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Original Research

Evaluation of stresses produced around the root of teeth with different orthodontic treatment approaches

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***ABSTRACT*:**
Background: Orthodontic mini-implants (OMIs) are used for various anchorages. For treatment of bialveolar protrusion, anchorage preservation during space closure is important for maximum retraction of the anterior teeth after premolar extractions. OMIs have been reported to be effective anchorage for en-masse space closure. When using mini implants we must understand the stress and strain distribution in the bone around the implant. Stability of the mini-implant again relies on degree of inflammation, accompanying local irritation, quality and quantity of cortical bone, proximity of mini-implant to the roots of adjacent teeth. **Aim of the study:** To **e**valuate the stresses produced around the root of teeth, when placed at different distances from the root of the maxillary first molar and to evaluate the influence of the magnitude of the force applied on the resultant stresses generated. **Materials and methods:** The present study was conducted in the Department of Orthodontics of the Dental institution. The ethical clearance for the study was approved from the ethical committee of the hospital. Finite element modeling is the representation of geometry in terms of a finite number of elements and their connection points known as nodes. These are the building blocks of numerical representation of the model. The elements present are of finite number as opposed to a theoretical model with complete continuity. **Results:** On comparing all the teeth with different forces, the highest maximum stress was to be found in the second molar by varying implant placement height, with and without Curve of Spee. On comparing all the teeth with different forces, the highest maximum stress was found in the second molar followed by first molar, second premolar, lateral incisor, central incisor and then canine in varying implant placement height with & without Curve of Spee. On comparing all the teeth with different forces, the highest maximum stress was found at 16mm implant height compared to 13mm and 10mm implant height anterior to the extraction space. **Conclusion**: Within the limitations of the present study, it can be concluded that irrespective of the height of implant placement, the maximum stress generated on the root surface was at the last molar included in the set up in the second molar. Anterior to the extraction space, the stress increases as the implant height increases and the posterior to extraction space stress increases as the implant height decreases. This can be attributed to greater stress generated by the larger vertical component anteriorly and larger horizontal component posteriorly.
Keywords: Dental protrusion, Orthodontic treatment, mini implant, maximum force

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Introduction:

Dental protrusion is common in many ethnic groups around the world. It is characterized by dentoalveolar flaring of maxillary or both the maxillary and the mandibular anterior teeth with resultant protrusion of the lips and the convexity of the face. The present trend to treat protrusion is extraction of the 4 first premolars, followed by anterior tooth retraction to obtain the desired dental and soft-tissue profile changes. [1] Osseointegrated implants are considered reliable sources of anchorage for orthodontists. However, the large size of these implants limits their usage. To overcome this problem, mini-implants were developed. Their advantages, in addition to size, include minimal anatomic limitations, minor surgery, increased patient comfort, immediate loading, and lower costs. Because these devices are used for specific time periods, mostly rely on mechanical retention, and do not always osseointegrate. Though terms such as mini-screws, miniscrew implants, micro-screw, and temporary anchorage devices have been used, there is no general agreement on the nomenclature. The term "mini-implant" is used because it is currently the most frequently used in the orthodontic literature. Many mini-implants are now available, and orthodontists are trying to incorporate them in various clinical situations.[2] Orthodontic mini-implants (OMIs) are used for various anchorages. For treatment of bialveolar protrusion, anchorage preservation during space closure is important for maximum retraction of the anterior teeth after premolar extractions. OMIs have been reported to be effective anchorage for en-masse space closure. [3] The Curve of Spee (COS) is a naturally occurring phenomenon in the human dentition. this Curve of occlusion was first described as the line on a cylinder tangent to the anterior border of the condyle, the occlusal surface of the second molar, and the incisal edges of the mandibular incisors. Andrews mentioned a natural tendency for deepening of the COS with aging. [4] Hemley described the COS as mesial tipping of the mandibular molar and distal tipping of the mandibular canine with the 2 premolars locked below the line of occlusion. He indicated that these conditions create a exaggerated COS; by distally uprighting the molar and mesially uprighting the canine, the 2 premolars will be free to erupt into the line of occlusion. [4] When using mini implants we must understand the stress and strain distribution in the bone around the implant. Stability of the mini-implant again relies on degree of inflammation, accompanying local irritation, quality and quantity of cortical bone, proximity of mini-implant to the roots of adjacent teeth. Stress analyses of implants are necessary for the investigation of maximum anchorage possible. Since clinical determination of stress distribution in the bone is not possible, the use of alternative technique have been investigated. [5] Hence, the present study was conducted to **e**valuate the stresses produced around the root of teeth, when placed at different distances from the root of the maxillary first molar and to evaluate the influence of the magnitude of the force applied on the resultant stresses generated.

Materials and methods:

The present study was conducted in the Department of Orthodontics of the Dental institution. The ethical clearance for the study was approved from the ethical committee of the hospital.

Finite element modeling is the representation of geometry in terms of a finite number of elements and their connection points known as nodes. These are the building blocks of numerical representation of the model. The elements present are of finite number as opposed to a theoretical model with complete continuity. The object of interest has to be broken up into a 'meshwork' that consists of a number of nodes on and in the object. These nodes or points are then connected to form a system of elements. By knowing the mechanical properties of the object, such as modulus of elasticity and Poisson's ratio, one can determine how much distortion each part of the cube undergoes when other part is moved by a force.

Steps involved in Finite Element Modeling

1. Construction of the geometric model.
2. Conversion of the geometric model to a finite element model.
3. Material property data representation.
4. Defining the boundary condition.

Material Property Data Representation:- The different structures involved in this study include teeth, the periodontal ligament and alveolar bone. Each structure has specific material property. The material properties used here were used in finite element studies done by Motoyashi M et al.[6]

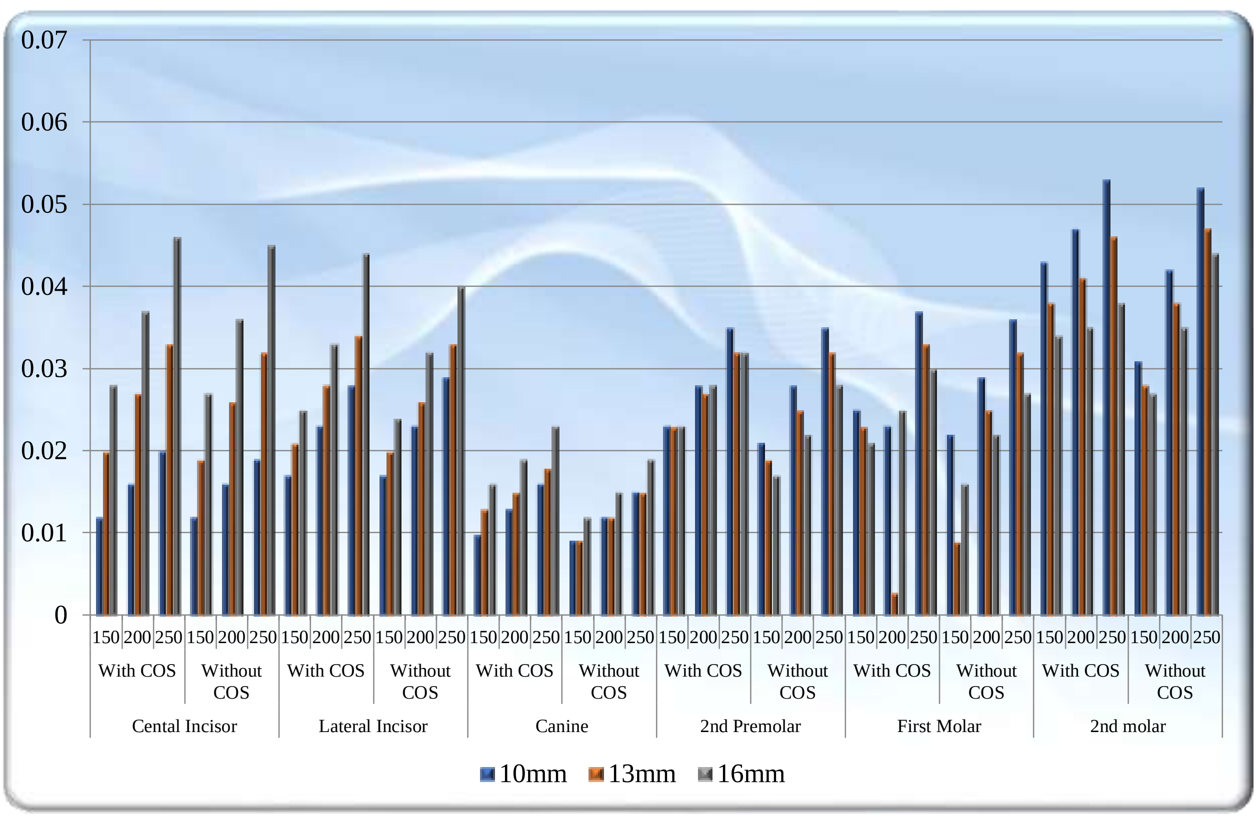
The statistical analysis of the data was done using SPSS version 11.0 for windows. Chi-square and Student's t-test were used for checking the significance of the data. A p-value of 0.05 and lesser was defined to be statistically significant.

Results:

On comparing all the teeth with different forces, the highest maximum stress was to be found in the second molar by varying implant placement height, with and without Curve of Spee. On comparing all the teeth with different forces, the highest maximum stress was found in the second molar followed by first molar, second premolar, lateral incisor, central incisor and then canine in varying implant placement height with & without Curve of Spee (table 1, graph 1). On comparing all the teeth with different forces, the highest maximum stress was found at 16mm implant height compared to 13mm and 10mm implant height anterior to the extraction space. As the point of force application was anteriorly maximum stress can be attributed to the larger vertical component of the force from 16mm implant, as compared to 10mm implant. No specific pattern for minimum stress was observed on application of different amount of forces (150, 200 and 250 gms) at varying implant height (10, 13 and 16mm) (Table 1, Graph 2).

Table 1: Maximum stress value (MPa) generated at all the teeth with different forces (150, 200 and 250gms) and different implant placement height, with & without COS

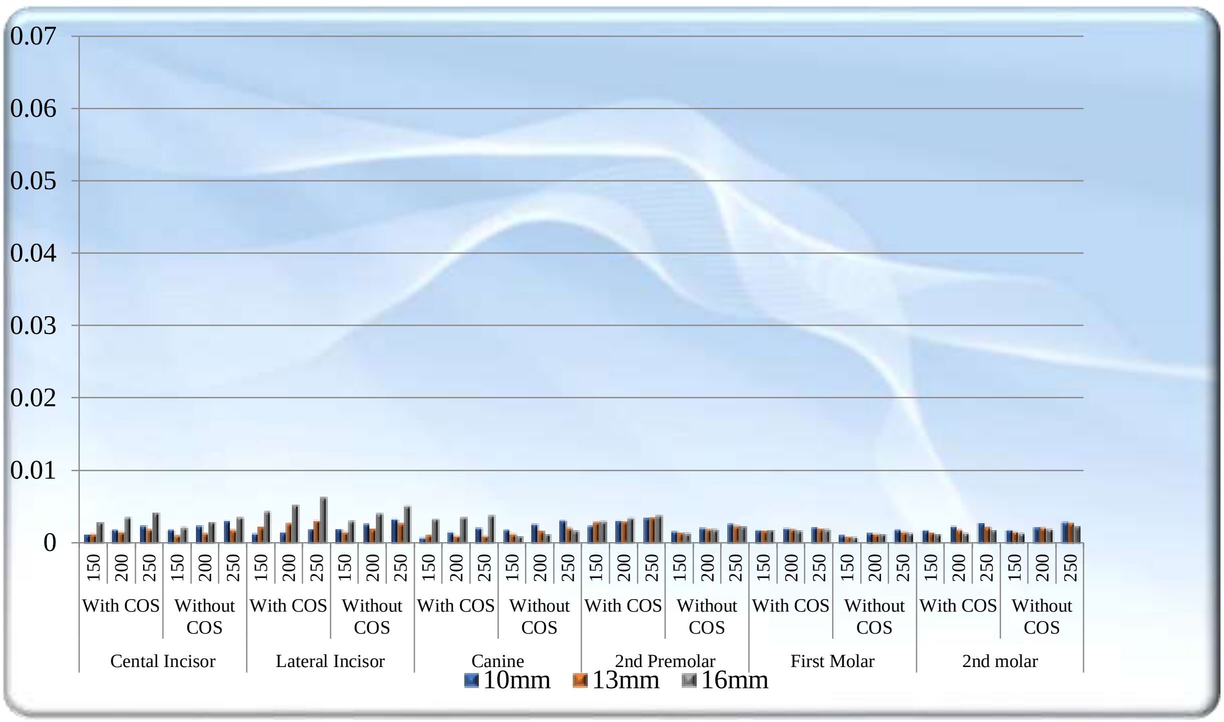
	Cental Incisor						Lateral Incisor						Canine						2nd Premolar						First Molar						2nd Molar					
	With COS			Without COS			With COS			Without COS			With COS			Without COS			With COS			Without COS			With COS			Without COS			With COS			Without COS		
	150	200	250	150	200	250	150	200	250	150	200	250	150	200	250	150	200	250	150	200	250	150	200	250	150	200	250	150	200	250	150	200	250	150	200	250
10 mm	0.012	0.016	0.02	0.012	0.016	0.019	0.017	0.023	0.028	0.017	0.023	0.029	0.0099	0.013	0.016	0.0092	0.012	0.015	0.023	0.028	0.035	0.021	0.028	0.035	0.025	0.023	0.037	0.022	0.029	0.036	0.043	0.047	0.053	0.031	0.042	0.052
13 mm	0.02	0.027	0.033	0.019	0.026	0.032	0.021	0.028	0.034	0.02	0.026	0.033	0.013	0.015	0.018	0.0092	0.012	0.015	0.023	0.027	0.032	0.019	0.025	0.032	0.023	0.0028	0.033	0.009	0.025	0.032	0.038	0.041	0.046	0.028	0.038	0.047
16 mm	0.028	0.037	0.046	0.027	0.036	0.045	0.025	0.033	0.044	0.024	0.032	0.04	0.016	0.019	0.023	0.012	0.015	0.019	0.023	0.028	0.032	0.017	0.022	0.028	0.021	0.025	0.03	0.016	0.022	0.027	0.034	0.035	0.038	0.027	0.035	0.044



Graph 1: Maximum stress value (MPa) generated at all the teeth with different forces (150, 200 and 250gms) and different implant placement height, with & without COS.

Table 2: Minimum stress value (MPa) generated at all the teeth with different forces (150, 200 and 250gms) and different implant placement height, with & without COS.

	Central Incisor						**Lateral Incisor**						**Canine**						**2nd Premolar**						**First Molar**						**2nd molar**					
	With COS			**Without COS**			**With COS**			**Without COS**			**With COS**			**Without COS**			**With COS**			**Without COS**			**With COS**			**Without COS**			**With COS**			**Without COS**		
	150	200	250	150	200	250	150	200	250	150	200	250	150	200	250	150	200	250	150	200	250	150	200	250	150	200	250	150	200	250	150	200	250	150	200	250
10 mm	0.0012	0.0018	0.0024	0.0018	0.0024	0.003	0.0013	0.0015	0.0019	0.0019	0.0026	0.0032	0.00077	0.0015	0.0021	0.0018	0.0025	0.0031	0.0024	0.003	0.0034	0.0016	0.0021	0.0026	0.0017	0.002	0.0022	0.0011	0.0014	0.0018	0.0017	0.0023	0.0027	0.0017	0.0022	0.0028
13 mm	0.0013	0.0016	0.0019	0.0011	0.0014	0.0018	0.0023	0.0027	0.0031	0.0016	0.002	0.0027	0.0012	0.001	0.001	0.0013	0.0017	0.0021	0.0029	0.003	0.0035	0.0015	0.0019	0.0024	0.0017	0.0019	0.002	0.00097	0.0013	0.0016	0.0015	0.0018	0.0022	0.0016	0.0021	0.0027
16 mm	0.0029	0.0036	0.0042	0.0022	0.0029	0.0036	0.0044	0.0053	0.0063	0.0031	0.0041	0.0051	0.0033	0.0036	0.0039	0.001	0.0013	0.0017	0.003	0.0035	0.0039	0.0014	0.0019	0.0024	0.0018	0.0017	0.0019	0.00087	0.0013	0.0014	0.0013	0.0014	0.0018	0.0014	0.0019	0.0024



Graph 2: Minimum stress value (MPa) generated at all the teeth with different forces (150, 200 and 250gms) and different implant placement height, with & without COS.

Discussion:

Anchorage is a critical component of en-masse retraction. Clinicians pay considerable attention to Newton's third law—the law of action and reaction. They know that every action they take will have an equal and opposite reaction. The retraction of four incisors after canine retraction is accepted as a method to minimize the mesial movement of the posterior teeth segment, whereas en- masse retraction of six anterior teeth may create anchorage problems. En- masse retraction of the six anterior teeth, instead of step-by step retraction of the canine and four incisors can reduce treatment time and allow an early change of the facial profile. This increases patient cooperation in treatment. An important aspect of this approach is that teeth can be moved to their exact treatment goal. The amount of maxillary retraction or teeth movement can be controlled by continuing or discontinuing the retracting force.[6] Analytical results of the finite element models depends highly on the models developed, so they must be constructed to be equivalent to a real object in various aspects. For a more accurate model, more nodes would be needed. Generating more sophisticated models is laborious. Despite these limitations and assumptions, previous studies by De Tolla et al [8] and Geng et al [9] have shown that the finite element analysis technique is reasonably reliable for stress analysis. In this study, the micro implants used were the self drilling type with the 1.6mm diameter and 8mm length with 90^0 angulation. Drill-free screws have more bone contact than pre-drilling screws. However, in thick, dense cortical bone, it has been suggested that screws should be placed with a pre-drilling method. [10] Chen et al [11] concluded that self-drilling micro implants have high initial stability and can be used in the maxilla and at thin cortical bone areas of the mandible. The drill-free implants showed less mobility and more histomorphometric bone-metal contact. This might be because drill-free insertion produces little bone debris and less thermal change. On comparing all the teeth with different forces, the highest maximum stress was to be found in the second molar by varying implant placement height, with and without Curve of Spee. A similar trend was observed by Kojima et al. [12] Hence the more stress observed at distal most tooth could be attributed to fact that the friction was produced in the posterior teeth when the arch wire slid through the bracket slots. This friction force tended to move the posterior teeth in a distal direction. In this study, friction was not taken into account as it cannot be adequate determine. The stress at initial placement of force could be assessed without the wire sliding distally through the tube. Hence in the presence of a static situation the stress pattern was observed to be greater in the last erupted tooth, because of increased horizontally directed force. On comparing all the teeth with different forces, the highest maximum stress was found in the second molar followed by first molar, second premolar, lateral incisor, central incisor and then canine in varying implant placement height with & without Curve of Spee. On comparing all the teeth with different forces, the highest maximum stress was found at 16mm implant height compared to 13mm and 10mm implant height anterior to the extraction space. As the point of force application was anteriorly maximum stress can be attributed to the larger vertical component of the force from 16mm implant, as compared to 10mm implant. The maximum stress was to be found in cervical area of the root surface. Similar effect of high placement implant have been studied by Bohara et al. [13] who reported that the maximum stress in PDL was found in the cervical area, moreover, the nature of stress changes from tensile to compressive from cervical area to root apex. in the present study no differences in the type of stress was seen and all stresses hence were assumed to be of compressive nature as all the values were positive. In posterior to the extraction space the highest maximum stress was found at 10mm implant height followed by 13mm and 16mm implant height, because hence the posterior horizontal components increased, with Curve of Spee and without Curve of Spee. Similar effect of high placement implant have been studied by Song et a. [14] reported that low and high OMI traction both generated a retraction force towards the posterior and superior.

The maximum stress was found to be greater in with Curve of Spee, as compared to without Curve of Spee. Sung, et al, [15] stated that as the amount of compensating Curve increases in the arch wire the tensile stress also increase. On lateral incisor stress was found to be more, when compared to central incisor, because of deformation of the arch wire at the point of placement of the retraction hook was placed which was distal to the lateral and mesial to canine. The same was observed and reported by Sung et al where they showed the deformation using magnified FEM imaged of the area. In the present study the same effect is reflected in the stress distribution seen on the lateral incisor and canine wherein the highest point of stress was observed at the distal cervical margin of the lateral and at the mesial cervical margin of the canine in all the tested scenarios. Analytical results of FEM are highly dependent on the models developed; therefore they have to be constructed to be equivalent to real objects in various aspects. The results of this study were obtained from a simulated model, from which biologic variability may occur. The resultant values should be interpreted only as a reference to aid clinical judgment. However one should be aware that the structural and spatial relationships of various dento-facial components vary among the individuals. It is important to realize that these factors may contribute to varied responses of the dentofacial components on loading. Other limitations of this study include approximations in material behavior and shapes of the tissues. The PDL was modeled as a layer of uniform thickness and was treated as linear elastic and isotropic, even though the PDL exhibits anisotropy and non linear visco-elastic behavior because of tissue fluid. There is no reliable and adequate data that pertain to anisotropic and non linear properties of the PDL. The teeth were modeled as a uniform solid and the various dental tissues were not modeled. Similarly, bone was modeled only as a cancellous bone and cortical bone was not included. Lastly the bracket model used in this study was arranged according to MBT norms and mechanics. Achieving the exact MBT norms is not always possible in a clinical scenario. The further direction of FEM studies should involve more accurate simulation of loading and approximation of material behaviors as well as variations in geometries of PDL, bone and teeth in three-dimensional finite element analysis.

Conclusion:

Within the limitations of the present study, it can be concluded that irrespective of the height of implant placement, the maximum stress generated on the root surface was at the last molar included in the set up in the second molar. Anterior to the extraction space, the stress increases as the implant height increases and the posterior to extraction space stress increases as the implant height decreases. This can be attributed to greater stress generated by the larger vertical component anteriorly and larger horizontal component posteriorly. Incorportion of the Curve of Spee was found to increase the stress on the root surface. The greater stress was seen at lateral incisor as compare to central incisor and canine, which could be attributed to the deformation of the wire, at the hook, which is the point of force application.

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