Original Article

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Comparative evaluation of variations in torque expression in maxillary incisor and canine using different bracket prescriptions placed at different crown levels by finite element (FE) method: An *in-vitro* analysis

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Abstract

OBJECTIVE: While using preadjusted brackets, the position of the bracket on the crown is one of the deciding factors that determine the tooth's final tip, torque, height, and rotation. The final tooth position is not optimal if the bracket is placed incorrectly or if the varying crown morphology does not correspond with the bracket design. The present study was conducted to evaluate and compare the variations in torque expression in maxillary incisor and canine using different bracket prescriptions placed at different crown levels by finite element method.

METHODS: For the present study, three-dimensional models of maxillary right central incisor and canine were made using CREO version 4.0 software. CREO is a powerful three-dimensional (3-D) computer-based, computer-aided design (CAD) software developed by Parametric Technology Corporation (PTC) to aid in design processes. Simulation was done to replicate the clinical situation of an active palatal root torque acting on the incisor and canine. The induced palatal movement of root tips and labial movement of crowns tips, overall stress, and von Mises stress generated in the brackets and the total equivalent strains developed in the periodontal ligament (PDL) were calculated, while the values obtained were tabulated and subjected to statistical analysis.

RESULTS: Based on the findings of the present study, the average maximum stress produced in the bracket was calculated as 265.069 Mpa in incisor and 166.742 Mpa in the canine. Likewise, the average of the maximum displacement of root apex observed in the present study was calculated as 0.01401 mm in the incisor and 0.00421 mm in the canine, while the average strain developed in the PDL was calculated as 0.0587 for incisor and 0.0498 for the canine. Furthermore, it was, also, observed that the magnitude of strain developed in the PDL increased with increase in the stress produced by the bracket prescription for both incisor and canine.

CONCLUSIONS: Within the limitations of the present study, it was concluded that the magnitude of displacement of root apex was significantly influenced by bracket prescription and bracket position. Also, the stress developed in the bracket was influenced by bracket prescription and position, while the variation in crown morphology in the incisor and canine played a significant role in the eventual strain developed in the PDL after torque application.

Keywords:

Bracket prescription, canine, finite element analysis, *in-vitro* study, maxillary incisor, torque expression

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Introduction

Angle introduced the edgewise system based on a three-dimensional (3-D) tooth control obtained by engaging a rectangular wire into a bracket with a rectangular slot.[1] Andrews took advantage of the control offered by the edgewise system and advocated the use of the straight wire appliance.[2] While using preadjusted brackets, the position of the bracket on the crown determines the tooth's final tip, torque, height, and rotation.[3] The final tooth position is not optimal if the bracket is placed incorrectly or if the varying crown morphology does not correspond with the bracket design.[4] Vertical bracket positioning and its effect on torque and tooth inclination has been extensively studied, while it was found that a difference of even 1 mm in the height of bracket placement might produce as much as 10° variation in torque expression.[5,6] A prescribed bracket height has been proposed for each bracket system for obtaining the optimal, final inclination. The prescribed heights for bracket placement have been different according to different philosophies such as by Alexander RG[7] (1983), Ricketts RM[8] (1984), Kesling PC[9] (1988), and Bennett and McLaughlin[10] (1997), varying between 4-5 mm for the incisors and 4.5-5 mm for the canines from the incisal edges. Creekmore and Kunik[11] suggested that bonding brackets according to the overbite can result in a difference in height of almost 1 mm. Muchitsch *et al*.[12] proposed that depending on the varying crown morphology of the incisal third of the crown, the bond height for canines might vary by 0.5 mm. All these suggestions result in a different effect on the final torque of a tooth. Even if bracket attachment is performed perfectly, variations in tooth morphology would render any prescription variable in obtaining ideal tooth positions.[13] Root resorption, a sequel of orthodontic treatment, has been linked to the amount of torque applied to a tooth.[14] Proper buccolingual inclination of both posterior and anterior teeth is essential for providing stability and proper occlusal relationship in orthodontic treatment. The torque achieved in case of maxillary anterior teeth is particularly critical in this regard in establishing an esthetic smile line, proper anterior guidance, and an ideal Class I relationship because undertorqued anterior teeth can preclude retraction of the anterior maxillary dentition. Suboptimal torque of incisors and canines can deprive space in the dental arch, while suboptimal torque of the posterior teeth might not allow appropriate cusp to fossa relationships between the maxillary and mandibular teeth. Rauch E[15] described torque as a moment generated by the torsion of a rectangular wire in the bracket slot. Depending on the amount of torsion, the size and quality of the wire, the play of the wire in the bracket slot, and the angulation and deformability of the bracket, the arch wire moves the root in buccal or lingual direction due to the torsional load induced.[16] The development of a finite element (FE) model makes it possible to quantify and evaluate the effects of torsional forces applied to achieve tooth movement.[17] The optimal treatment outcomes require effective torque expression which is sensitive to variations in tooth morphology, the size, morphology, and engagement of the arch wire in the bracket, as well as the position, material properties, and slot size of the bracket. In this context, canines, in particular, have variable crown morphology and vertical error in bracket placement has major variations in the expression of torque.[4] There were no studies comparing torque expression between maxillary incisor and canine using standard edgewise brackets. The present study was conducted to evaluate and compare the variations in torque expression in maxillary incisor and canine using different bracket prescriptions placed at different crown levels by FE method.

Materials and Methods

The objectives of the present FE analysis study were to study the stress distribution in the brackets, and hence, the torqueing force in the bracket slots, and subsequent, strain in the periodontal ligament (PDL), that particular portion of the periodontium which acts as the attachment of the teeth to the surrounding alveolar bone through the cementum, and alveolar bone, by placing the arch wire into the bracket slot. The FE parameters used in the study are listed in Table 1, while the biomechanical properties of the materials used in the present study are listed in Table 2. The objectives and need for the study were approved by the Institutional Ethics and Review Board via. Letter approval no. SDDC/IERB/01-46-2022 before the start of the study. For the present study, 3-D models of maxillary right central incisor and canine were made using CREO version 4.0 software based on the measurements taken from Nelson and Ash[18] Wheeler's Dental Anatomy, Physiology, and Occlusion [Table 3]. CREO is a family of computer-aided design applications supporting product design for discrete manufacturers developed by Parametric Technology Corporation (PTC). The suite consists of applications with each application delivering a distinct set of capabilities for a user role within product development. CREO runs on Microsoft Windows and provides applications for 3-D computer-aided design parametric feature solid modeling, 3-D direct modeling, 2-D orthographic views, FE analysis and simulation, schematic design, technical illustrations, and viewing and visualization. CREO can, also, be paired with Mastercam (Machining based software) to machine any designed model in a minimal timeframe. The PDL and alveolus were constructed considering uniform thickness of 0.2 mm and 0.5 mm, respectively, while the brackets were designed by CREO according to the measurements provided by the manufacturers

Table 1: Finite element (FE) parameters used in the study

	Materials used in the study			
Assignment	**Bone**	**Tooth**	**Bracket**	**Wire**
Nonlinear Effects			Yes	
Thermal Strain Effects			Yes	
Properties				
Volume	303.76 mm^3	472.95 mm^3	11.733 mm^3	2.8 mm^3
Centroid X	0.19143 mm	2.865e-003 mm	-2.1733e-007 mm	-2.6434e-016 mm
Centroid Y	7.7668 mm	3.3546e-002 mm	-1.6552 mm	-1.6576 mm
Centroid Z	8.5276e-004 mm	0.21819 mm	3.6987 mm	4.5341 mm
Statistics				
Nodes	1636	1927	9703	164
Elements	860	1014	5267	13

Table 2: Material properties of materials used in the study

Material	Young's modulus (in Mpa)	Poisson's ratio
Bone	2000	0.30
Periodontal ligament (PDL)	Bilinear: 0.05/0.20 Ultimate strain e12:7.0%	0.30
Tooth	20000	0.30
Adhesive-composite resin	8823	0.25
Brackets	200000	0.30
Wire-TMA	65000	0.30

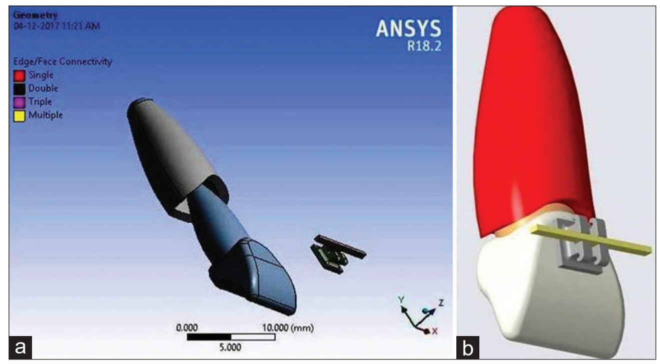


Figure 1: (a and b) (Left to Right) (a) Dismantled (schematically represented) and (b) assembled (with bracket and arch wire fixed to the tooth) three-dimensional (3-D) incisor model

in 0.018 inch slot (0.46 mm). The 0.018 inch bracket slot was selected for better torque expression compared to 0.022 inch slot.[19] A partial orthodontic fixed appliance was, then, constructed with the recommended stainless steel metal bracket of 0.018 inch slot, while a composite adhesive layer of thickness 0.2 mm was used to fix the bracket to the tooth and a rectangular titanium molybdenum alloy wire (also called as β titanium wire) of dimensions 0.46 mm × 0.64 mm (0.018 × 0.025 inch) was passively inserted into the bracket slot [Figures 1a, b; and 2a, b]. The brackets were constructed in three torque prescriptions for central incisor including no torque in the standard edgewise bracket system with torque value of 0^o, medium torque in the Roth bracket system with torque value of 12^o, and high torque in the Rickets bracket system with torque value of 22^o [Figure 3a, b] [Table 4]. The torque prescriptions for the brackets for maxillary canine included no torque in the standard edgewise bracket system with torque value of 0^o, positive torque in the McLaughlin, Bennett, and Trevisi (MBT) bracket system with torque value of $+7^o$, and negative torque in the MBT bracket system with torque value of -7^o [Figure 3a, b] [Table 5]. The MBT bracket system has been the mainstay in the practice of orthodontics since its introduction by McLaughlin, Bennett, and Trevisi[20] in the year 1993. The vertical positions of the bracket on the labial surface of the incisor and canine crown chosen were at the center of the middle third of the crown, at the center of the apical third of the crown, and at the center of the incisal third of the crown. A total of 18 3-D models (nine models each for central incisor and canine) were constructed. Based on the FE model, FE mesh was constructed and a node to node connection was made between brackets, adhesives, PDL, and alveolar bone [Figure 4a, b]. The FE mesh of brackets and arch wire were created separately. The 3-D FE model consisted of 7,154 solid elements and 13,430 nodes. Simulation was done to replicate the clinical situation of an active palatal root torque acting on the incisor and canine [Figure 5a and b]. A torsional moment of 2 Newton (N) was applied in the bracket slot.[21] The boundary conditions included were holding the apical bone surface and keeping the ligatures tight with a spring nodal tie. The overall stress [Figure 6a and b], and von Mises stress [Figures 7a, b; and 8a, b] generated in the brackets, induced palatal movement of root tips and labial movement of crowns tips [Figure 9a and b], and the total equivalent strains developed in the PDL [Figure 10a and b] were calculated, while the values obtained were tabulated and presented in the form of Tables and Graphs. All simulation was performed with FE software Ansys version 18.2.

Results

In the present study, maximum displacement of the tooth was observed at the root apex where stress distribution had the maximum value, while the strains developed in

Table 3: Dimensions of teeth taken from *Wheeler*'s dental anatomy, physiology, and occlusion

Tooth selected	Crown length (in mm)	Root length (in mm)	Mesiodistal diameter of crown (in mm)	Mesiodistal diameter of crown at cervix (in mm)	Labiolingual diameter of crown (in mm)	Labiolingual diameter at cervix (in mm)
Maxillary central incisor	10.5	13.0	8.5	7.0	7.0	6.0
Maxillary canine	10.0	17.0	7.5	5.5	8.0	7.0

Table 4: Bracket dimensions used for maxillary central incisor

Name (Appliance)	Slot (in inch)	Torque (in degrees)	Angulations	In/Out (in mm)	Height (in mm)	Width (in mm)
Standard Edgewise	0.018×0.03	0	0	0.7	3.0	3.5
Roth	0.018×0.03	12	5	0.7	3.4	3.9
Ricketts	0.018×0.03	22	5	0.7	3.5	4.3

Table 5: Bracket dimensions used for maxillary canine

Name	Slot (in inch)	Torque (in degrees)	Angulations	In/Out (in mm)	Height (in mm)	Width (in mm)
MBT 18	0.018×0.03	0	0	0.7	3.8	3.5
MBT 18	0.018×0.03	+7	8	0.7	3.8	3.5
MBT 18	0.018×0.03	-7	8	0.7	3.8	3.5

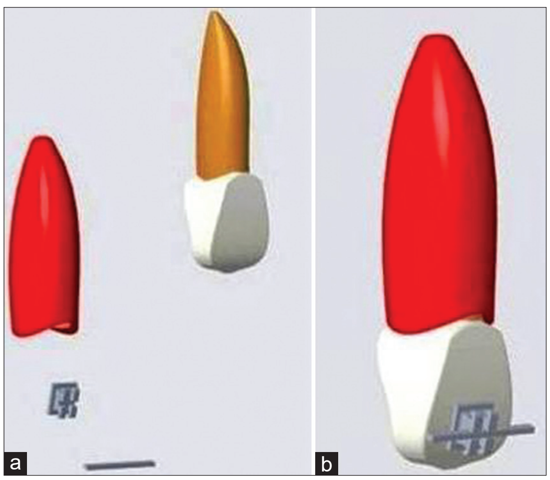


Figure 2: (a and b) (Left to Right) (a) Dismantled (with individual units- bracket and arch wire) and (b) assembled (with bracket and arch wire fixed to the tooth) three-dimensional (3-D) canine model

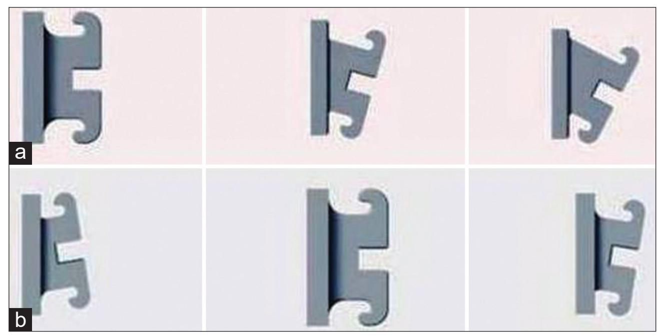


Figure 3: (a and b) (Left to Right) Bracket profile views for (a) Incisor brackets- a. 1) 0 degree torque, a. 2) +12 degree torque, and a. 3) +22 degree torque; and (b) Canine brackets- b. 1) -7 degree torque, b. 2) 0 degree torque, and b. 3) +7 degree torque

the PDL were observed mostly at the apical regions of the tooth wherein the root tips were displaced {(Graphs 1-3 for incisor) and (Graphs 4-6 for canine)}. Also, stress in the brackets was mostly concentrated at the bracket walls where the wire edges came into contact with the brackets. With increasing torque values of the brackets, an increase in torque expression was observed for both incisor and canine. Also, the von Mises stress produced in the brackets along with the displacement observed in relation to the tooth increased with an increase in the torque values of the brackets, while strain developed in the PDL increased correspondingly with an increase in stress levels in the brackets for both incisor {[Tables 6-8 and Graphs 7-9 for incisor] and [Tables 9-11 and Graphs 10-12 for canine]}. Comparing the torque expression of maxillary incisor with canine, maxillary incisor had more amount of torque expression which was indicated by more amount of apical displacement in the incisor than canine [Table 12 and Graphs 13-15]. Based on the findings of the present study, the average maximum stress produced in the bracket was calculated as 265.069 Mpa in incisor and 166.742 Mpa in the canine. Likewise, the average of the maximum displacement of root apex observed in the present study was calculated as 0.01401 mm in the incisor and 0.00421 mm in the canine, while the average strain developed in the PDL was calculated as 0.0587 for incisor and 0.0498 for the canine. Furthermore, it was, also, observed that moving the brackets from the middle third of the crown to incisal third led to a decrease in torque expression which was indicated by the displacement of the root apex. Also, moving the brackets apically from the middle third of the crown produced more strain in the PDL, while stated conversely, moving the brackets toward the incisal third produced less strain in the PDL both in case of incisor and canine.

Discussion

The objective of the present FE study was to assess the influence of tooth morphology, bracket placement, and

Table 6: Displacement, stress, and strain in the PDL produced by 0-degree torque in the incisor

Torque (in degrees)	Position	Maximum displacement		von Mises stress		Strain in the PDL	
		(in mm)	(in %)	(in Mpa)	(in %)	(in mm)	(in %)
0	Incisal	0.00491	-15.03	147.408	-11.8	0.0338	-42.38
	Middle	0.00578	0	167.129	0	0.0587	0
	Gingival	0.007232	25.11	187.986	12.48	0.0659	12.39

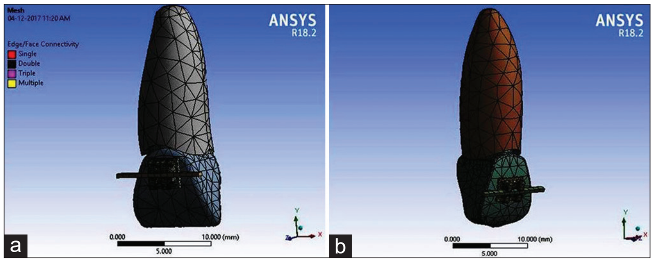


Figure 4: (a and b) (Left to Right) Meshing of (a) incisor and (b) canine models with bracket and arch wire assembly

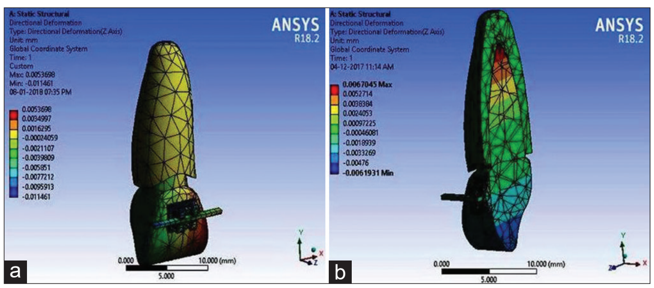


Figure 6: (a and b) (Left to Right) Overall stress in the tooth

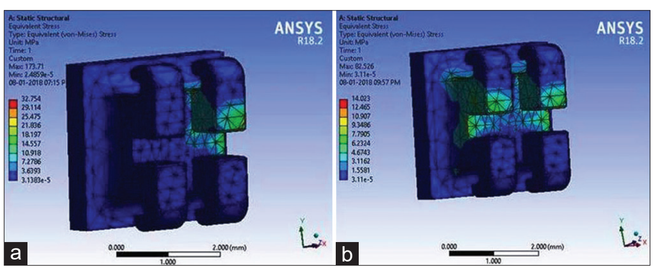


Figure 8: (a and b) (Left to Right) von Mises stress in the (a) incisor and (b) canine brackets

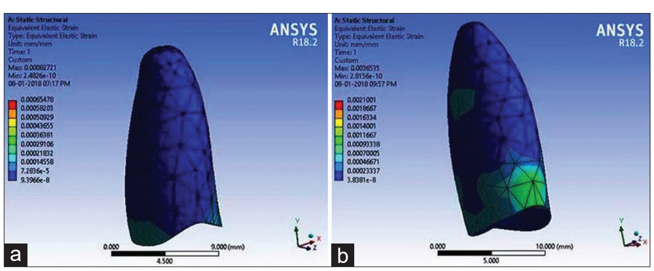


Figure 10: (a and b) (Left to Right) Strain in the periodontal ligament (PDL) of (a) incisor and (b) canine models

bracket prescription on the biomechanics of torque expression. The initial studies conducted in this regard have concluded that the displacement of tooth was mainly influenced by bracket prescription and positioning, while

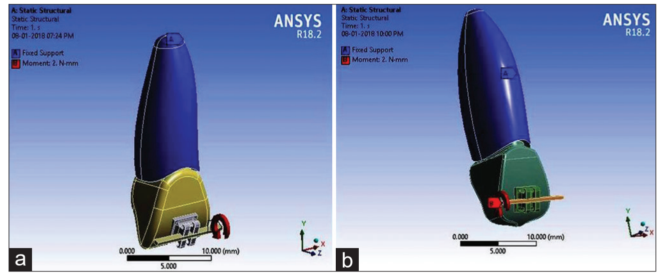


Figure 5: (a and b) (Left to Right) Torquing moment for palatal root torque

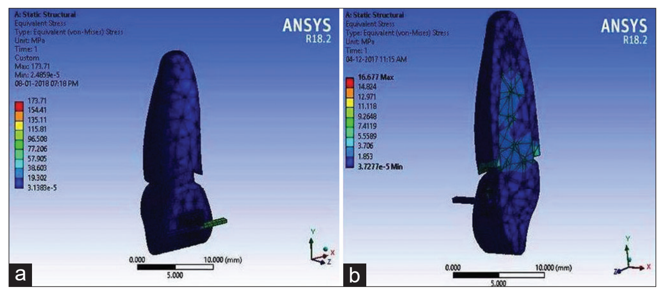


Figure 7: (a and b) (Left to Right) von Mises stress in the tooth

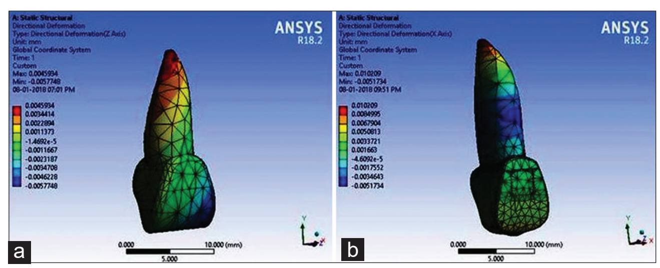
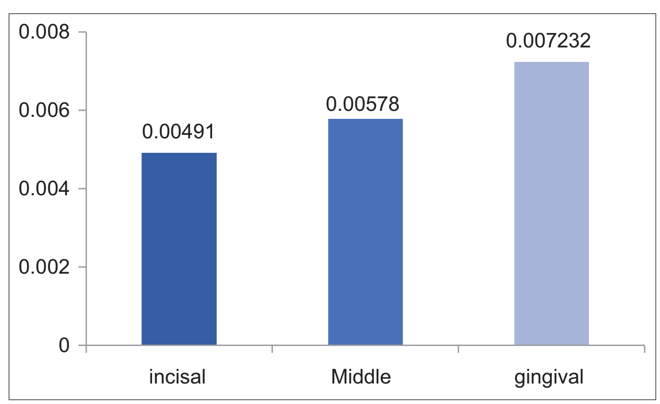
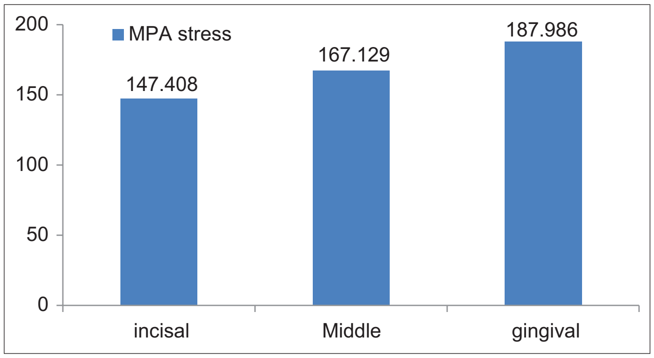


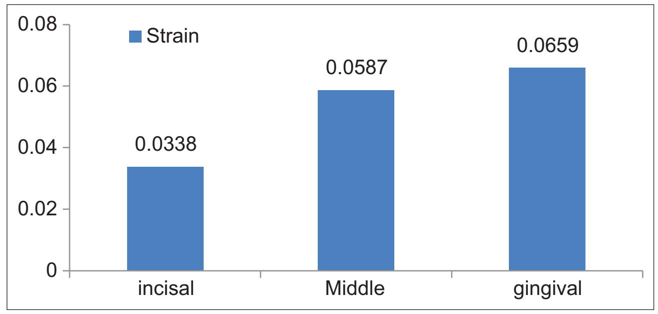
Figure 9: (a and b) (Left to Right) Displacement of apex in the (a) incisor and (b) canine models



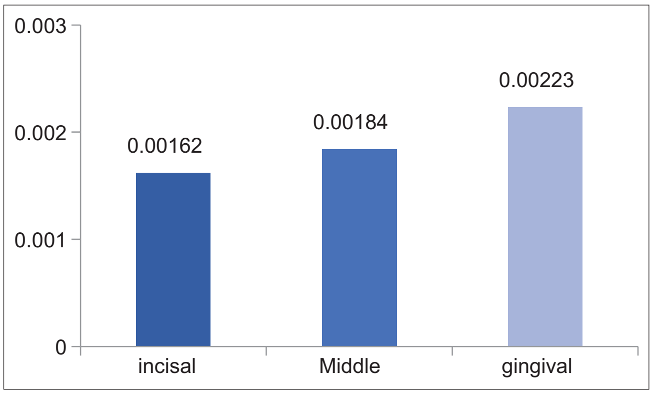
Graph 1: Maximum apical displacement of root by bracket placed at three different crown levels in the incisor



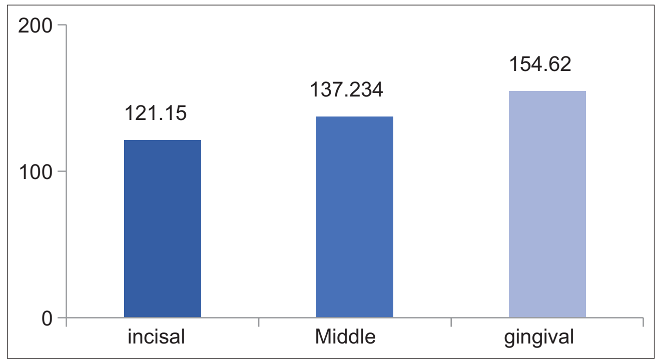
Graph 2: von Mises stress produced by bracket placed at three different crown levels in the incisor



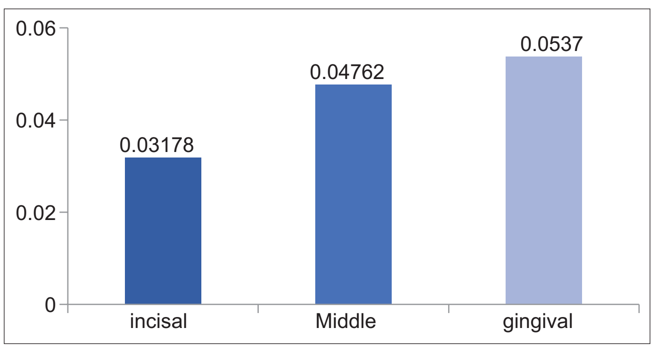
Graph 3: Strain developed in the PDL by bracket placed at three different crown levels in the incisor



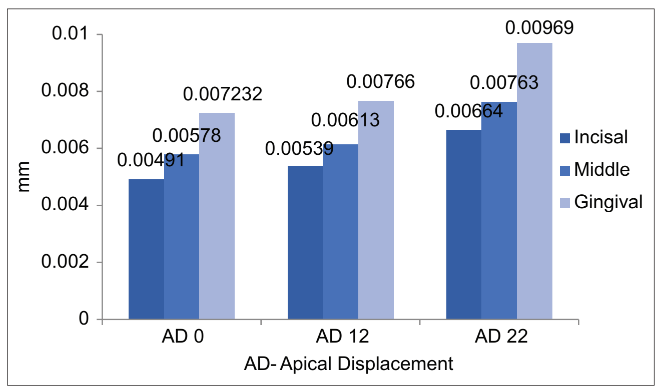
Graph 4: Maximum apical displacement of root by bracket placed at three different crown levels in the canine



Graph 5: von Mises stress produced by bracket placed at three different crown levels in the canine



Graph 6: Strain developed in the PDL by bracket placed at three different crown levels in the canine



Graph 7: Maximum apical displacement of root by 0-degree, +12-degree, and +22-degree torque in the bracket placed at three different crown levels in the incisor

the strain developed was subjective to the crown root angulations and bracket positioning.[19] In addition, the stress developed in the bracket was, also, controlled by bracket prescription. Orthodontic treatment is based on the use of various appliances which produce a force that causes orthodontic tooth movement. The force applied to the tooth produces stresses, and correspondingly, strain in the surrounding PDL and alveolar bone transferred via mechano-transduction for effective remodeling inducing orthodontic tooth movement.[11]

Torque in orthodontics plays a key role in the final positioning of the teeth during fixed appliance therapy.[22] It is a complex biomechanical phenomenon which is influenced by multiple factors which include tooth anatomy, crown morphology, material properties, bracket prescription, and bracket position. According to Andrews LF's[23] six keys of occlusion, crown inclination refers to the labiolingual and buccolingual inclination of the long axis of the crown and it is considered to be one of the major factors for stability after orthodontic treatment. The FE method is an approximation technique used by numerical equations. This method has been suggested by many authors for studying stress and deformation.[24,25] The development of an FE model makes it possible to

Table 7: Displacement, stress, and strain in the PDL produced by +12-degree torque in the incisor

Torque (in degrees)	Position	Maximum displacement		von Mises stress		Strain in the PDL	
		(in mm)	(in %)	(in Mpa)	(in %)	(in mm)	(in %)
+12	Incisal	0.00539	-12.42	223.159	-10.9	0.0466	-23.74
	Middle	0.00613	6.04	250.459	49.86	0.0611	4.23
	Gingival	0.00766	24.19	283.043	13.01	0.0701	14.76

Table 8: Displacement, stress, and strain in the PDL produced by +22-degree torque in the incisor

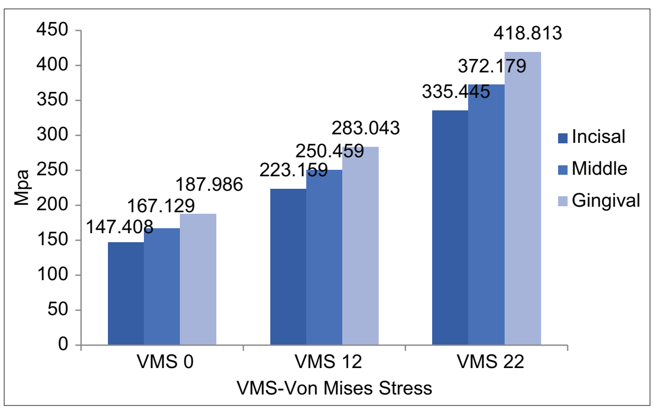
Torque (in degrees)	Position	Maximum displacement		von Mises stress		Strain in the PDL	
		(in mm)	(in %)	(in Mpa)	(in %)	(in mm)	(in %)
+22	Incisal	0.00664	-13	335.445	-9.87	0.04606	-33.64
	Middle	0.00763	32.21	372.179	122.69	0.0694	17.63
	Gingival	0.00969	27.17	418.813	12.53	0.0774	11.62

Table 9: Displacement, stress, and strain in the PDL produced by 0-degree torque in the canine

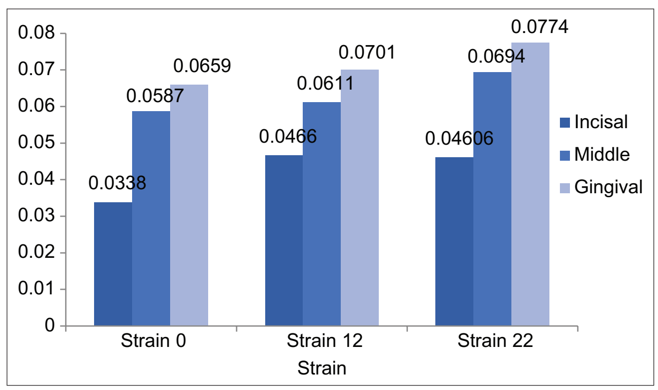
Torque (in degrees)	Position	Maximum displacement		von Mises stress		Strain in the PDL	
		(in mm)	(in %)	(in Mpa)	(in %)	(in mm)	(in %)
0	Incisal	0.00162	-12.02	121.15	-11.72	0.03178	-33.27
	Middle	0.00184	0	137.234	0	0.04762	0
	Gingival	0.00223	21.42	154.62	12.67	0.0537	12.78

Table 10: Displacement, stress, and strain in the PDL produced by +7-degree torque in the canine

Torque (in degrees)	Position	Maximum displacement		von Mises stress		Strain in the PDL	
		(in mm)	(in %)	(in Mpa)	(in %)	(in mm)	(in %)
+7	Incisal	0.00167	-11.34	161.787	-10.87	0.04021	-27.45
	Middle	0.00188	4.03	181.519	32.27	0.05542	16.39
	Gingival	0.002324	23.11	208.223	14.71	0.0611	10.26



Graph 8: von Mises stress produced by 0-degree, +12-degree, and +22-degree torque in the bracket placed at three different crown levels in the incisor



Graph 9: Strain developed in the PDL by 0-degree, +12-degree, and +22-degree torque in the bracket placed at three different crown levels in the incisor

quantify and evaluate the effects of torsional forces applied to achieve tooth movements.[17]

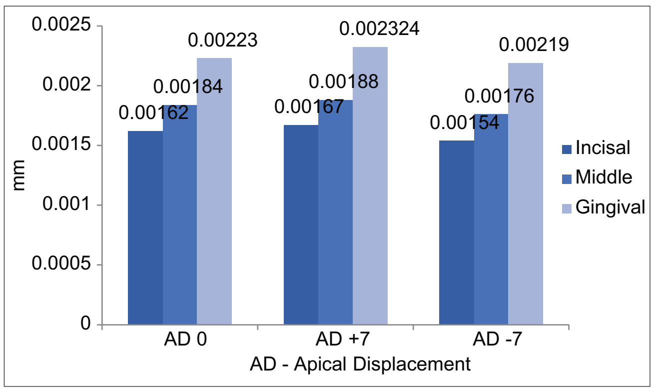
The anatomy of the anterior teeth, especially incisors and canine, has great variation in the crown root angulations and labial convexity. It is due to this reason that minor variations in bracket positioning and bracket prescription and the labial crown morphology have great control on torque expression for the anterior teeth. While torqueing the incisors, the labial cortical bone thickness and crown root angulations of the root must be considered. Improper torque application may lead to root resorption and dehiscence due to abnormal pressure on the root on the labial cortex.[26] The inclination of anterior teeth is essential to achieve a Class I canine and molar relation. Since there is a great variation in the morphology of incisor and canine, the amount and direction, that is, the labial or palatal root torque has to be decided according to the clinical scenario. Holdaway RA[27] stated that a good labial axial inclination of upper incisors was essential for apical base reorientation and bodily retraction of anterior teeth. This, further, produced a more marked reduction in the sella, nasion, A point angle (sella, nasion, A point

Table 11: Displacement, stress, and strain in the PDL produced by -7-degree torque in the canine

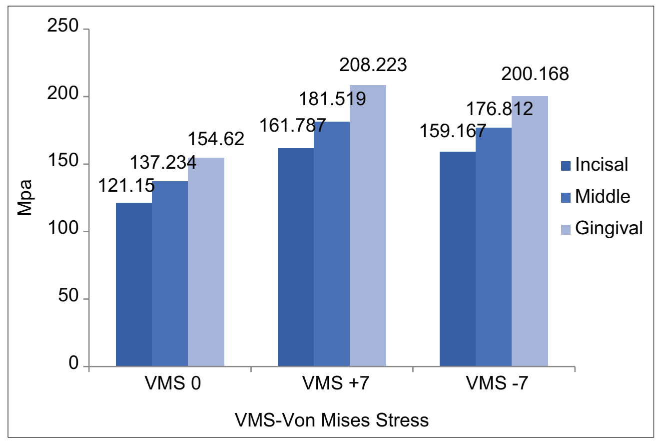
Torque (in degrees)	Position	Maximum displacement		von Mises stress		Strain in the PDL	
		(in mm)	(in %)	(in Mpa)	(in %)	(in mm)	(in %)
-7	Incisal	0.00154	-12.45	159.167	-9.98	0.03884	-29.76
	Middle	0.00176	-4.216	176.812	28.84	0.05529	15.98
	Gingival	0.00219	24.51	200.168	13.21	0.06444	16.56

Table 12: Comparison of torque expression of incisor and canine by 0-degree torque at three different crown levels

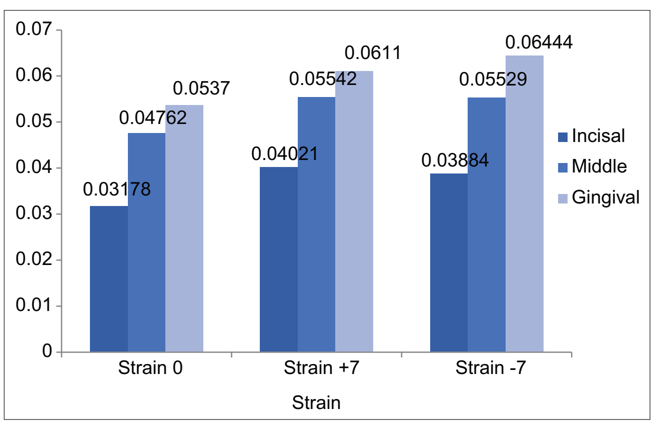
Torque (in degrees)	Position	Incisor						Canine					
		Maximum displacement		von Mises stress		Strain in the PDL		Maximum displacement		von Mises stress		Strain in the PDL	
		(in mm)	(in %)	(in Mpa)	(in %)	(in mm)	(in %)	(in mm)	(in %)	(in Mpa)	(in %)	(in mm)	(in %)
0	Incisal	0.00491	-15.03	147.408	-11.8	0.0338	-42.38	0.00162	-12.02	121.15	-11.72	0.03178	-33.27
	Middle	0.00578	0	167.129	0	0.0587	0	0.00184	0	137.234	0	0.04762	0
	Gingival	0.007232	25.11	187.986	12.48	0.0659	12.39	0.00223	21.42	154.62	12.67	0.0537	12.78



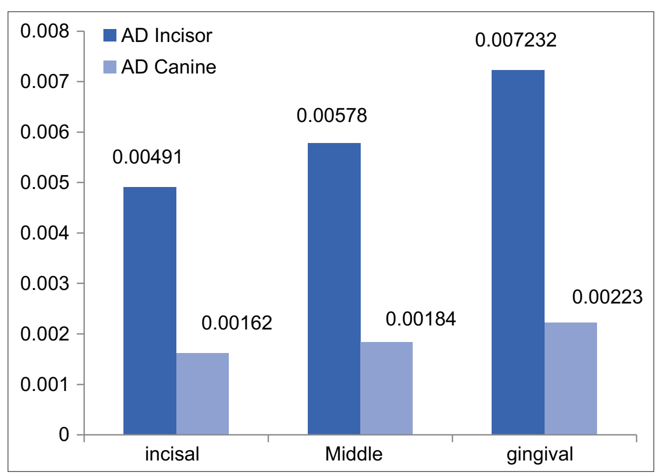
Graph 10: Maximum apical displacement of root by 0-degree, +7-degree, and -7-degree torque in the bracket placed at three different crown levels in the canine



Graph 11: von Mises stress produced by 0-degree, +7-degree, and -7-degree torque in the bracket placed at three different crown levels in the canine



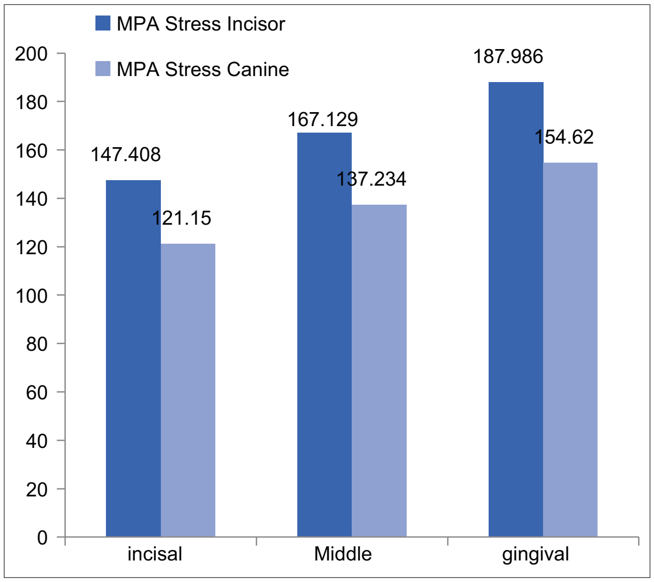
Graph 12: Strain developed in the PDL by 0-degree, +7-degree, and -7-degree torque in the bracket placed at three different crown levels in the canine



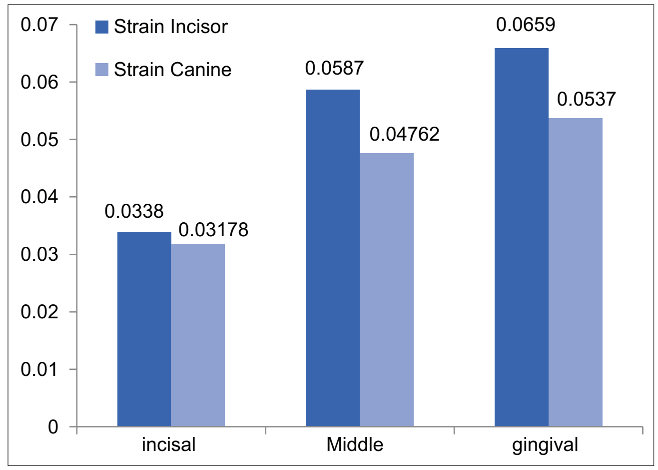
Graph 13: Maximum apical displacement of root in incisor vs. canine by 0-degree torque in the bracket placed at three different crown levels

used to indicate whether or not the maxilla is normal, prognathic, or retrognathic) than to mere lingual tipping movements of the teeth.

Variability in tooth morphology is an important consideration in the attainment of an optimal occlusion of teeth. In similar context, Bryant *et al.*[28] studied variation in the morphology of maxillary incisor and its clinical implication in torque application according to the variation in tooth anatomy. In yet another study, Germane *et al.*[4] studied the contours of the facial surface of canine and their effect on the tip and torque present in the preadjusted appliances used in the study and



Graph 14: von Mises stress produced by 0-degree torque in the bracket placed at three different crown levels in incisor vs. canine



Graph 15: Strain developed in the PDL by 0-degree torque in the bracket placed at three different crown levels in incisor vs. canine

concluded that the effective torque of the brackets was influenced by the tooth morphology at the bracket's base, while the presence of these normal biologic variables either enhanced or minimized the torque supplied by the preadjusted appliances depending on a combination of the bracket prescription used and the biologic variable present.

Based on the observations made in the previous studies, the present study was based on maxillary incisor and canine which have wide variations in the crown root angulations and labial surface contours.[4,28] In the present study, variation in torque due to labial morphology of incisor and canine were evaluated in terms of bracket prescription and positioning. Sardarian *et al.*[29] had conducted a similar study in relation to mandibular first premolar and concluded that the variation in the vertical positioning of the bracket can have an important effect on the torque and subsequently on the stresses and pressures developed in the PDL. The findings of the present study were in close accordance with the previous literature and studies conducted in this regard wherein a significant difference was noted in torque expression, stress produced in the bracket, and strain developed in the PDL due to variations in the crown morphology.

The observations made in the present study, also, revealed that maximum root displacement was seen at the apex when applying a palatal torsional force. Also, as per the observations made in the present study, maximum stress was produced in the incisor bracket having the highest torque in the bracket (+22 degree). Comparing the torque using the standard edgewise bracket in the incisor and canine, placing the bracket in the middle third of the crown produced more torque in the incisor than canine. Also, while moving the bracket from the middle to incisal third, a decrease in root displacement both in incisor and canine was observed. Similarly, movement of the bracket from the middle to the apical third led to an increase in root displacement both in incisor and canine. The observations made in the present study, also, suggested that tooth anatomy and labial contour had a definite impact on the strain developed in the PDL, while this strain developed in the PDL produced the biologic effect in producing tooth movement.

Several considerations should be taken in to account when interpreting the results of the present study which aimed at evaluating the net effective torque on the tooth and the surrounding supporting structures. In the present study, full-size arch wires were used, while in most of the contemporary and previous studies conducted, dimensional inaccuracies in slot size and arch wire have been observed during manufacture. Also, the interplay of variables at the bracket-arch wire interface decreases the net effective torque. In similar context, torqueing moment was applied to the individual tooth units in the present study which is not the actual clinical scenario wherein the net torque produced depends on the adjacent tooth position and inclination. In the actual clinical conditions, bracket prescription, bracket position, and the limited or available labial and buccal alveolar bone thickness should be considered in achieving the proper torque needed. The proper selection of brackets for labiolingual inclination and positioning of the brackets at the prescribed levels produce an optimal crown inclination. The labial contour of the tooth should, also, be considered when bonding brackets to achieve desired crown inclination. To conclude, apart from crown morphology, various other factors such as bracket slot size, material properties of the arch wire, arch wire size, position of the adjacent teeth, interplay of variables at the bracket-arch wire interface, and the biological response have all been suggested to play a combined and significant role in the net effective expression of torque required for optimal orthodontic outcome.

Limitations of present study

One of the major limitations of the present study was that the PDL was assumed to have isotropic and elastic behavior, while this may not be the actual clinical condition. Also, the virtual mechanical properties of the materials differ from the actual desirable properties, while the behavior of materials changes in the actual clinical condition. Furthermore, the neighboring teeth were not taken into account for the analysis, while torqueing moment was applied to the individual tooth units which is not the actual clinical scenario wherein the net torque produced depends on the adjacent tooth position and inclination.

Conclusions

In the present study, amount of root displacement, stress produced in the bracket, and subsequent strain developed in the PDL were quantified in relation to variation in crown morphology, bracket prescription, and bracket position. Within the limitations of the present study, it was concluded that the magnitude of displacement of root apex was significantly influenced by bracket prescription and bracket position. Also, the stress developed in the bracket was influenced by bracket prescription and position, while the variation in crown morphology in the incisor and canine played a significant role in the eventual strain developed in the PDL after torque application. Furthermore, based on the observations made in the present study, it was found that maxillary incisor had more displacement of the root apex than canine, while the stress produced in the bracket and the strain developed in the PDL were, also, more in incisor than in canine for the similar degrees of torque applied. The findings of the present study, thus, suggested that preadjusted edgewise bracket system can produce variable amount of torque depending on factors like tooth anatomy, crown root angulations, material properties, bracket prescription, bracket-arch wire interaction, and bracket position. The present study, although, is an in-vitro analysis. Further clinical studies are needed for correlating the results obtained in the actual clinical settings.

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Conflicts of interest

There are no conflicts of interest.

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