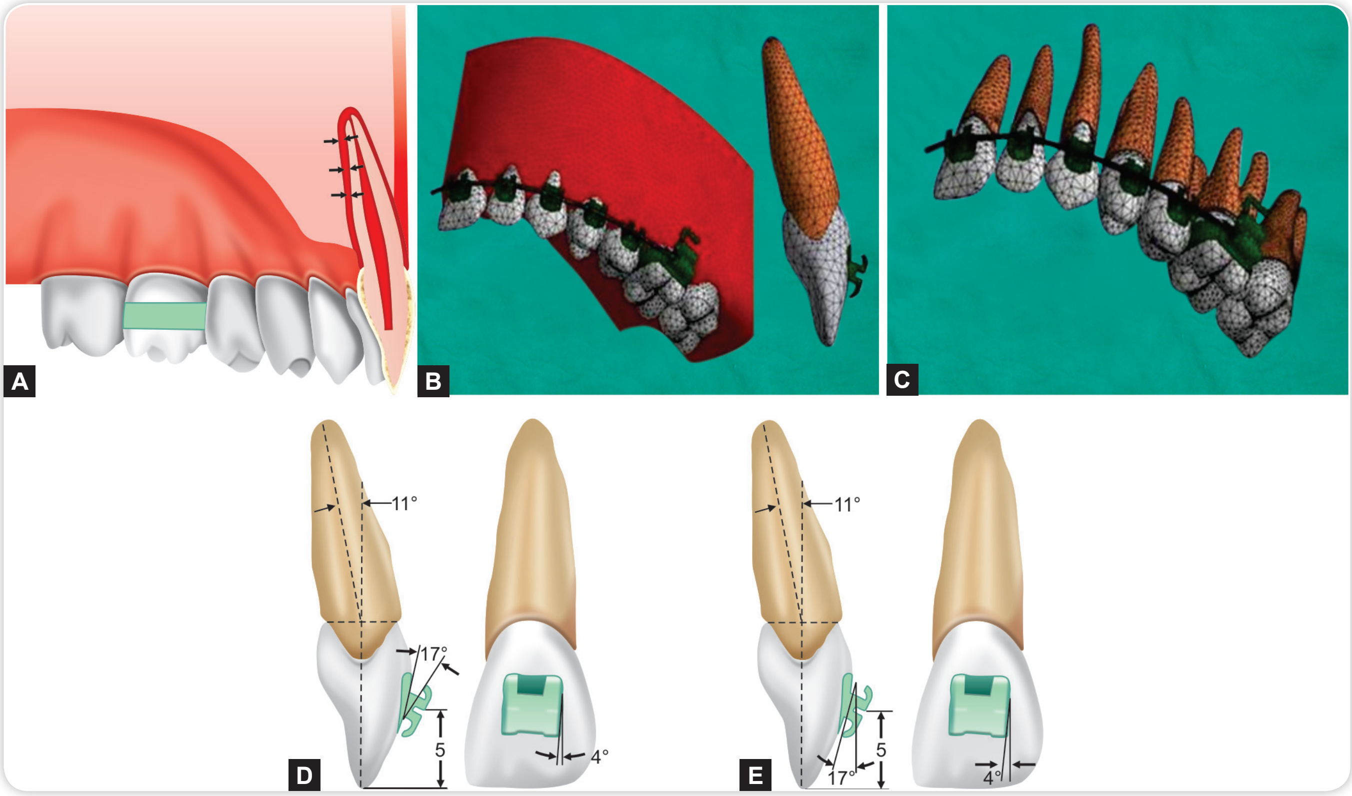
The higher prevalence of root resorption seen in central incisors with increased column angle after orthodontic treatment, warranted the need to study the stress patterns over these teeth during alignment and intrusion. Finite element model (FEM) is an accepted model to study and analyse the interaction between materials, forces and the pattern of stress distribution in a given mass (Figs 2A to E). It has been used to study orthodontic tooth movements in several studies.[1] So, in this study FEM has been used to evaluate and compare the effect of normal bracket and inverted bracket positioning on stress distribution in PDL and root displacement of maxillary central incisors with 11° collum angles during application of intrusion force.

MATERIALS AND METHOD

Three-dimensional models of maxillary central incisor with normal collum angle (6°) and a high collum angle (11°) representing the class II division 2 teeth were modelled using SolidWorks Software from "Dassault Systèmes Solid Works Corporation" (Waltham, MA 02451, USA). The crown length was considered to be 11.2 mm and the root length of teeth is considered to be 13 mm, and the other dimensions such as the crown-root ratio and mesiodistal width of the teeth were taken from Wheeler's textbook on dental anatomy.[7] The thickness of PDL is considered to be 0.25 mm and which is constant. The position and axial inclination of teeth is based on ideal occlusion of Andrews,[8] and all the elements contributing in the model are assumed to be homogenous. Four different Young's moduli[1] were chosen to represent 1. Cancellous bone: 1.370 MPa, 2. Cortical bone: 13.700 MPa, 3. PDL (0.05 MPa) and tooth structure (20,000 MPa) (Fig. 2A). The objects to be studied were graphically simulated in a computer in the form of a mesh that defines its geometry and also define degrees of freedom in a process called discretization. This mesh gets



Figures 1A and B (a) Positive torqued bracket can cause impingement of root during alignment and intrusion (b) Negative torque bracket would keep the root in cancellous bone during alignment and intrusion. Diagrammatic representation of the effect of positive and negative torque (inverted bracket) on maxillary incisors with increased collum angle



Figures 2A to E (A) Thickness of PDL, Cementum and Cortical bone; (B) Model nodes of upper central incisor and surrounding bone and (C) their elements in left upper arch; (D) CI_{CA}+17°; (E) CI_{CA}-17°

divided into a number of subunits termed elements, which are connected at a finite number of points called nodes. Nodes are generally located at the corners of elements. Importing 3D model to FEA software i.e. ANSYS Software from ANSYS, Inc. (Canonsburg, PA 15317, USA). The ANSYS element library contains more than 100 different element types. Solid 186 and Solid 187 elements were used in this analysis. Each model had 26,968 nodes and 14,645 elements (Figs 2B and C). MBT prescription brackets were also modelled and fixed at 5 mm from the incisal edge. Also, the working wire used is 0.019 x 0.025 stainless steel wire as recommended by MBT philosophy.[9] An intrusive force of 0.25 N that was parallel to the labial surface of the teeth was loaded at 5 mm distance from the incisal edge to the models with normally positioned and inverted brackets, in order to understand the equivalent stress patterns, deformation and displacement of the teeth in X and Z coordinates. Effect of horizontal and vertical component of the intrusive force can express itself in different modes: compression (negative) or tension (positive). There are a variety of methods for assessing the pattern of loading. The adding up the absolute values of the stresses (along X, Y, and Z axis) is known as von Mises stress.[9] This norm will be used to evaluate the pattern of stress generated. von Mises stress is used to predict yielding of material under any loading condition from results of simple uniaxial tensile tests. The formula[9] was used to calculate the von Mises stress is $(S1-S2)^2 + (S2-S3)^2 + (S3-S1)^2 = 2Se^2$.

S1, S2 and S3 are the principal stresses that can be calculated at any point, acting in the x, y, z directions. S1 is the maximum stress showing tension zone, S3 is the minimum stress showing compression zone and S2 is the medium stress showing the combination of tension and compression. *Se* is the equivalent stress, or von Mises stress. These norms were used to evaluate the pattern of stress generated.[10-12]

RESULTS

In this study, the vertical and horizontal displacement of the teeth and the stress distribution in PDL which is the biologic connector for tooth movements were evaluated using FEM models. An intrusive force of 0.25 N was loaded parallel to the teeth (CI+17 °, CI_{CA}+17° *see* Fig. 2A, CI_{CA}-17° *see* Fig. 2B), at the slot of bracket. The stresses generated at the nodes designating points A, B1, B2, B3, P1, P2 and P3 (Fig. 3) for each model were tabulated in the Table 1. It was observed that the stress distribution at point A, B1, B2, B3, P1, P2, P3 were

Table 1

Stress on model of Maxillary central incisors, by placing Normal (CI+17°, CI_{CA}+17°) and Inverted Bracket (CI_{CA}-17°), during intrusion force (0.25N) loading, $1e^{-004}$ = 0.0001

S. no.	Points on CI +17° (C)	Stresses in C	Points on CI_{CA}+17° (C1)	Stresses in C_1	Points on CI_{CA}-17° (C_2)	Stresses in C_2	Difference C_1-C_2
01.	A	2.7601 e^{-004}	A	6.5416 e^{-004}	A	2.7601 e^{-004}	3.7815 e^{-004}
02.	B1	4.7022 e^{-004}	B1	6.1399 e^{-004}	B1	4.7022 e^{-004}	1.4377 e^{-004}
03.	B2	3.1009 e^{-004}	B2	8.7443 e^{-004}	B2	3.1009 e^{-004}	5.6434 e^{-004}
04.	B3	4.2853 e^{-003}	B3	5.7918 e^{-003}	B3	4.2853 e^{-003}	1.5065 e^{-003}
05.	P1	2.3742 e^{-004}	P1	4.7247 e^{-004}	P1	2.3742 e^{-004}	2.3505 e^{-004}
06.	P2	4.8559 e^{-004}	P2	6.5762 e^{-004}	P2	4.8559 e^{-004}	1.7203 e^{-004}
07.	P3	7.7141 e^{-003}	P3	8.0155 e^{-003}	P3	7.7141 e^{-003}	0.3014 e^{-003}

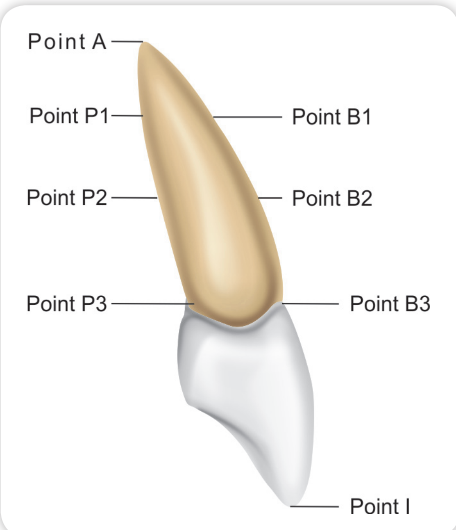


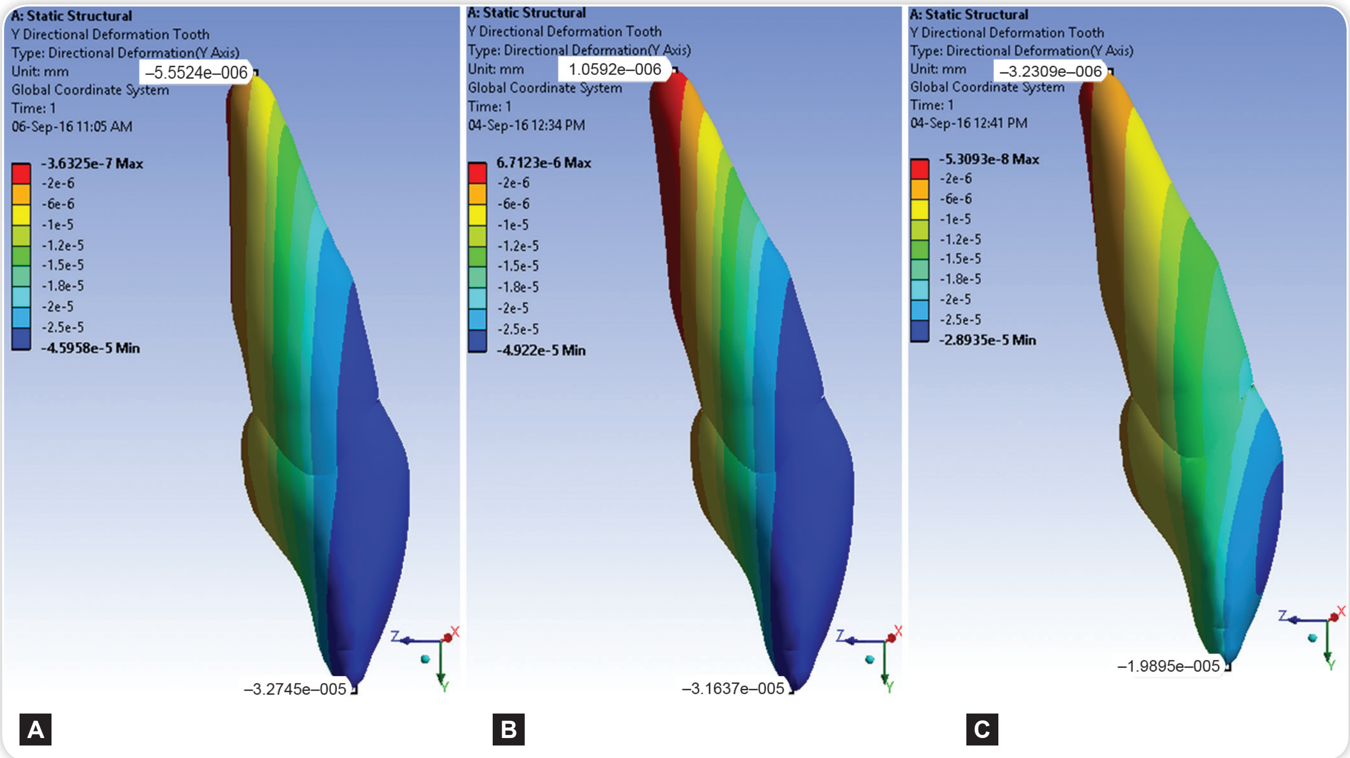
Figure 3 Point A-apex; B1-a node in the labial surface, near the apex; B2-a node in the labial surface, near the middle of the root; B3-a node in the labial surface, near the cervix; CRA-crown-root angle; P1-a node in the palatal surface, near the apex; P2-a node in the palatal surface, near the middle of the root; P3-a node in the palatal surface, near the cervix; Point I-a node in a tip of incisal edge

similar or lower in the tooth with increased collum angle when bonded with inverted bracket (CI_{CA}-17°) when compared to the normal tooth bonded with positive torque prescription bracket (CI+17°). Also, the stress distribution at point A, B1, B2, B3, P1, P2, P3 were much lower in the tooth with inverted bracket (CI_{CA}-17°) compared to the tooth with increased collum angle with positive torque prescription bracket (CI_{CA}+17°). The differences were at the level of thousands.

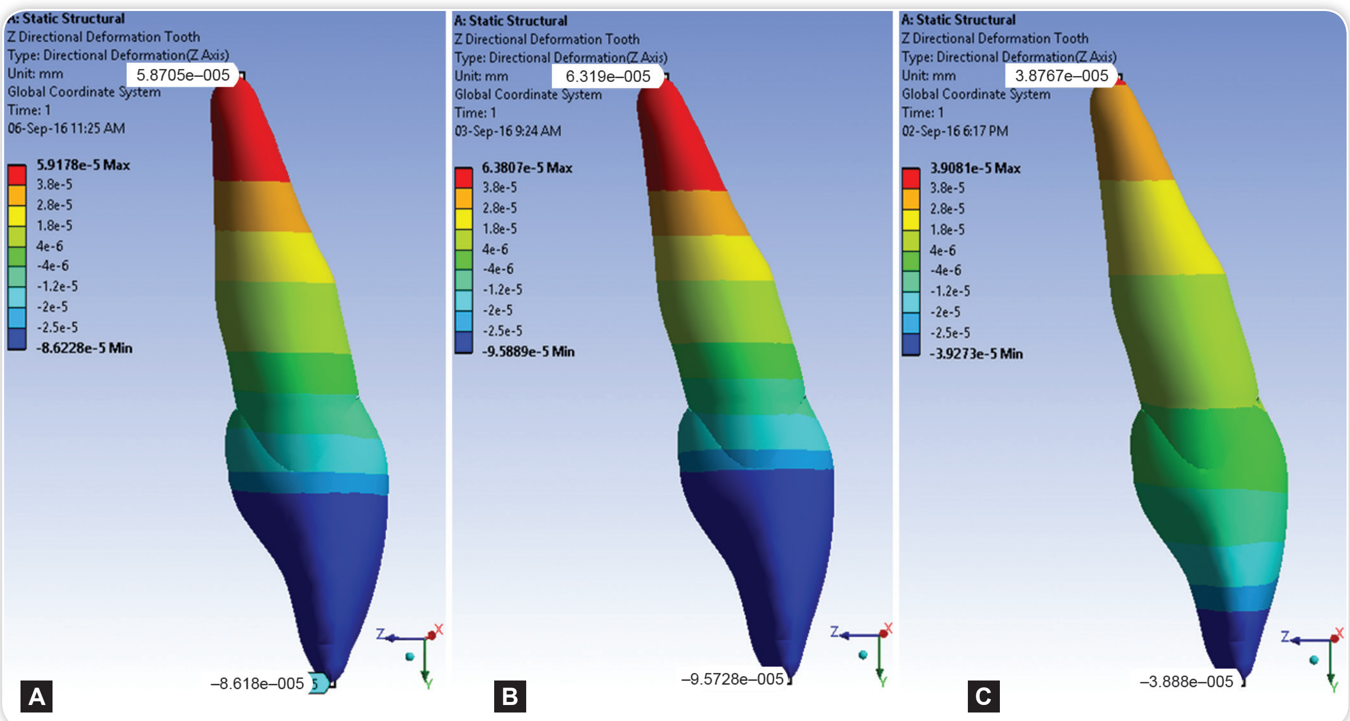
Figures 4A to C shows, the Y-directional deformation of the FEM models. CI_{CA}+17° model exhibited higher stresses extended over larger area on the palatal surface extending over point A, P1 and P2 when compared to the CI+17° and CI_{CA}-17°. The CI_{CA}-17° model showed lower value of stress which extended over smaller area extending from the palatal surface at point A and P1 only. The CI_{CA}+17° model, also shows uncontrolled tipping as the tooth at point A has moved palatally by 1.0592 e^{-006} and point I has moved labially by -3.1637 e^{-005} indicating that the tooth has rotated counter-clock wise causing lingual root movement and labial crown movement of tooth. In the CI_{CA}-17° model, labial movement of root at point A by -3.2309 e^{-006} and -1.9895 e^{-005} of incisal edge at point I shows, that the root has uprighted during intrusion, as the entire tooth has rotated clockwise.

Figures 5A to C, shows the Z-directional deformation of the FEM models. CI+17° model and CI_{CA}+17° model exhibited higher stress extended over larger area i.e. almost the entire apical 1/3rd of the root from points A to P1 and B1. In the Fig. 6C, significantly smaller area of stress extended around the apex at point A only is seen. CI_{CA}+17° tooth shows uncontrolled tipping, the root has moved palatally with displacement of 6.319 e^{-005}at point A and crown has moved labially at point I by -9.5728 e^{-005}. The CI_{CA}-17° tooth shows better control on tipping i.e. root has moved palatally with displacement of 3.8767e^{-005} at point A and crown has moved labially at point I by 3.8887 e^{-005}.

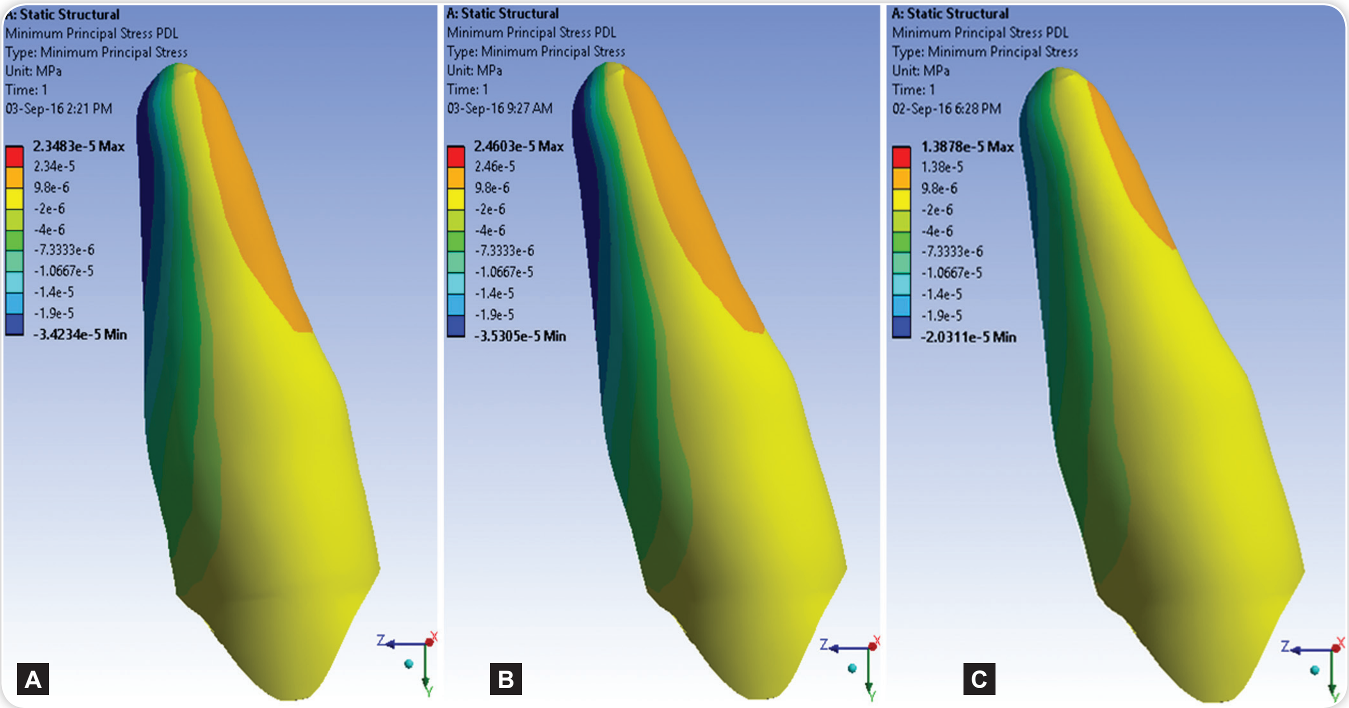
Figures 6 and 7, shows the minimum principal stress on PDL (sectional view) and root tip of CI+17°, CI_{CA}+17° and CI_{CA}-17°. Minimum principal stress zone of PDL corresponds to the maximum compression zone of palatal alveolar bone, which would resorb to accommodate tooth movement. There is a larger area of minimum principal stress on the palatal surface of CI+17° and CI_{CA}+17° extending over points A, P1



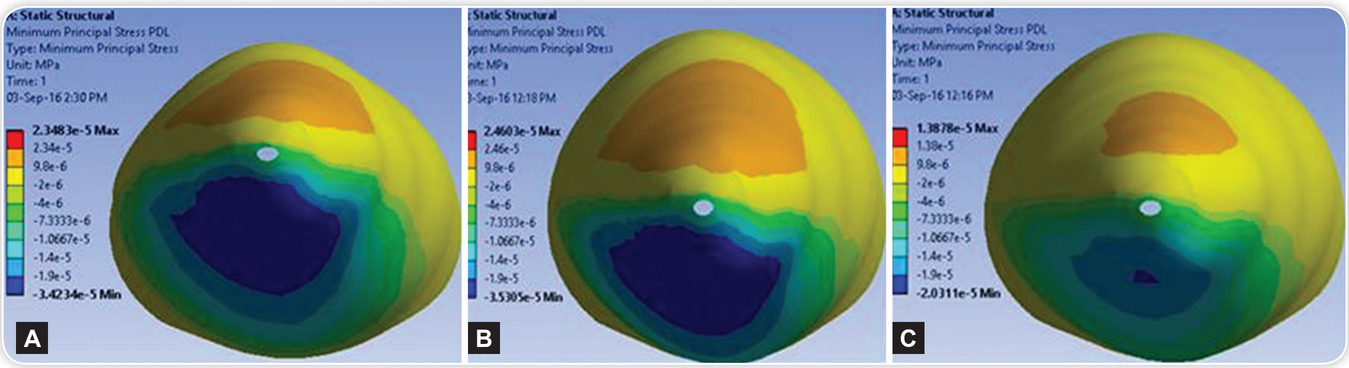
Figures 4A to C Y-directional deformation of (A) CI+17,° (B) CI_{CA}+17° and (C) CI_{CA}-17°



Figures 5A to C Z-directional deformation of (A) CI+17,° (B) CI_{CA}+17° and (C) CI_{CA}-17°



Figures 6A to C Minimum Principal Stress on PDL of (A) CI+17°, (B) CI_{CA}+17° and (C) CI_{CA}-17°

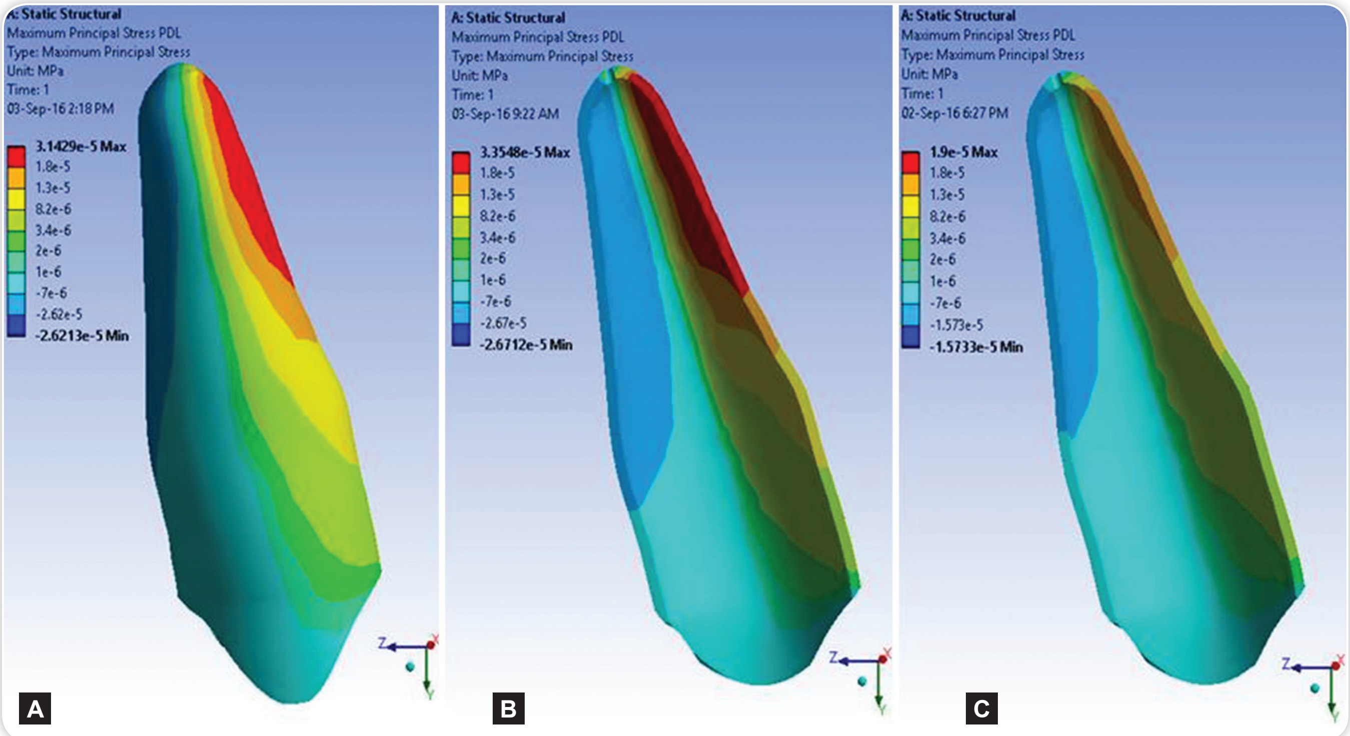


Figures 7A to C Minimum Principal Stress on PDL of (A) CI+17°, (B) CI_{CA}+17° and (C) CI_{CA}-17°

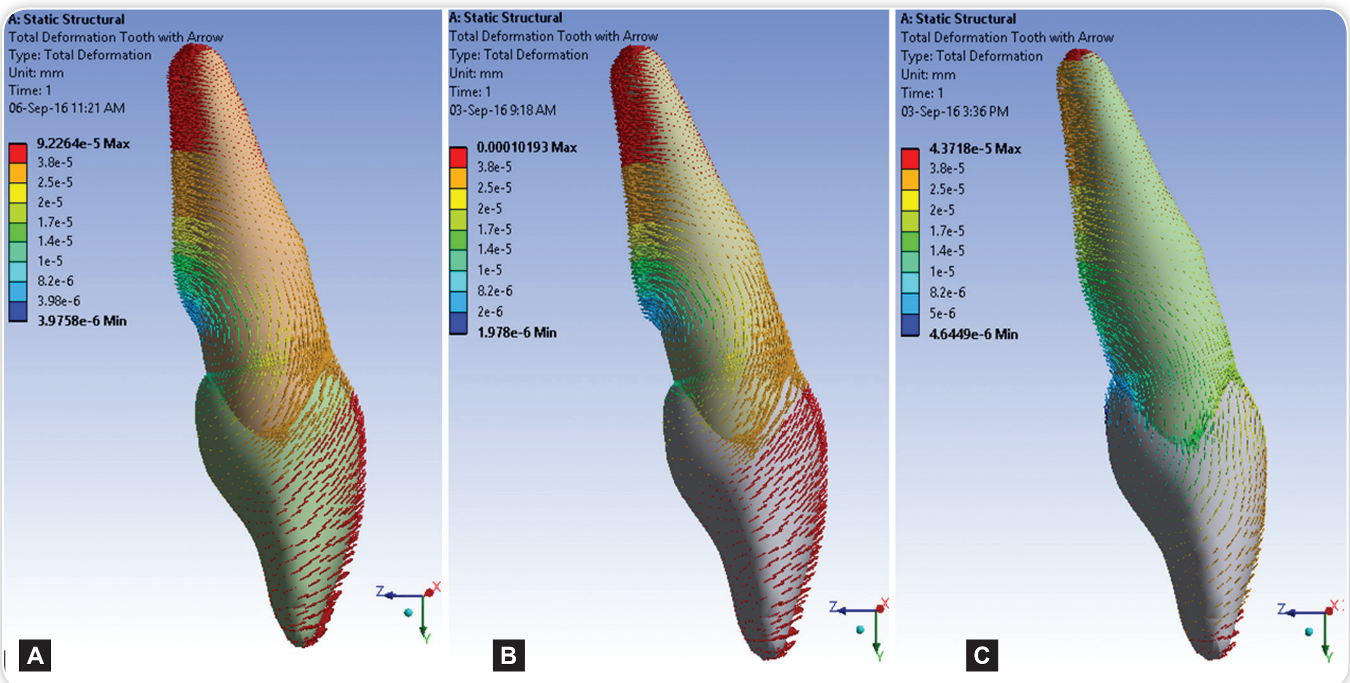
and P2 (Figs 6A and B) and on root tip (Figs 7A and B). In contrast, the CI_{CA}-17° tooth exhibits smaller area of minimum principal stress on the palatal surface and on root tip (Figs 6C and 7C). The alveolar bone adjacent to the compressed PDL causes bone resorption on palatal surface due to the horizontal force component of the intrusive force.

Figures 8A to C, shows the maximum principal stress in PDL of CI+17, CI_{CA}+17° and CI_{CA}-17°. There is larger area of PDL under maximal tensile stress (represented by red color) on the labial surface of CI_{CA}+17° extending over points A, B1 and B2, which shows the maximum tension zone. These tension zone corresponds to areas where bone deposition would occur. When we compared with the CI_{CA}-17°, there is much smaller area under maximal tensile stress on the labial surface (represented by orange color).

Figures 9A to C, shows the vectograph of the total deformation of CI+17 and CI_{CA}+17° model (Figs 9A and B) reveals that the centre of rotation is near to the point P2 i.e. around middle of the root. In case of CI_{CA}-17° model, the centre of rotation has shifted downwards around Point P3 i.e. around the cervix of the crown. This shows that there is lesser crown and more root movement occurring, thus less round tripping would occur to retract the central incisor crown.



Figures 8A to C Maximum Principal Stress on PDL of (A) CI+17,° (B) CI_{CA}+17° and (C) CI_{CA}-17° (Sectioned view)

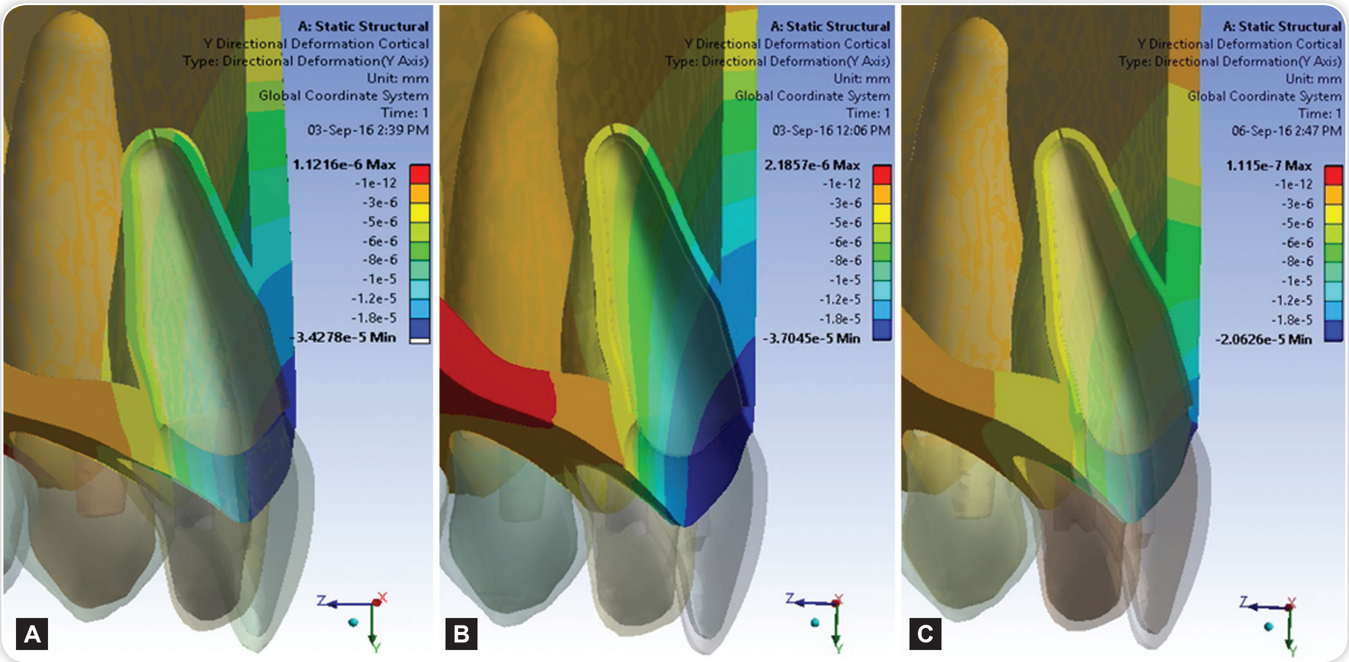


Figures 9A to C Vectograph of the Total Deformation (A) CI+17°, (B) CI_{CA}+17° and (C) CI_{CA}-17°

Figures 10A to C deformation within the palatal cortical bone of the CI+17° and CI_{CA}-17° shows lesser stress compared to the CI_{CA} +17°.

DISCUSSION

Finite element studies have provided the orthodontists with new concepts on the behavior of the oral and dental tissues



Figures 10A to C Deformation within the surrounding alveolar bone (A) CI+17°, (B) CI_{CA}+17° and (C) CI_{CA}-17°

in response to the forces.[13-15] Although it's not possible to simulate the *in vivo* conditions such as blood pressure, cellular responses, pH, and oxygen pressure precisely, results of fem studies have been found to be highly reliable.[5,15] There are significant differences in the collum angles of maxillary central incisors among different malocclusions. The abnormal axial inclination of maxillary central incisors in patients with class II, division 2 malocclusions is thought to play an important role in the development of deep bite[16], thus requiring true intrusion for correction during orthodontic treatment. Increased collum angle deviate intended axial loads for intrusion and extrusion and may cause the root to encroach on palatal cortical plate. It is feasible to partially anticipate various tooth movements with the help of FEM. Thus, in the current study effect of positive and negative torque on the stress distribution pattern over the roots and in the PDL of upper central incisors with increased collum angle, when intrusive force of 0.25 N is applied were assessed.

Numerous studies[5,6,17] have implicated that an increased collum angle affects and complicates intrusion and torque, during treatment of Class II, Division 2 malocclusions. Intrusive forces on maxillary central incisors with a pronounced Collum angle causes intrusion and palatal root translation simultaneously. Application of higher than optimal intrusive force has been suggested by these authors to address the element of the root translation.[18] Torquing of such teeth must be preceded by careful examination of the position of the root to the palatal cortical plate. As the roots might be positioned closer to the cortical plate than expected, and the danger of perforating the cortical plate is increased. Torquing of the teeth is known to induce heavy force on the root tips. Sustained heavy orthodontic forces have been reported to induce odontoclastic activity leading to root resorption. Loss of root length has been observed after intrusion of teeth within 35 days in a scanning electron microscope study (Harry and Sims, 1982)[19], but clinically there is a marked variation in time when root resorption can be observed.

Class II div 2 malocclusion is associated with deep bite needs intrusion of the retroclined incisors. The intrusive force applied to these incisors will divide into vertical and horizontal components. Application of intrusive force in the model with positive torque bracket would result in summation of the moments generated by the positive torque in the bracket as well as the horizontal component of the intrusive force, thus resulting in excessive palatal root movement. This could explain the occurrence of root resorption associated with these teeth. Studies (Farzin Heravi et al 2013)[1] have reported that during intrusion with positive torque prescription, the stress generated in the PDL of central incisors with normal collum angle was higher in teeth with increased collum angle. In our study, the stress generated in both the models i.e. normal teeth with positive torque bracket and model with negative torque bracket (CI_{CA}-

17°) were approximately similar, but significantly lower than the model with increased collum angle with positive torque bracket.

The stress in the buccal and lingual root surfaces, especially in the apical and cervical areas, was higher in CI_{CA}+17° compare to CI_{CA}-17°. The differences in the stress of the corresponding points are at the level of ten thousands, and these diversities make significant difference in the amount of the optimal force and the resultant tooth movements. Theoretically, when applying a retraction or intrusion force, the vertical distance between the point of force application and the center of resistance of the tooth would be lesser than the normal teeth. Therefore, less moment is generated and less stress is also expected in the PDL of collum angle tooth.[20,21] This FEM analysis showed the same result. The maximum principal stress on PDL of CI_{CA}+17°, shows there is larger area of stress in the PDL on the labial surface at point A, B1 and B2, which shows the maximum tension zone (Fig. 8A). When we compared with the CI_{CA}-17°, there is much lower range of stress on the labial surface (represented by orange color), therefore no maximum tension zone (Fig. 8B). Minimum principal stress is showing the area of compression in the PDL which is covering Point A, P1 and half of root so this region represent the area next to which bone resorption would occur (Figs 6 and 7). So, this figures demonstrating the effect of the horizontal component of the intrusive force which is more predominant than the vertical component. The confined zone of minimum stress area representing the compression of PDL shows that true intrusion is occurring due to predominant Y-component of the force.

This FEM study also shows that palatal cortical alveolar bone is less strained when labial root torque (-17°) is applied on teeth with increased collum angle. The use of negative torque brackets (labial root movement) produces antagonistic moments which would balance out the horizontal component of the intrusive force. Thus smaller moment results in lesser stress and better intrusion in the teeth with increased collum angle. Also, much smaller surface area of the root was seen to be stressed in the teeth fixed with negative torque brackets. This FEM analysis showed that the horizontal displacement of incisal edge and the root tip is greater in the model with +17° torque bracket than the model with -17° torque bracket, thus reducing the round tripping during these clinical procedures.

In cases where the lateral incisors are in-standing, inversion of the maxillary lateral incisor bracket is an accepted practice to bring about labial root movement. There is concern over the possibility of development of extremely high moments often above the physiologic limit when SS archwires were used in these lateral incisors. Another observation worth noting is that the reciprocal effects on adjacent teeth might override the built in torque, and the tooth may experience a moment quite different from the intended one. Thus, warranting the need for another study to explore such consequences in the central incisors with increased collum angle when bonded with inverted brackets. Thurow,[22] has recommended use of undersize archwires in these situations, also torquing moments exerted from TMA and NiTi archwires are known to be below the physiologic limit, thus making them an obvious choice in situations where very high moments are expected to be generated from SS archwires.[23]

Indiscriminate use of a prescribed bracket torque may justifiable in some patients but not of others. Increased collum angle results in different faciolingual root positions in spite of constant crown positions.[24] Customized bracket which are adjusted to individual variations in tooth morphology must be prioritized in such cases. Treatment must be customized in accordance to the biologic variation presented by the individual patient.[25] This study is bound by all the limitations of FEM models, so further researches and clinical assessment would be needed to validate our observations.

CONCLUSION

The conclusion of this study is that the maxillary central incisors with increased collum angle must be managed judiciously. The higher prevalence of root resorption seen in these teeth after orthodontic treatment warranted the need to study the stress patterns over these teeth during alignment and intrusion. In this FEM study, application of negative torque over these teeth applied via inverting the brackets resulted in better intrusion while exerting lower stress values that were extended over smaller surface area of the roots when compared to the conventional bracket placement which exerts positive torque resulting in root impingement frequently seen with such teeth. Routine collum angle assessment may be considered in orthodontic treatment planning for Angle Class II division 2 patients. The ideal position of the tooth movement should be decided by the root rather than the location of the crowns. The results of this study warn against the use of positively torque brackets, for Angle Class II division 2 subjects with increased collum angle typical. The orthodontic treatment must be tailored with respect to the biologic variations presented by the individual patient.

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