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Determination of Optimal Loading Conditions Using Lever Arm and Mini- Implant System for En-masse Retraction in Lingual Orthodontics – A FEM study

Abstract:

Aim: To evaluate the stress distribution along the periodontal ligament and alveolar bone by various combinations of mini-implants and lever arm used during en-masse retraction of anterior teeth using finite element method.

Materialsand Methods: Four three-dimensional finite element models of the bilateral maxillary first premolar extraction casewas constructed. Lingual brackets were (0.018" slot) positioned over the center of the clinical crown. In all four models 150 g of retraction force with the help of the NiTi closed coil springs was applied with different combinations of mini-implants and lever arm. A finite element analysis was then performed to evaluate stress distribution, the principle stress, von Mises stress and displacement of the anterior teeth using ANSYS 12.1 software.

Result: In this study the constructed models along with the load application were imported into ANSYS (version 12.1) software for analyzing the displacement and stress distribution corresponding to the force application. The maximum tensile stress of periodontal ligament were observed at distal root apex area of canine in all four models. Variable amount of displacements like lingual crown tipping, lingual root tipping and extrusion were observed in all the models suggesting different combinations of lever arm and mini-implants affect the direction of the tooth displacements in lingual mechanics.

Conclusion: In lingual orthodontics tipping movement of crown decreases as the height of lever arm increases. It was also found that when mini-implants were placed at higher position the amount of tipping movement decreases with minimum amount of extrusion seen in central incisor and lateral incisor.

Keywords: Anterior En-masse Retraction, Lever arm, Lingual orthodontics, Mini-implants, Stress, Displacement, von Mises and principle stress, Finite element method.

Introduction:

Lingual orthodontics (LO) is highest aesthetic orthodontic technique which developed rapidly in recent years and offering a comprehensive treatment for most malocclusions with the three dimensional control of dentition.[1] The fundamental and critical stage in any orthodontic treatment (lingual and labial) is the anterior teeth retraction, while doing so torque control becomes a deciding factor for achieving optimum esthetics. In lingual orthodontics the point of force application is on lingual side when compared to labial, this difference in point of force application from the center of resistance is present in both sagittal and vertical planes.[2] Direct application of moment and force or lever arm is used to gain the desired line of force with respect to center of resistance to control anterior torque. In lever arm system, modification in the length of lever arm and the site of force application leads to attainment of anticipated tooth movement.[3]

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Anchorage plays a very crucial role indiagnosis and treatment planning of labial or lingual orthodontics. Anchorage requirement can be met with various means like headgear, teeth or mini implants, this becomes even more critical in lingual orthodontics,[4] so to overcome the problems associated with lingual orthodontics, the skeletal anchorage with the mini-implants and mini-screws have been successfully applied to lingual orthodontics.[5] Mini implants have been used on each side of palate to avoid deepening of anterior bite and uncontrolled tipping during en masse retraction in lingual orthodontics.[2]

For studying the optimal loading conditions using lever arm and mini- implant system for en-masse retraction in lingual orthodontics, we choose to use the finite element method, as it can rebuild the size and shape of a model alike to the actual object and it is superior in the calculation of stress and strain of various complex structures.

The teeth response to sliding mechanics during en- masse retraction of anteriors was examined by using finite element method. In three dimensional computer model, numerous conditions can be replicated by varying the simulation parameters. The initial response to the alveolar bone, PDL and teeth can be assessed quantitatively and qualitatively.6So this tool has been chosen to understand the biomechanics that occur during anterior retraction in lingual orthodontics.

This present FEA study is aimed to determine the optimal loading conditions using different heights of lever arm and different positions of mini implant for en masse retraction in lingual orthodontic treatment.

Materials and Methods:

In the present study, four 3-dimensional finite element models of the bilateral maxillary first premolar extraction case consisting of 12 teeth with its periodontal ligament, alveolar bone, lingual brackets, archwire, lever arm and mini-implants were constructed. And the stresses produced onto the periodontal ligament and alveolar bone were determined on applying the retraction forces using NiTi closed coil springs on the maxillary anteriors with the help of various combinations of mini-implants and lever arms. Table 1: Details of the software and hardware used in the study are mentioned in Table 1.

Table 1: Details of the software and hardware used in the study

S.NO.	SOFTWARE	HARDWARE
1.	**MIMICS(version 8.11)** for CT scan	4GB RAM
2.	**Rapidform 2004** for the conversion of the CT scan into the geometric model	Intel core 2.5gigahertz processor
3.	**HYPERMESH(version 13)** for the creation of FE model	80 GB hard disk
4.	**ANSYS(version 12.1)** for the analysis & Post processing	

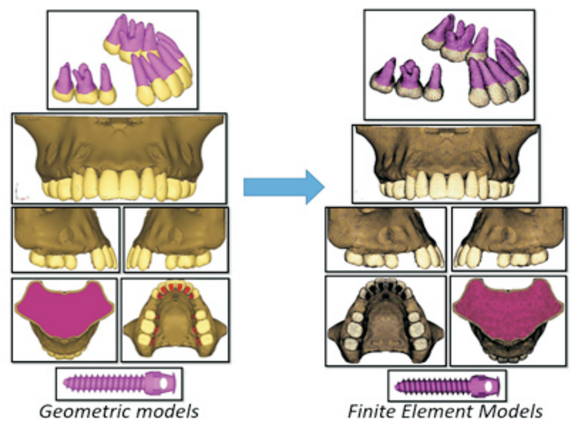

Figure 1: Construction of Geometric models of the teeth, periodontal structures, maxilla, brackets, archwire and mini-implants.

Steps involved in the finite element model preparation7:

1) Construction of the Geometric model of the maxillary dentition with its periodontal structures (periodontal ligament, alveolar bone).
2) Conversion of the geometric models to a finite element model. (Figure 1)
3) Incorporation of material properties of tooth structure and periodontium .(Table 2)
4) Defining boundary condition. (Figure 2)
5) Loading configuration.

Translation of results and interpretation.

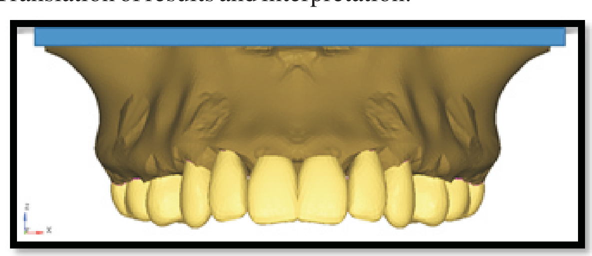

Fig 2: Finite element models with defined boundary condition

S.NO.	Materials	Young's Modulus(MPa)	Poisons ratio
1.	Hard bone	13700	0.38
2.	Soft bone	1370	0.38
3.	Periodontal ligament	0.068	0.49
4.	Teeth	20000	0.3
5.	Titanium implants	11,0000	0.3
6.	Stainless Steel wire	20,0000	0.3

Table 2: Material properties used in the Finite Element Model

In this study 4 models were formed:

1. In the first model, mini-implants were placed at furcation level of second molar bilaterally between first molar and second molar on palatal surface. Lever arm of 10 mm in height in palatal direction were placed on the arch wire between lateral incisor and canine bilaterally. For this model total number of nodes and elements were 86841 and 406925 respectively.

2. In the second model, mini-implants were placed at furcation level of second molar bilaterally between first molar and second molar on palatal surface. Lever arm of 15mm in height in palatal direction were placed on the arch wire between lateral incisor and canine bilaterally. For this model total number of nodes and elements were 86841 and 406948 respectively.

3. In the third model, mini-implants were placed at root apex level of second molar bilaterally between first molar and second molar on palatal surface. Lever arm of 10 mm in height in palatal direction were placed on the archwire between lateral incisor and canine bilaterally. For this model total number of nodes and elements were 89496 and 422763 respectively.

4. In the fourth model, mini-implants were placed at root apex level of second molar bilaterally between first molar and second molar on palatal surface. Lever arm of 15 mm in height in palatal direction were placed on the archwire between lateral incisor and canine bilaterally. For this model total number of nodes and elements were 89496 and 422763 respectively.

In this study, the geometric system was coordinated. The Y-axis was the mid-sagittal line of the dental arch on the occlusal view, the Z-axis was perpendicular to the Y-axis in occluso-gingival direction. A net force of 150g was applied through NiTi closed coil springs on both sides in all four models.

Color coding for stress and displacement:

Blue colour shows the minimum stress, red colour shows the maximum and the remaining shades are the variation of stress from minimum to maximum. (Figure 3)

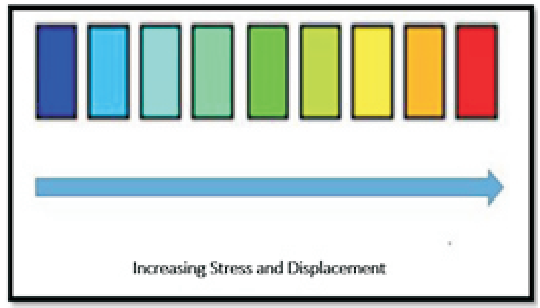

Figure 3: Color coding of the stress & displacement analysis

Co-ordinates for displacement: In this study, displacement was seen in Y- and Z- Axis. Y-Axis denotes labio-lingual movement of central and lateral incisors while for canine it denotes mesio-distal movement. Positive value in both quadrants indicates lingual movement of the central, lateral incisors and distal movement of the canines while negative value indicates labial movement of the central, lateral incisors and mesial movement of the canines and Z-Axis denotes occluso-gingival movement of all the anterior six teeth. Positive value in both quadrants for all the anterior six teeth indicates intrusion of teeth and negative value indicates extrusion of teeth (Figure 4).

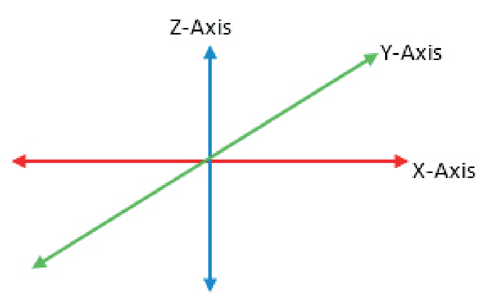

Figure 4: X-, Y-, Z- Co-ordinates

STATISTATICAL ANALYSIS- In Finite element study it is enough to validate the analysis results obtained by software tools with finite element simulation instead of experimental readings. Thus it doesn't need statistical analysis.

Result:

The constructed models along with the load application were imported into ANSYS (version 12.1) software for analyzing the displacement and stress distribution corresponding to the force application. In present study models the nature of stress distribution in periodontal ligament changes from being tensile at root apex of canine on distal surface to compressive towards the mesial surface of all anteriors and the stress in the alveolar bone are tensile in nature in the vicinity of the mini-implant and changes to compressive away from the mini-implants while the teeth shows controlled lingual crown tipping in all four models. It proves that en-masse retraction in lingual orthodontics is not an easy task, it is very difficult in lingual orthodontics to achieve a bodily movement.

The results obtained consisted of the maximum Von Mises stress concentrations (Table 3), Principle stress distribution in the hard bone, soft bone, PDL, teeth (Table 4), and initial displacement of each individual anterior tooth in all the three X, Y, and Z-axis [Table 5].

REGION	FORCE APPLIED (g)	MODEL 1		MODEL 2		MODEL 3		MODEL 4	
		Positive Values	Negative Values	Positive Values	Negative Values	Positive Values	Negative Values	Positive Values	Negative Values
Hard Bone	150	60.996	-74.090	52.500	-76.044	82.837	-91.650	68.623	70.573
Soft Bone	150	2.900	-0.454	2.904	-0.386	4.281	-0.906	3.563	-0.921
PDL	150	0.00001	0.00000	0.00001	-0.00000	0.00001	0.00000	0.00001	0.00000
Teeth	150	3.248	-0.246	3.189	-0.442	1.617	-0.148	1.395	-0.198

Table 3. Von Mises stress concentrations in the hard bone, soft bone, PDL, teeth.

REGION	FORCE APPLIED (g)	MODEL 1	MODEL 2	MODEL 3	MODEL 4
Hard Bone	150	57.971	56.249	76.466	65.107
Soft Bone	150	2.534	2.292	4.56	4.394
PDL	150	0.00001	0.00001	0.00001	0.00001
Teeth	150	3.54	3.44	1.98	1.683

Table 4. Principle stress distribution in the hard bone, soft bone, PDL, teeth

TOOTH	AXIS	MODEL 1		MODEL 2		MODEL 3		MODEL 4	
		CROWN	ROOT	CROWN	ROOT	CROWN	ROOT	CROWN	ROOT
CENTRAL INCISOR	X	0	0	0	0	0	0	0	0
	Y	**0.011**	**0.003**	**0.008**	**0.003**	**0.007**	**0.002**	**0.006**	**0.002**
	Z	**-0.007**	-0.001	**-0.005**	-0.001	**-0.004**	-0.001	**-0.003**	0.001
LATERAL INCISOR	X	0	0	0	0	0	0	0	0
	Y	**0.0011**	**0.003**	**0.008**	**0.003**	**0.007**	**0.002**	**0.006**	**0.002**
	Z	**-0.006**	-0.001	**-0.004**	-0.001	**-0.003**	-0.001	**-0.003**	0.001
CANINE	X	0	0	0	0	0	0	0	0
	Y	**0.011**	**0.003**	**0.008**	**0.003**	**0.007**	**0.002**	**0.006**	**0.002**
	Z	**-0.006**	-0.001	**-0.004**	-0.001	**-0.003**	0.000	**0.003**	0.000

Table 5. Displacement of each individual anterior tooth in all the three X, Y, and Z-axis

Von Mises stress and Principle stress distribution in hard bone, soft bone, PDL & teeth are shown in Figure 5 and Figure 6 respectively. Displacement of central incisor, lateral incisor, and canine in X-axis, Y-axis, and Z-axis for Models 1, 2, 3, and 4 are shown in Figures 7.

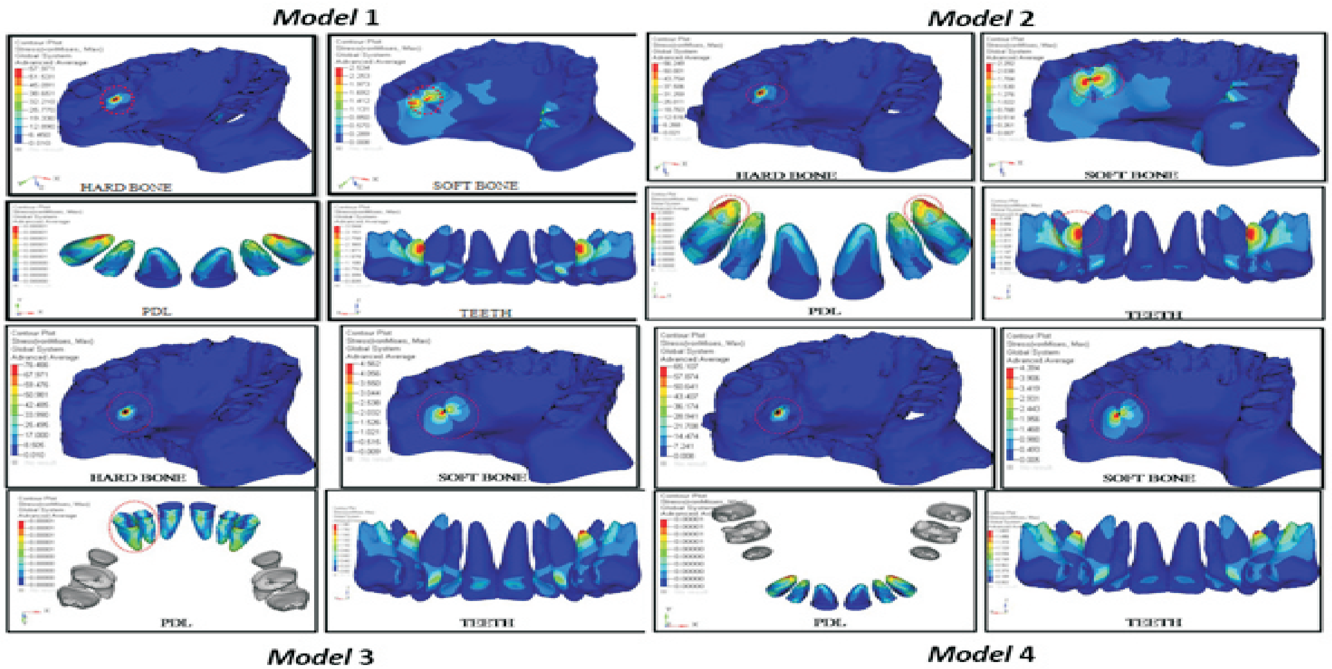

Figure 5. Von mises stress distribution in hard bone, soft bone, PDL & teeth.

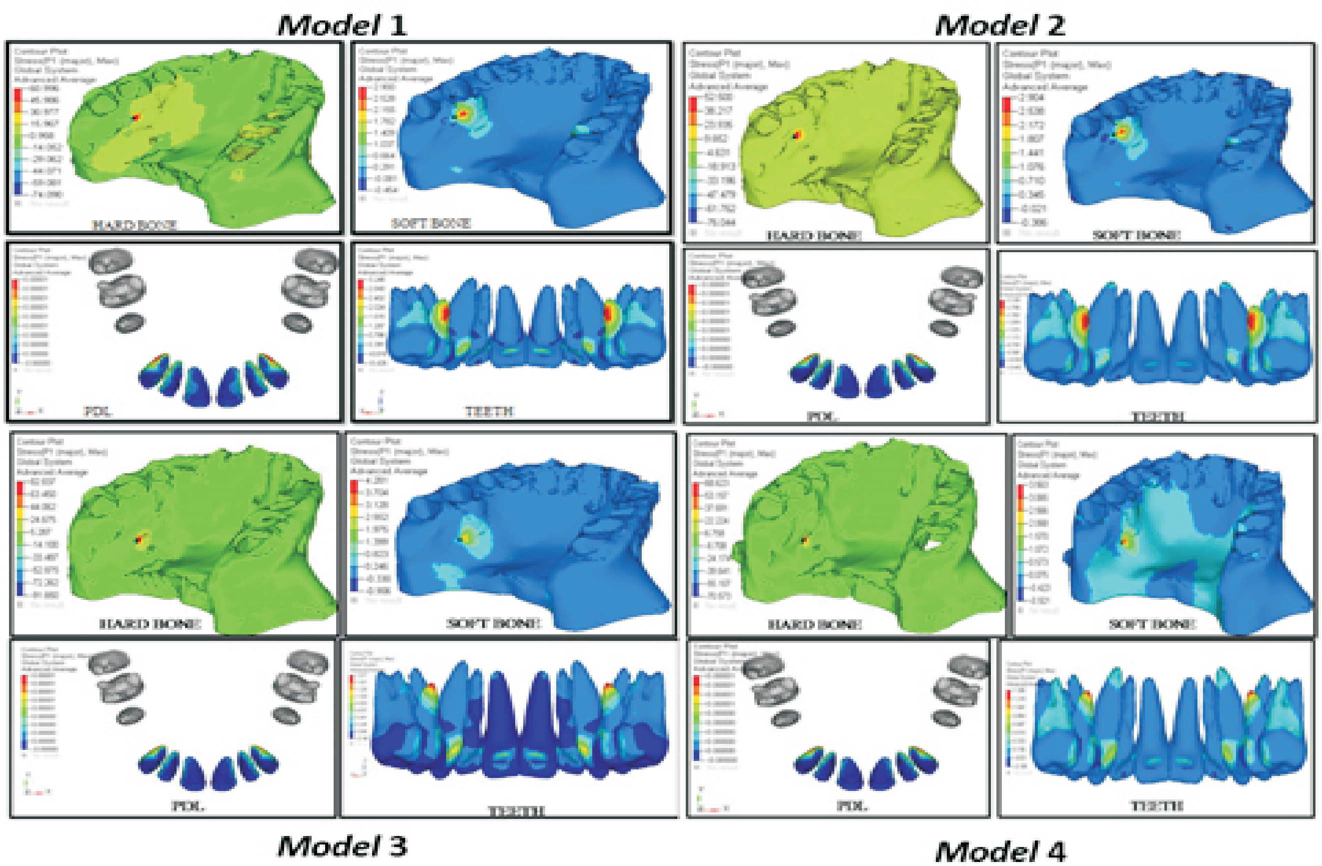

Figure 6. Principle stress distribution in hard bone, soft bone, PDL & teeth.

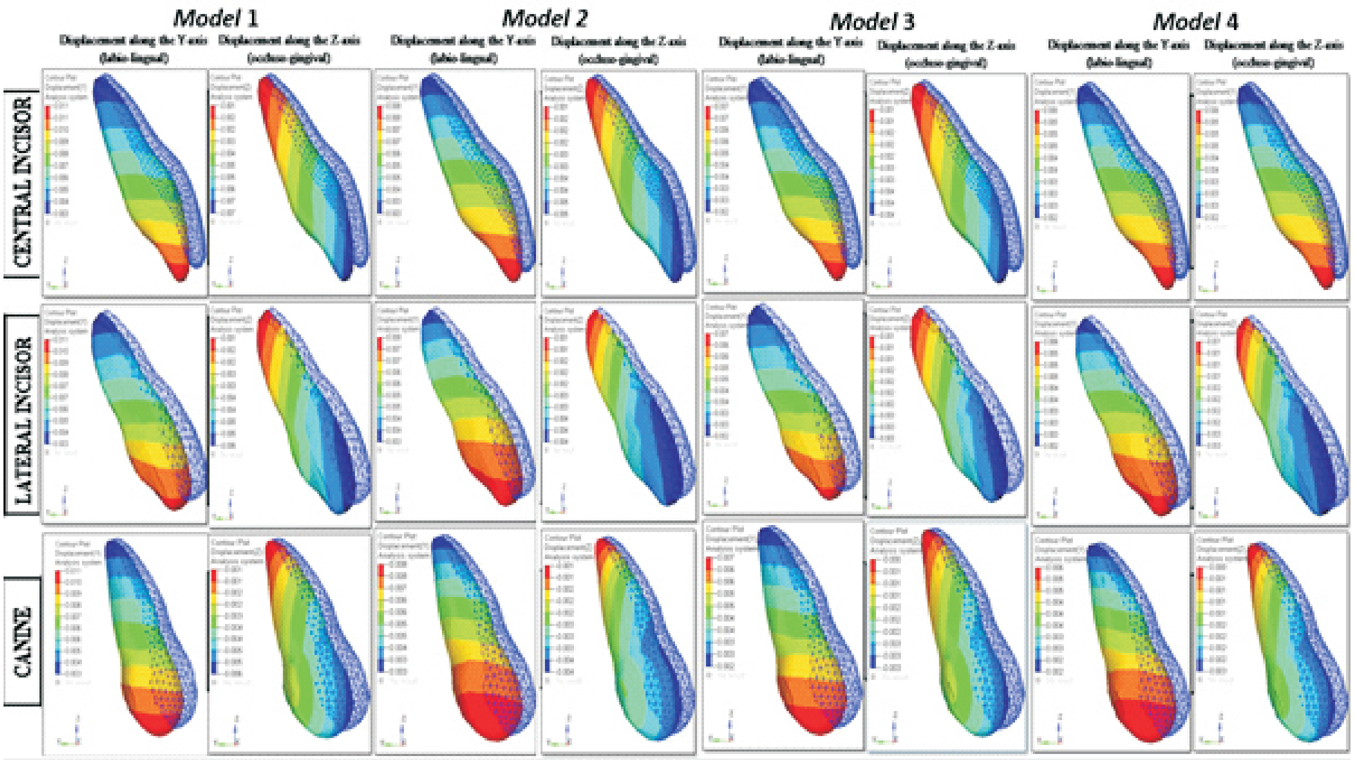

Figure 7. Displacement of central incisor, lateral incisor, and canine in X-axis, Y-axis, and Z-axis.

Discussion:

The anchorage value of the posterior teeth in the anterior-posterior and vertical directions appear to be higher in lingual orthodontics than in labial orthodontics (Takemoto, 1997). En masse retraction can cause many mechanical problems such as bowing effect (vertical and transverse) and anchorage control. The vertical bowing effect is the most serious problem, since it cannot be avoided with simple auxiliaries like transpalatal arches and by using mini implants. When a strong retraction force is used in an anterior–posterior direction, the upper anterior segment (3-3) may tip lingually.8 In extraction cases, en-masse retraction of six anterior teeth using sliding mechanics has been widely used in orthodontic space closure with the extensive use of straight wire appliances. In sliding mechanics, the tendency towards lingual crown or lingual root movement of the anterior teeth will be determined by the direction of the retraction force and notably by the rotational effects derived from the relation of the line of action of the retraction force relative to center of resistance. To achieve bodily displacement of anterior teeth during retraction, clinician should exert force passing through the center of resistance of the anterior segment or a horizontal force combined with the proper moment, which produces homogeneous stress distribution in the periodontium.

Thus, mini-implants are used extensively to solve the anchorage problems, to control the anterior torque and manage the level of the force system. By adjusting the height of the lever arms and mini-implants the movement of the teeth can be achieved in preprogrammed direction like controlled lingual crown tipping, bodily translation movement and controlled labial-crown movement. 9

Attempts have been made to apply retraction force to the position close to the center of resistance of the anterior teeth by increasing the length of the retraction hooks. Thus, the possibility of translating the anterior teeth parallel to the desired direction by using a retraction force have been examined in many previous studies.10In this study, closed coil springs were used due to constant force application over varying lengths of time with no force decay11 and 150g of retraction force was used which is within the normal physiologic limits for retraction as told by Ricketts12 and same force was used in some other studies also.9,13,14,15

The aim of this study was to evaluate the stress distribution along the periodontal ligament and alveolar bone by combinations of various mini-implants and lever arm during en-masse retraction of anterior teeth. A segmented archwire is used in this study to develop a precise and predictable force system16. Here, we get to know in detail about nature of stress distribution, displacement contours and von Mises stress following the application of an external force. The von Mises stress of a material when compared gives an idea that the material is going to fail or not corresponding to the load applied.

vonMises stress is a stress in a component which tells you whether the component has failed or it is safe. In this study von Mises stress values for the bone in all the four models are far below the ultimate tensile strength of alveolar bone of 135 MPa.17 also the von Mises stress values for the periodontal ligament in all the four models are below than the ultimate tensile strength of the periodontal ligament of 2.4 MPa.So, both the alveolar bone and periodontal ligament in above 4 models are safe during en-masse retraction of anterior teeth.
Principle stress will help us in understanding the nature of stress, if it is tension or compression. If the stress values are positive then the nature is tension and if the values are negative the nature is compression. We have to check this nature of stress to prevent problems in future.

Maximum principle stress seems to be compressive in nature along lingual surfaces of upper anterior except root apex and cervical portion of canine.The nature of stress pattern changes in periodontal ligament from tensile in the distal root apex of canine and compressive at lingual surface of anteriors.

Displacement of teeth along the Y-Axis- all the four models showed controlled lingual crown tipping. According to Tominagaet al15 lingual crown tipping of maxillary incisor was observed when retraction force was at 0 mm (bracket slot level). The direction of tooth rotation was changed from lingual crown tipping to lingual root tipping on increasing the height of the retraction hook. They found bodily movement of central incisor at the level of 5.5 mm of retraction hook. Sung et al stated that the lingual tipping of the central incisor and lateral incisor reduces on increase in height of the retraction hook. Similarly in first model of this study which was done by lingual mechanisms showed that when the force was applied onto the lever arm of 10 mm placed palatally and the position of mini- implants is at the furcation level of second molar between first and second molar, more of lingual crown tipping occurred and canines shows distal tipping in all the four models.

Along the Z-Axis:In this study all the four models showed extrusion of crowns while it was observed in model 3 and 4 that when we placed mini implants at apical level of second molar less amount of extrusion occurs and it was also observed that among the all four models the minimum amount of extrusion is noticed in model 4 and maximum amount of extrusion is noticed when the height of lever arm is 10mm and mini- implants was also placed at furcation level of second molar.

The reason for such extrusive movement can be that archwire did not have enough rigidity to maintain their original vertical position. Retraction force caused the lever arm to bend backward or forward, the archwire mesial to it to bend upwards, and archwire distal to it to bend downwards.14,15
Thus, this study helps to understand and apply the retraction mechanics for space closure as per the need of the clinician and also helps evaluate the movement of the teeth. The appropriate vertical height of the lingual anterior retraction hooks allows the clinician to produce controlled tipping, bodily movement and lingual root movement during retraction18.Here in this study it was proved that en-masse bodily movement of anterior teeth seems to be very difficult in lingual orthodontics as compared with lingual orthodontics.

Conclusion:

Based on the various combination of lever arms and mini-implants used in all the four models in this finite element study for en-masse retraction, following conclusion can be drawn, The teeth showed controlled lingual crown tipping in all four models. It proves that en-masse retraction in lingual orthodontics is not an easy task, it is very difficult in lingual orthodontics to achieve a bodily movement. Lever arm of 10 mm length is associated with more amount of lingual crown tipping suggesting that retraction force is passing away from the centre of resistance. So the height of lever arm could be the most easily modifiable clinical factor in determining the direction of anterior teeth displacement during en-masse retraction of anterior teeth. Continuous and Segmented archwirescan be used in lingual orthodontics, the benefit of using segmented archwire is that it is possible to achieve a precise and predictable force system between anterior and posterior segment.

So, finally from this study we can conclude that in lingual orthodontics tipping movement of crown decreases as the height of lever arm increases, as seen in model 2 and model 4. It was also found that when mini-implants were placed at higher position the amount of tipping movement decreases with minimum amount of extrusion seen in central incisor and lateral incisor and there were no movement seen in canine.

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