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Comparison of stress developed on teeth during lingual and labial orthodontics using 3D finite element modeling.

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ABSTRACT

Background: The introduction of lingual appliances in orthodontics has led to great improvement in the aesthetic aspect in orthodontics. Lingual appliances have their own specific biomechanics, which are quite different from that of conventional labial orthodontics, and therefore proper care must be taken in their use. The measurement of stress produced at different locations of the root clinically by various types of orthodontic tooth movement is very difficult but important procedure.

Aim : To compare stress developed on teeth during lingual and labial orthodontics using 3d finite element modelling.

Materials and Methods: The coordinate system with three axes namely X, Y, and Z axes which were perpendicular to each another was used in this study. 3DS Max program (Autodesk, USA) was the computer program which was utilised for the purpose of construction of geometric morphology and 3Dimensional model. Calculations of the strains and displacement at every nodal point was carried out with the help of Algor program (Algor, USA) which is finite element program. The minimum negative principal stress area was taken as that of the maximum compressive stress. The area which showed the maximum positive principal stress was taken as the area of maximum tensile stress.

Results: When maximum and minimal principal stress was evaluated then it was found that stress developed on the teeth in central incisor, lateral incisor, canine, mesial and distal surface of first molar were significantly greater in case of lingual orthodontics as compared with the labial orthodontics. However stress developed in second premolar, mesial and distal surface of second molar during lingual orthodontics was greater than labial orthodontics but the difference was not statistically significant.

Conclusion: Within the limitations of the study it can be concluded that stress produced during lingual orthodontics is generally greater as compared with the labial orthodon

INTRODUCTION

The introduction of lingual appliances in orthodontics has led to great improvement in the aesthetic aspect in orthodontics. Due to some features like reduced obstruction, recent improvements in indirect lingual bracket bonding, introduction of new archwire materials, and computerized planning systems, this lingual orthodontic technique has become more simple and precise.[1] Lingual appliances have their own specific biomechanics, which are quite different from that of conventional labial orthodontics, and therefore proper care must be taken in their use. One of the significant difference observed in lingual orthodontics is retraction of the six anterior teeth as a single unit for aesthetic purpose. Therefore care should be taken that there is no creation of space between canines and lateral incisors.[2]

In lingual orthodontics there is good anchorage on the lower posterior teeth as compared to the labial orthodontics. This is due to the difference in the point of application of force. But movement of the posterior teeth in the mesial direction is more difficult in lingual orthodontics as compared to the labial orthodontics.[3] This is due to the fact that the periodontal stresses produced as a result of orthodontic forces are transferred to the alveolar bone which results in resorption in regions which are under compressive stress and apposition in those areas of the bone which are under tensile stress. The measurement of stress produced at different locations of the root clinically by various types of orthodontic tooth movement is very difficult procedure.[4]

There are several conventional diagnostic and investigational methods for evaluation of stresses at teeth such as holography, photoelasticity and strain gauges. These methods have provided some information related to the mechanism of tooth movement in orthodontic treatment. But these methods have been unable to elaborate the changes taking place around the periodontal ligament and inside the bone surrounding the tooth.[5] However, a newer and advanced method namely finite element method (FEM) introduced by Zienkiewicz are believed to provide good information in several dental procedures including details regarding the changes taking place in the periodontal ligament, teeth and alveolar bone during the orthodontic tooth movement.[6]

Finite Element Method (FEM) usually is a mathematical method. In this method the shape of geometric objects which are complex alongwith their physical properties are studied with the help of computer which construct a model. After that physical interactions taking place among various components of the model are calculated in terms of stress and strain. It provide elaborate details about the interaction taking place between anatomical structures with and the surrounding tissue. Such information are very difficult to obtain from other methods.[7] This study was therefore conducted with the aim of comparison of the stresses developed during the en masse retraction of teeth during the labial and lingual orthodontics with the help of 3D finite element model.

Methods and Materials

The present study was done in the Department of Orthodontics and Dentofacial Orthopedics of the Dental College. The Dental institution approved the ethical clearance for the study. All the patients were informed regarding the study, and their consent was obtained. A 3D Finite Element Model of each mandibular tooth was prepared according to the detailed information about morphology and anatomy. The ideal mandibular dentition was prepared by insertion of a .018 × 0.025-in. stainless steel labial archwire of full dimensions in the slots of tubes and brackets to be used in labial orthodontics. Once ideal dentition was established, a 0.018 × 0.025- in. stainless steel mushroom arch wire was utilised for the placement of lingual tubes and brackets in their appropriate positions. It was assumed that the physical material properties of various dentoalveolar structures were homogeneous and isotropic in nature. The thickness of PDL was assumed to be uniform equivalent to 0.25 mm around the root. Similarly the thickness of the alveolar cortical bone was kept uniform equivalent to 1.0 mm.

The coordinate system with three axes namely X, Y, and Z axes which were perpendicular to each another was used in this study. The X axis was meant to show the changes taking place in the bucco-lingual direction (buccal−, lingual+). The Y axis was meant to represent the changes taking place in the mesio-distal direction (distal− , mesial+ ,) The Z axis was used to represent changes taking place in the vertical direction (apical+, occlusal−). 3DS Max program (Autodesk, USA) was the computer program which was utilised for the purpose of construction of geometric morphology and 3D model. Calculations of the strains and displacement at every nodal point was carried out with the help of Algor program (Algor, USA) which is finite element program.

In order to make the expression of displacements of tooth more easier, reference nodes were kept at the roots and crowns. The magnitude of initial displacement in these landmark nodes present on the X, Y, and Z axes after the application of orthodontic forces were magnified by 10,000 to help in interpretation by FEM. The pattern of distribution of tensile stresses and compressive stress developing at the surface of root was mapped at minimum principal stresses and maximum principal stresses. The minimum negative principal stress area was taken as that of the maximum compressive stress. The area which showed the maximum positive principal stress was taken as the area of maximum tensile stress.(Fig 1 to 4)

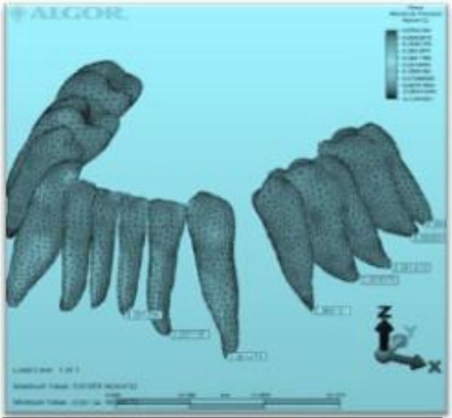

Fig 1: FEM image showing Maximal stresses during labial orthodontics

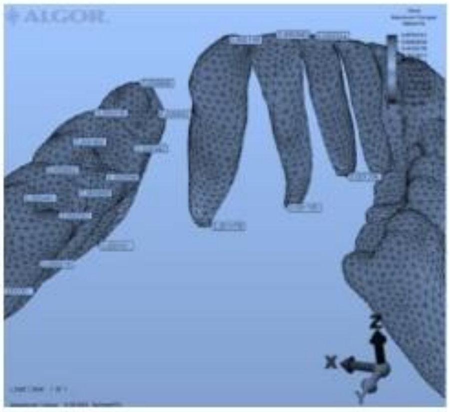

Fig 2: FEM image showing maximal stresses in lingual orthodontics

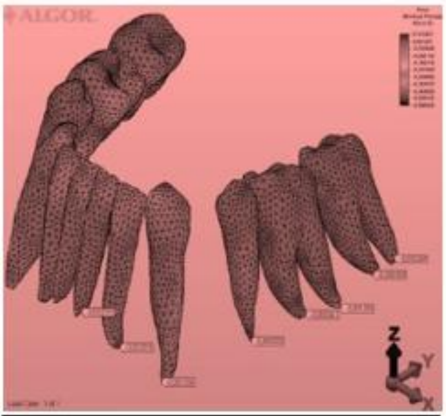

Fig 3: FEM image showing minimum stress during lingual orthodontics

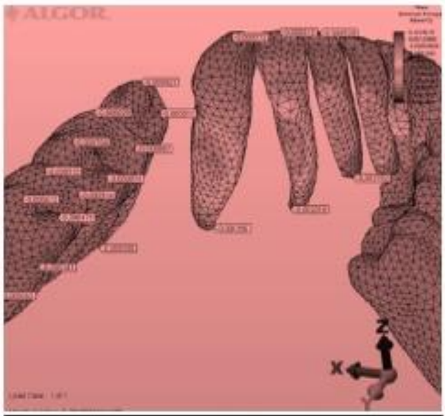

Fig 4: FEM image showing minimum stress during lingual orthodontics

Results:

When maximum principal stress was evaluated then it was found that stress developed on the teeth in central incisor, lateral incisor, canine, mesial and distal surface of first molar were significantly greater in case of lingual orthodontics as compared with the labial orthodontics. However stress developed in second premolar, mesial and distal surface of second molar during lingual orthodontics was greater than labial orthodontics but the difference was not statistically significant**.** (Table 1)

	Maximum Principle Stress		
Tooth	**Labial Orthodontics**	**Lingual Orthodontics**	**p value**
1.Central incisor (C.I)	13.94	20.06	0.02
2.Lateral incisor (LI)	12.08	19.63	0.03
3.Canine (C)	15.79	21.80	0.04
4.Second premolar (SP)	2.54	2.48	0.07
5.First molar mesial(FMM)	0.88	1.89	0.03
6.First molar distal (FMD)	16.22	4.12	0.02

7.Second molar mesial (SMM)	0.61	0.83	0.08
8.Second molar distal (SMD)	5.41	4.78	0.06

TABLE 1: Data showing maximum principle stress values of the reference nodes at the tooth apex ($\times 10^{-4}$ N/mm)

On the other hand when minimum principal stress was calculated then stress developed in second premolar, mesial and distal surface of second molar during lingual orthodontics was greater than labial orthodontics but the difference was not statistically significant. However stress developed on the teeth in central incisor, lateral incisor, canine, mesial and distal surface of first molar were significantly greater in case of lingual orthodontics as compared with the labial orthodontics.(Table 2)

Minimum Principle Stress			
Tooth	**Labial Orthodontics**	**Lingual Orthodontics**	**p value**
1.Central incisor (C.I)	−22.91	−29.45	0.02
2.Lateral incisor (LI)	−21.11	−27.15	0.03
3.Canine (C)	−13.57	−29.72	0.04
4.Second premolar (SP)	−4.36	−6.03	0.07
5.First molar mesial(FMM)	−3.42	−4.13	0.03
6.First molar distal (FMD)	−13.36	−4.39	0.02
7.Second molar mesial (SMM)	−2.64	−2.38	0.08
8.Second molar distal (SMD)	−3.83	−3.62	0.06

TABLE 2: Data showing minimum principle stress values of the reference nodes from tooth apex ($\times 10^{-4}$ N/mm)

DISCUSSION:

In orthodontic treatment involving premolar extraction, the orthodontist has different options for closure of space. However, in the lingual orthodontic technique, en masse retraction of the anterior six teeth is most preferred option. This is due to the fact that in full canine retraction proceedure, inter-bracket span that develop between the canine and premolar would be very less.[8] As a result the bend of the archwire placed distal to the canine would affect the closure of space. Besides, when aesthetics is concerned, then adult patients do not prefer the space between lateral incisor and canine as a result of full retraction.[9] For the purpose of en masse retraction during orthodontic treatment, several archwires, such as TMA, 0.016 × 0.016- and 0.016 × 0.022-in. SS , can be used, but we decided to use a 0.016 × 0.022-in SS archwire to create a situation similar to that of the labial orthodontic technique.[10]

There are several conventional diagnostic and investigational methods for evaluation of stresses at teeth such as holography, photoelasticity and strain gauges. These methods have provided some information related to the mechanism of tooth movement in orthodontic treatment. But these methods have been unable to elaborate the changes taking place around the periodontal ligament and inside the bone surrounding the tooth.[11] However, a newer and advanced method namely finite element method (FEM) is believed to provide good information in several dental procedures including details regarding the changes taking place in the periodontal ligament, teeth and alveolar bone during the orthodontic tooth movement.[12]

In the current study it was observed that stress produced by the lingual bracket system was greater as compared to that of lingual orthodontics except in case of second premolar and second molar where the difference was not statistically significant.[13]Mascarenhas, et al conducted a study to compare the stress developed during orthodontic tooth movement in labial and lingual orthodontics using 3D FEM and they found that the maximum principal stress developed during lingual orthodontics is greater than that of labial orthodontics. The results of this study was similar to that observed in the current study.[14]Kumari S et al conducted a study to compare the midline diastema cases with both lingual as well as labial orthodontics using CBCT and found that stress produced in labial orthodontics was lesser as compared to the lingual orthodontics. But in our study the results were different as the stress produced was greater in lingual orthodontics as compared to labial orthodontics. [15]This was due to the presence of smaller inter-bracket distance in the anterior region in the current study, which causes increased stress on the teeth. Lombardo L et al conducted a study to compare the stress developed during the labial orthodontics and lingual orthodontics using 3D FEM and found that stress developed during the lingual orthodontics was greater as compared to the labial orthodontics.[16] Similarly, in this study, the stress produced by the lingual bracket system was greater than that generated by the labial appliance.

Finite Element Method (FEM) usually is a mathematical method. In this method the shape of geometric objects which are complex alongwith their physical properties are studied with the help of computer which construct a model.[17] After that physical interactions taking place among various components of the model are calculated in terms of stress and strain. It provide elaborate details about the interaction taking place between anatomical structures with and the surrounding tissue. Such information are very difficult to obtain from other methods.[18] This study was therefore conducted with the aim of comparison of the stresses developed during the en masse retraction of teeth during the labial and lingual orthodontics with the help of 3D finite element model

In lingual orthodontics there is good anchorage on the lower posterior teeth as compared to the labial orthodontics. This is due to the difference in the point of application of force. But movement of the posterior teeth in the mesial direction is more difficult in lingual orthodontics as compared to the labial orthodontics.[19] This is due to the fact that the periodontal stresses produced as a result of orthodontic forces are transferred to the alveolar bone which results in resorption in regions which are under compressive stress and apposition in those areas of the bone which are under tensile stress.[20]

Conclusion

Within the limitations of the study it can be concluded that stress produced during lingual orthodontics is generally greater as compared with the labial orthodontics. However more studies should be conducted in future to obtain more accurate results.

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