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Comparative evaluation of stress related changes in the periodontium during conventional and rapid canine retraction – a finite element study

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Abstract

Assessment of stress related changes in the periodontium is of prime importance while applying forces of differential magnitude. A detailed knowledge of these stresses in the biological systems provides an insight on the favorable and unfavorable responses during a clinical procedure over time.

Material and Methods: Two patients undergoing fixed orthodontic treatment requiring extraction of their first premolars were selected for the study, canine retraction with 150 grams force using Niti coil spring in one subjects and other subject for canine retraction with 250 grams of force by dentoalveolar distraction with a distraction device was performed.

Results: A nonparametric, Mann-Whitney U test was performed for the comparison of two procedures and it was observed that the stresses generated in the teeth, periodontal ligament and bone were considerably high in rapid canine retraction method compared to the conventional method of canine retraction.

Conclusion: Rapid canine retraction generates considerable amount of excessive stresses in the periodontium. Displacements per activation were within the physiological limits, which in turn induces bone remodelling resulting in tooth movement with minimal or no anchor loss. Rapid canine retraction is a physiologically acceptable process of canine retraction with clinically minimal or no side effects on the periodontium.

Keywords: Conventional, Rapid, Stress distribution, Finite element analysis.

Introduction

Orthodontic tooth movement (OTM) is mainly characterized by adaptive biochemical response to the applied orthodontic force which in turn results in series of sophisticated events in and around periodontal ligaments and alveolar bone cells by changing the mechanical force into molecular events (signal transduction) facilitating orthodontic tooth movement.[1]

The friction present during orthodontic sliding mechanics denotes a clinical challenge to the orthodontists because higher degree of friction may reduce the effectiveness of the mechanics, decreasing tooth movement efficiency hence further complicating control of anchorage. One of the primary focuses of the search for ideal conditions for orthodontic tooth movement (OTM) is the reduction of friction at the bracket-wire-ligature interface in certain stages of treatment.[2]

To a plan conventional tooth movement procedure such as a bodily tooth movement of a canine or any tooth, a clinician must be well versed with the knowledge of the forces to be implicated and the resultant outcome of the forces i.e., the stress generated in the tooth along with its related structures such as the periodontal ligament and the bone.

The principal underlying the idea of distraction of the periodontal ligament performed with a distraction device for stretching of the reparative bone tissue assumes that approximately 1 mm of bone generation takes place at the site of a corticotomy cut per day. Hence it is a commonly applied occurrence in obtaining a rapid canine retraction in a shorter duration of time.

The process of osteogenesis that occurs on a regular basis in a regular orthodontic treatment set up is mentioned to be around 1 mm per month which is much slower than the movements obtained by the application rapid canine retraction under the principals of distraction osteogenesis.[3]

When an orthodontic force is applied to dentoalveolar structures consisting mainly the tooth, periodontal ligament and its surrounding bone structures, stresses of differential nature are generated in its vicinity.

Finite element analysis because of its increased accessibility, competence, and ease of application of computer programs in modelling of biological structures has become a dominant tool for biomechanical research.[4]

In anticipation of acquiring the detailed knowledge of these two methods and there stress distribution along with its side effects, a (3D) finite element model of maxillary teeth, surrounding periodontal ligament and alveolar bone was created after the therapeutic extraction procedure was implemented involving extraction of first premolars. Assessing the status of stress generated with the application of a Finite Element Method (FEM) in regard to the teeth, periodontium (PDL), and alveolar bone during conventional and rapid canine retraction using a distracter device and how does it differ among the two methods of stress distribution when the movements are simulated was the main aim of this study.

Material and Method

Two patients were selected, who were to undergo extraction of first premolars as a part of the treatment plan. Both the patients were males in the age range of 18-20 years. First patient selected, had bimaxillary protrusion requiring extraction of all first premolars and was selected to undergo canine retraction with conventional method using Niti coil springs. Second patient selected for canine retraction by rapid method of retraction using a distraction device had class I severely crowded dentition requiring extraction of all first premolars along with the process of interdental grooving of bone. (Fig. 1)

A custom made rigid, tooth borne intraoral device was designed for dentoalveolar distraction and rapid tooth movement applying 250 grams of force. The device is made up of stainless steel and has a distraction screw and two guidance bars. The doctor turns the screw clockwise two times (morning and evening) with a special apparatus in order to move the canine distally. CT scans and clinical photographs of both the patients were taken immediately before the start of their respective procedures. (Fig. 1)

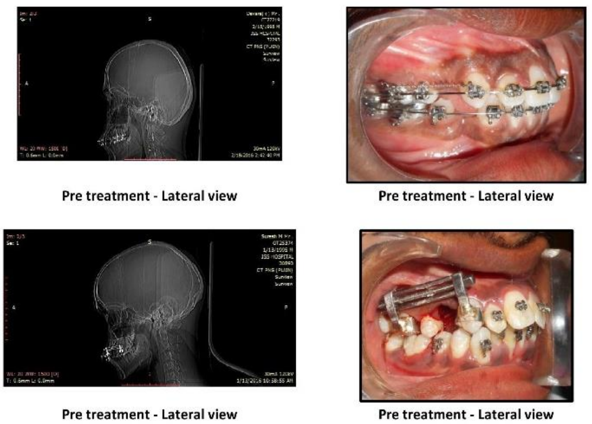

Fig. 1: CT scans and clinical photographs for conventional and rapid canine retraction method

Using the CT scans and clinical photographs of the patient finite element models were created. The study was done using a three dimensional finite element analysis, ANSYS 12.1, Hyper mesh 13.0 software used for converting geometric model into finite element model. The CT scan of a skull was considered and only the region of interest of the study (maxilla) is extracted and converted the dicom data into geometric models using reverse engineering technique. Mimics software was used to process the CT scan data. The brackets, mechanism device were modeled using reverse engineering method which includes scanning the models, measuring the length, diameter and other features using standard measuring instruments and scanning machines. (Fig. 2)

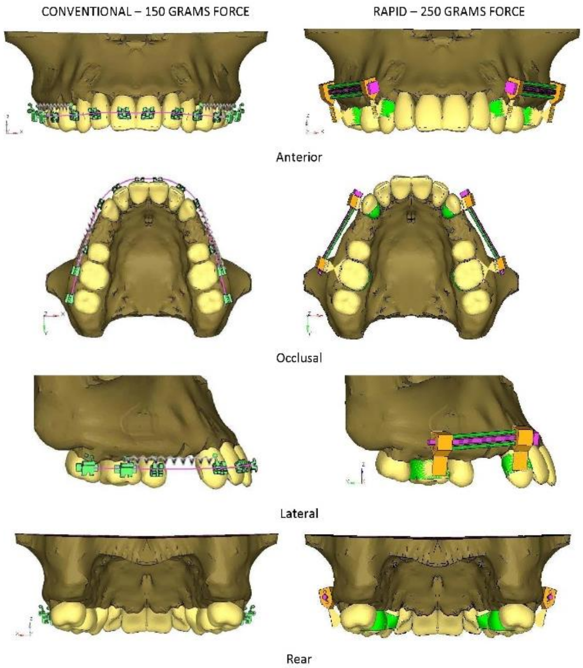

Fig. 2: Geometric model for conventional and rapid method of canine retraction

Geometric models of the maxilla including the teeth, PDL were then imported into the meshing software "Hyper mesh" (Fig. 3). In hyper mesh the individual parts like soft bone, hard bone, teeth, PDL, brackets, wire, mechanism device are then discretized (meshing) and assembled. The material properties, loads and boundary conditions was assigned to the FE-model (Table 1).

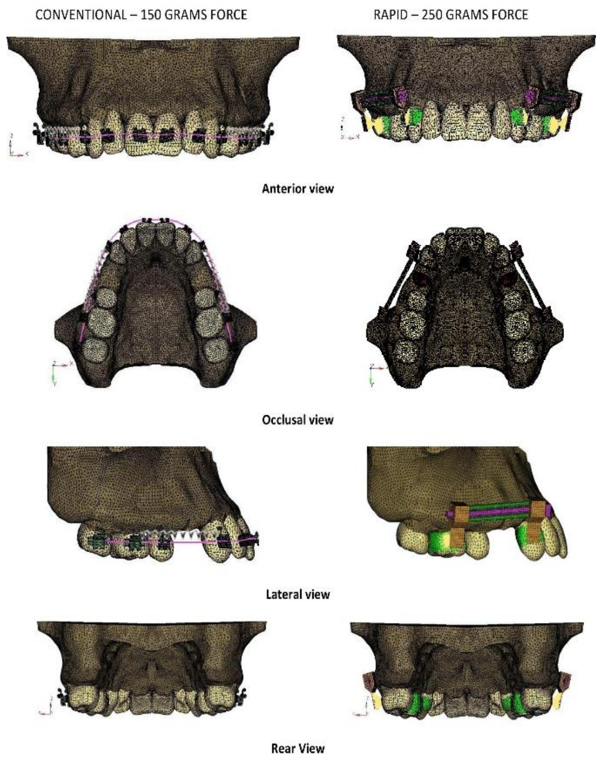

Fig. 3: Finite element model for conventional and rapid method of canine retraction

Table 1: Material properties

Materials	Young's Modulus (N/mm^2)	Poisson's Ratio
Teeth	2.60E+04	0.30
PDL	6.80E-01	0.49
Bone	1.40E+04	0.30
Bracket	2.14E+05	0.30
Steel	2.00E+05	0.31
SS303	1.93E5	0.3

Results

From the results of this study following patterns of stresses were derived through the conventional method of canine retraction with 150 grams of force (Fig. 4, Table 2) and rapid method of canine retraction with 250 grams of force (Fig. 5, Table 2) and comparison of stress distribution between the two methods of canine retraction (Table 3 and Graph 1).

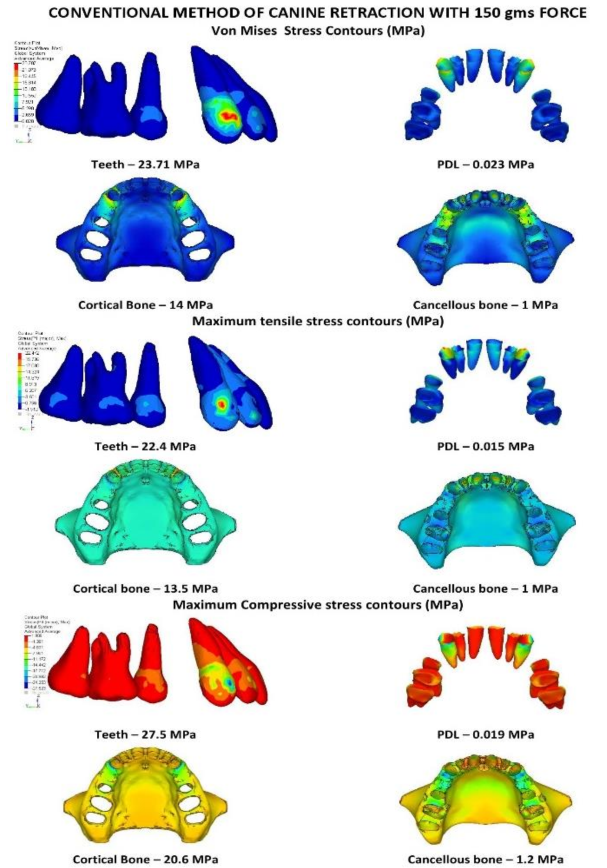

Fig. 4: Stress distribution patterns with conventional canine retraction method

Table 2: Distribution of Stress in the Periodontium with Conventional Method of Canine retraction (150 grams of force)

Stress	Teeth	PDL	Cortical bone	Cancellous bone
Conventional				
Von Mises stress	23.7 MPa	0.023 MPa	14 MPa	1 MPa
Maximum tensile stress	22.4 MPa	0.015 MPa	13.5 MPa	1 MPa
Maximum compressive stress	27.5 MPa	0.019 MPa	20.6 MPa	1.2MPa
Rapid				
Von Mises stress	38.75 MPa	0.234 MPa	52 MPa	3.25 MPa
Maximum tensile stress	36.67 MPa	0.175 MPa	51 MPa	1.8 MPa
Maximum compressive stress	31.24 MPa	0.130 MPa	38.6 MPa	3.45 MPa

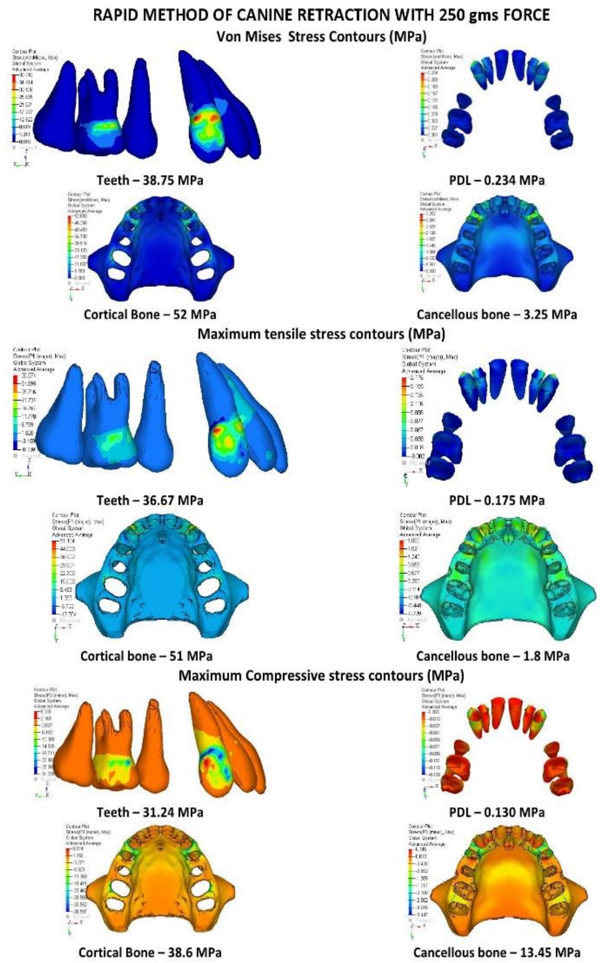

Fig. 5: Stress distribution patterns with rapid canine retraction method

Discussion

Application of biomechanics is crucial in orthodontics. After the solicitation of an unknown external force in the dental environment, the development of stress is anticipated in the periodontium and its related structures which may lead to unsuccessful outcomes. When an orthodontic force is applied to dentoalveolar structures consisting mainly the tooth, periodontal ligament and its surrounding bone structures, stresses of differential nature are generated in its vicinity.[3] Areas of compressive stress shows alveolar bone absorption while areas of tensile stress are depicted by areas of bone apposition.[5]

According to the study by Jing Yan et al[6] in bodily type of tooth movement highest stresses were distributed on the root surface mainly on the cervical area which declined towards the apex, this finding was in contrast to our study in which a higher stress was observed at the canine bracket interface. Jing Yan et al[6] in their study stated that the distribution of highest stresses were confined to the cervical region of the canine as well as the apical region of the canine which is in accordance with the findings of the present study which showed that stresses were distributed distal to the canine alveolar crest as well as distribution of stresses were observed at the apices of the anterior teeth including the canine. Apart from Von Mises stresses and Maximum compressive stresses, maximum tensile stress of 13.5 MPa was also seen to be distributed along the alveolar crest mesial to the canine in cortical bone.

Yukio Kojima and Hisao Fukui et al[7] in their study observed distribution of compressive stress on the distal surface of the canine near the neck of the tooth and a tensile stress near the apex which is in accordance with our study which showed distribution of compressive stress near the distal surface of the canine at the alveolar crest in cancellous bone and tensile stress in the apical region of the anterior teeth including the canine in the cancellous bone respectively. According to the results of the present study, there was distribution of compressive stress over the distal alveolar crest of canine in cancellous bone and distribution of tensile stress over the mesial alveolar crest of canine in cortical bone, these findings were in accordance with the findings of Kojima and Fukui et al,[7] who observed production of compressive stress over the distal surfaces of canine and a tensile stress production on the mesial half of canine and as a result of this, they concluded that this pattern of stress distribution indicated a movement similar to that of the typical bodily tooth movement.

In a study conducted by Adrien N Wilson et al,[8] to retract a maxillary canine tooth into a first premolar extraction space by applying a force level of 1 Newton in the mesio-distal direction angled at 30 degree and 60 degrees, a lower maximum principle tensile stresses were observed at the cervical margin of the periodontal ligament by true mesio-distally directed forces which is in accordance with the results of the present study which also showed the stress levels of 0.023 MPa in terms of Von Mises stress, 0.015 MPa in terms of maximum principle stress (lower tensile stress), it also showed a lesser value of minimum principle stress (lower compressive stress) of 0.019 which was an added finding. The highest value of the maximum tensile stress were found to be located at the cervical margin and at the apex, which is in accordance with the findings of the present study in which maximum compressive stress were found to be located at the alveolar crest mesial to the canine in cortical bone and at the apical region of the anterior teeth in cancellous bone.

According to the results of the study conducted by Junjie Xue et al[4] for the finite element analysis of rapid canine retraction through reducing resistance and distraction was performed by applying 1.5 Newton of force, distribution of Von Mises stresses on the canine tooth were found to be concentrated mainly on the distal side of the canine root which was in accordance with the results of the our study, however the distribution of Von Mises stresses in the PDL of canine in the previous study was found to be concentrated on the distal edge of the canine cervix which was in contrast to the present study in which it was mainly found to be concentrated at the cervical third on the labial surface. On comparing the Von Mises stress distribution patterns in the cortical and cancellous bone, cortical bone on the buccal side was the most stressed area which is in accordance with the results of the our study but this stressed area of cortical bone was more towards the distal alveolar crest in the our study.

The results of the study conducted by NC Challagulla et al[(9)] showed that maximum stresses were generated at the periodontal ligament which is in accordance with results of the our study. These stresses were maximum at the molar which was in contrast to the results of the our study in which maximum stresses were observed at the canine, this could be explained by taking into account the load, boundary conditions and the material properties that varies among different finite element analysis. Another finding of the present study which goes in accordance with the study of NC Challagulla et al,[(9)] was the distribution of compressive stress on the distal aspect and distribution of tensile stress on the mesial aspect of the cortical bone at the alveolar crest region. These stresses were found to be greater at the crest region than at the apex.

According to a study conducted by Vineeth V Thundukattil et al,[(10)] to evaluate the distribution of stress induced in the periodontium by an active retraction screw device (Hycon Device) based on the principle of rapid canine retraction by distraction means with the application of 410 grams of retraction force. According to the results of the study by Vineeth V Thundukattil et al[(10)] maximum tensile stress was observed on the labio-cervical and mesio-cervical aspect of canine which was in accordance with the findings of the our study that showed a distribution of tensile stress on the cervical third of the PDL labially, tensile stress was also found to be distributed at the mesial alveolar crest region of the canine. However, instead of mesio-cervical part of the canine the stresses were seen to be distributed at the disto-cervical part of the canine. A maximum compressive stress was seen to be distributed linguo-cervically in the previous study which was in contrast to our study that showed distribution of compressive stress at the labio-cervical part of the canine in the PDL.

Conclusion

1. Conventional method of canine retraction using coil spring with application of 150 grams of force
   a. Showed lesser and more uniform distribution of stresses patterns in the periodontium including teeth, PDL and bone. Although the stresses distributed are small, the conventional method retracts the canine into its place within a longer duration making it susceptible to anchor loss.
   b. Stress in conventional method of canine retraction were seen to be distributed along the cervical as well as the apical region of the anterior teeth including the canine making them prone to resorption.
2. Rapid method of canine retraction using a distraction device with application of 250 grams of force.
   a. Showed higher levels of stress patterns in the periodontium including teeth, PDL and bone.
   b. Canine region showed an unequal distribution of stress at the cervical region of teeth, PDL and bone and no stresses at apical region which reduces the chances of resorption and at the same time speeds up the retraction process.
3. Comparison of the stress distribution in conventional and rapid method of canine retraction.
   a. The stress levels by rapid method of canine retraction by 250 grams of force were found to be significantly higher compared to the conventional method of canine retraction using 150 grams of force.
   b. Conventional means of canine retraction using coil spring can retract the canine into the extraction space within a period of 4 to 6 months with a more uniform distribution of stress in the periodontium, even though higher stresses may be generated with dentoalveolar distraction it was found to be within the physiological limits and proves to be a promising technique favoring retraction of canine into the extraction space within a period of 12-14 days benefiting patients with compliance issues.

References

1. Richard S. Masella, Malcolm Meister. Current concepts in the biology of orthodontic tooth movement. Am J Orthod Dentofacial Orthop 2006;129:458-68.
2. Pacheco MR, Jansen WC, Oliveira DD. The role of friction in orthodontics. Dental Press J Orthod 2012;17(2):170-7.
3. Eric JW Liou, C. Shing Huang. Rapid canine retraction through distraction of the periodontal ligament. Am J Orthod Dentofacial Orthop 1998;114:372-82.
4. Junjie XUE, Niansong YE, Xin YANG, Sheng WANG, Jing WANG, Yan WANG, Jingyu LI, Congbo MI, Wenli LAI. Finite element analysis of rapid canine retraction through reducing resistance and distraction. J Appl Oral Sci 2014;22(1):52-60.
5. Kojima Y and Fukui H. Numerical simulation of canine retraction by sliding mechanics. Am J Orthod Dentofacial Orthop 2005;127:542-51.
6. Yan J, Xiang Long H, BiHuan C, Ding B. Three-dimensional FEM analysis of stress distribution in dynamic maxillary canine movement. Chinese Science Bulletin. July 2013;58(20):2454-2459.
7. Kojima Y, Kawamura J, Fukui H. Finite element analysis of the effect of force directions on tooth movement in extraction space closure with miniscrew sliding mechanics. Am J Orthod Dentofacial Orthop 2012;142:501-8.

8. Adrien N. Wilson, John Middleton, Niall McGuinness, Malcolm Jones. A Finite element Study of Canine Retraction with a Palatal Spring. British Journal of Orthodontics 1991;18:211-218.
9. Challagulla NC, Kailasam V, Chitaranjan AB. Stress distribution during rapid canine retraction with a distraction device: A finite Element Study. J Ind Orthod Soc 2013;47(4):312-318.
10. Thundukattil VV, Naik AKG, Unnikrishnan PK. Evaluation of stress on the periodontium induced by a fixed retraction screw appliance and an active tie-back: A three dimentional finite element study. APOS trends in orthodontics, November 2013;3(6):178-183.