How to Cite:
Barot, M., Shah, A., Hirani, S., Thakore, K., Desai, S., & Pancholi, D. (2022). Comparative evaluation of different loops for individual canine and en-masse retraction-a finite element method (fem) study. *International Journal of Health Sciences*, *6*(S1), 3037–3050.
https://doi.org/10.53730/ijhs.v6nS1.5302

Comparative Evaluation of Different Loops for Individual Canine and En-Masse Retraction-A Finite Element Method (Fem) Study

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***Abstract*---**The aim and objective was to compare and evaluate the T loop, Mushroom loop and Opus loop for individual canine and en-masse retraction for space closure without preactivation bends using finite element method. The geometric model of maxilla was constructed using CBCT scan. The bracket system simulated was of standard MBT bracket system and arch wire used were 19*25 Stainless Steel and 17*25 TMA for fabrication of loops. There were six different models generated with segmented T loop, Mushroom loop & Opus loop and Continuous T loop, Mushroom loop & Opus loop. The software used for post-processing of the model was ANSYS Hypermesh 2019.0. When retraction forces were given with activation of loops,

International Journal of Health Sciences ISSN 2550-6978 E-ISSN 2550-696X © 2022.
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Manuscript submitted: 18 Jan 2022, Manuscript revised: 09 Feb 2022, Accepted for publication: 27 March 2022

maximum amount of initial tooth displacement for individual canine retraction was observed for segmented T loop and for en masse retraction it was observed for continuous T loop. Although, there was intrusion of canine for all the three segmented loop, the preferred loop for canine retraction should be segmented T loop and for en masse retraction it should be continuous T loop as it shows least effect of retraction forces on anterior as well as posterior teeth during application of retraction force.

***Keywords*---**Finite element method, T Loop, Mushroom Loop, Opus Loop, Frictionless Mechanics.

Introduction

Space closure is one of the most challenging processes in Orthodontics. The ability to close spaces, especially those resulting from tooth extraction, is an essential skill required during orthodontic treatment. Space closure mechanics can result in failure if applied without proper knowledge[1-5].

Two basic biomechanical strategies can be used to close spaces: frictionless (loop) mechanics and frictional (sliding) mechanics.In Frictionless mechanics, a required amount of force is delivered to the teeth and spaces are closed with the help of loops incorporated in the Stainless Steel and Titanium Molybdenum Alloy TMA wire which increases the flexibility and springiness thereby producing optimal force for different types of tooth movement[2,3].

Space closure can be done either as two step retraction where the canines are distalized first followed by anterior retraction /that is supposed to be less detrimental to anchorage. However, the treatment time is prolonged. On the contrary, an en-mass / one step retraction is more beneficial in terms of duration of treatment. Nevertheless it is still debated if a two-step retraction is more beneficial compared to en-masse retraction for preserving anchorage[1].

There has been various studies done on different loops to determine the stress distribution and the different tooth movements occurring on the anterior and posterior teeth during space closure. However, the finite element analysis is a non-invasive technique, in which the object of various shapes of materials of non homogenous nature can be studied three dimensionally. It provides a quantitative data that increases the understanding of the physiologic reactions that occur after force application and may yield an improved understanding of the reaction and interactions of individual tissues. Thus the actual tooth movemnets, anchorage loss and stress distribution can be measured at any point of force application[10].

To the best of our knowledge, there has been no study that has evaluated and compared the biomechanical response and the different tooth movements that occurs during the individual canine and en-masse retraction with different loops. Hence this study has been taken up. The Aim of this study is to compare and evaluate the T loop, Mushroom loop and Opus loop for individual canine and en-masse retraction, different tooth movements occurring during space closure and stress distribution on cortical bone, cancellous bone, PDL and teeth without preactivation bends using finite element method.

Materials and Method

CBCT scan of a normal adult human maxilla with increased overjet where first maxillary premolar was removed to simulate the extraction space needed for retraction. For the present study, a finite element model was generated. This model was replica of the adult human maxilla. The software used for geometric modeling was HYPERMESH 2019.0. The model consisted of the periodontal ligament, alveolar bone and all the teeth except first maxillary premolar and third molars. The bracket system simulated was the standard MBT bracket system and the arch wire used were 0.019x0.025 inch Stainless Steel and 0.019x0.025 inch TMA wire for different loop fabrication. The finite element modeling is the representative of geometry in terms of finite number of elements and nodes. This process is called discretization. The element type used was 1st order Tetra. The main idea behind discretization is to improve the accuracy of the results. The total number of elements and nodes established were 1,15,3876 and 1,57,233 respectively.

The software used for the post-processing of the model was ANSYS Workbench (version 11.0; ANSYS, Canonsburg, Pa) in the study. The different structures involved in the study include teeth, the periodontal ligament and alveolar bone. Each structure has a specific property. The material properties that were used for the study are given in Table 1.

Once Meshing and contacts are defined the next process is to define boundary conditions. Boundary condition means defining loads and restraints. Once the loads are defined then the problem is solved and the results can be reviewed. A three dimensional finite element model of maxilla with segmented T loop, mushroom loop and Opus loop and continuous T loop, mushroom loop and Opus loop without preactivation bends were obtained(Figure1 and 2). The efficiency of space closure, stress distribution and anchorage loss was calculated by activation of each loop by 6mm.

Results

The study was conducted to compare the biomechanical efficiency of three different loops by creating six different FEM models for individual canine and en-masse retraction without the preactivation bends and the activation of the anterior and posterior leg of the loop by 6mm. The displacement of the dentition, the individual tooth and resultant stresses were calculated for activated 6 mm in maximum anchorage case using Finite Element Analysis.

The result consisted of displacement contours of the maxilla (Figure3-8), initial displacement of teeth during individual canine and en masse retraction (Table 2 and 3), maximum von Mises stresses on cortical and cancellous bone, stress distribution in PDL. The evaluation of displacement contours of the maxilla in the six FEM models were as follows: In each model maximum displacement was observed in the canine region, canine was displaced distally in every model. While comparing, the maximum canine displacement was seen in the Segmented T loop followed by mushroom, opus, continuous T loop, mushroom loop and least displacement was seen in continuous opus loop.

Evaluating the three different loop for individual canine retraction in X,Y and Z axis, the maximum movement was in Y axis (distally) for anterior teeth which was not significant. Intrusion was observed in Canine(Z axis) which was maximum for opus loop(0.36) followed by mushroom(0.346) and least in T loop(0.342). For Premolar and Molar maximum movement was observed in Y axis (mesially) which was maximum for opus loop(-0.123) followed by mushroom(-0.120) and least in T loop(-0.119).

Evaluating three different loop for en masse retraction in X,Y and Z axis maximum movement was observed in Y axis (distally) in anterior teeth due to the direction of force applied causing the distal movement of the incisors. Intrusion was in canine as well as anterior teeth. The maximum intrusion was seen in Opus (0.255) followed by Mushroom(0.243) and least in T loop(0.241). For Premolar and Molar maximum movement in Y-direction (mesial).

While evaluating the stress in the teeth, maximum stress was commonly at bracket attachment region in continuous loop model and no significant stress for segmented loop model for anterior teeth. For canine maximum stress at bracket attachment region for segmented loop model and for premolar and molar stress at bracket attachment was similar in both the models.

For continuous loop, maximum stress was seen at apical region in anterior teeth and no significant stress for segmented loops. The apical region of canine showed maximum stress with segmented loops and for premolar and molar maximum stress was seen on mesial side and was similar in both the treatment modalities.
Cortical bone showed maximum stress in continuous loop models and is maximum at the cervical region of canine and incisors. For segmented loop model maximum stress was seen at canine and second premolar cervical regions on buccal side. For Cancellous bone Maximum stress for continuous loop model was at the apical region of canine and incisors. For segmented loop model maximum stress at apical region of canine.

While evaluating the stress distribution in PDL maximum compressive stress was observed in continuous loops for the anterior teeth at the apical region and for canine it was observed maximum for the segmented opus loop. For Premolar and molar the maximum compressive stress is observed at the medial side and is similar for both the cases.

Table 1: Material properties required are Poissons ratio and Young's modulus of each component

Materials	Young's Modulus (Mpa)	Poisson's ratio
Tooth	20,000	0.30

Periodontal ligament	0.059	0.49
Alveolar bone	2,000	0.30
Bracket	2,00,000	0.30
Archwire	2,00,000	0.30

Table 2: Displacement of teeth in all axis (mm) for segmented loop

Teeth	Segmented T Loop		Segmented Mushroom Loop		Segmented Opus Loop	
	Crown	Root	Crown	Root	Crown	Root
Central Incisor X-axis Y-axis Z-axis	0.0 0.002 0.002 -0.001 0.001	0.0 -	0.0 0.002 0.002 -0.001 0.001	0.0 -	0.000 0.002 -0.001	0.000 0.002 -0.001
Lateral Incisor X-axis Y-axis Z-axis	0.0 0.002 0.002 0.001 0.001	0.0	0.000 0.000 0.002 0.002 -0.001 0.001	-	0.000 0.002 -0.001	0.000 0.002 -0.001
Canine X-axis Y-axis Z-axis	-0.081 0.042 0.495 0.402 0.302 0.346	-	-0.080 0.042 0.490 0.397 0.298 0.342	-	-0.086 0.045 0.510 0.415 0.322 0.367	-
Second Premolar X-axis Y-axis Z-axis	0.047 0.033 -0.163 0.120 0.033 0.019	-	0.047 0.033 -0.162 0.119 0.035 0.020	-	0.055 -0.166 0.001	0.039 -0.123 0.016
Molar X-axis Y-axis Z-axis	0.051 0.036 -0.153 0.126 -0.010 0.028	- -	0.050 0.036 -0.151 0.125 -0.009 0.028	- -	0.050 -0.158 -0.008	0.036 -0.130 -0.027

Table 3: Displacement of teeth in all axis (mm) for continuous loop

Teeth	Continuous T Loop		Continuous Mushroom Loop		Continuous Opus Loop	
	Crown	Root	Crown	Root	Crown	Root
Central Incisor						
X-axis	-0.003	-0.001	-0.003	-0.001	-0.000	-0.003
Y-axis	0.203	0.189	0.202	0.188	0.210	0.196
Z-axis	0.071	0.082	0.070	0.082	0.074	0.085
Lateral Incisor						
X-axis	-0.002	0.013	-0.002	-0.013	-0.003	0.013
Y-axis	0.234	0.209	0.232	0.208	0.240	0.215
Z-axis	0.122	0.136	0.121	0.135	0.128	0.142
Canine						
X-axis	0.051	0.061	0.051	0.061	0.062	0.052
Y-axis	0.309	0.255	0.307	0.253	0.314	0.260
Z-axis	0.216	0.243	0.215	0.241	0.228	0.255
Second Premolar						
X-axis	0.049	0.034	0.049	0.034	0.056	0.040
Y-axis	-0.166	-0.122	-0.164	-0.121	-0.167	-0.124
Z-axis	0.014	0.029	0.015	0.030	0.003	0.013

Molar X-axis Y-axis Z-axis	0.052 0.037 -0.155 - 0.128 -0.010 -0.029	0.051 0.036 -0.154 -0.127 -0.010 -0.029	0.051 0.036 -0.159 -0.131 -0.009 -0.028

Figure 1- Three dimensional finite element model of maxilla with segmented T loop, mushroom loop and Opus loop

Figure 2- Three dimensional finite element model of maxilla with continuous T loop, mushroom loop and Opus loop

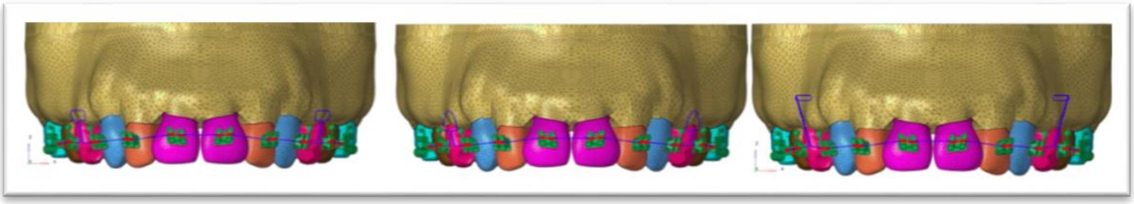


Figure 3- Displacement contours of maxilla ‘mm ’for Segmented T loop

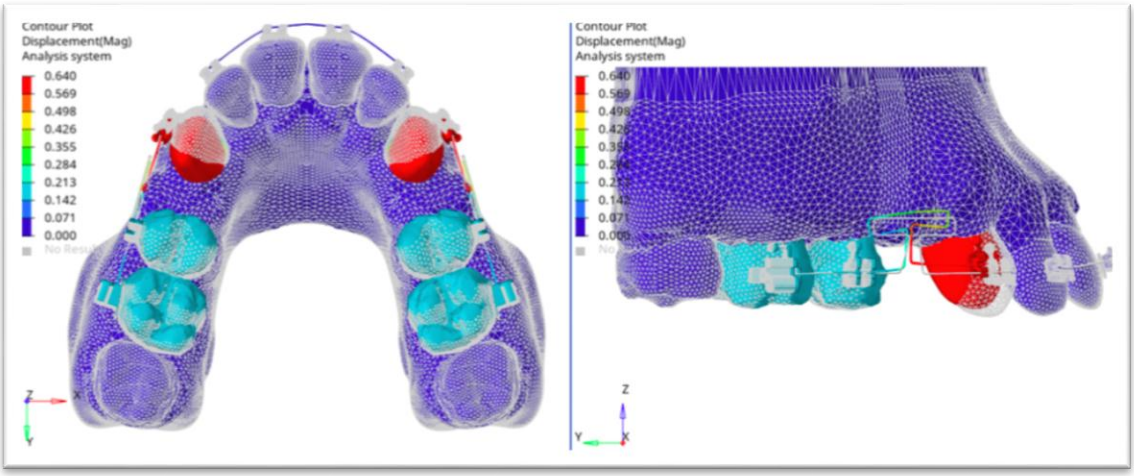


Figure 4- Displacement contours of maxilla ‘mm ’for Segmented Mushroom loop

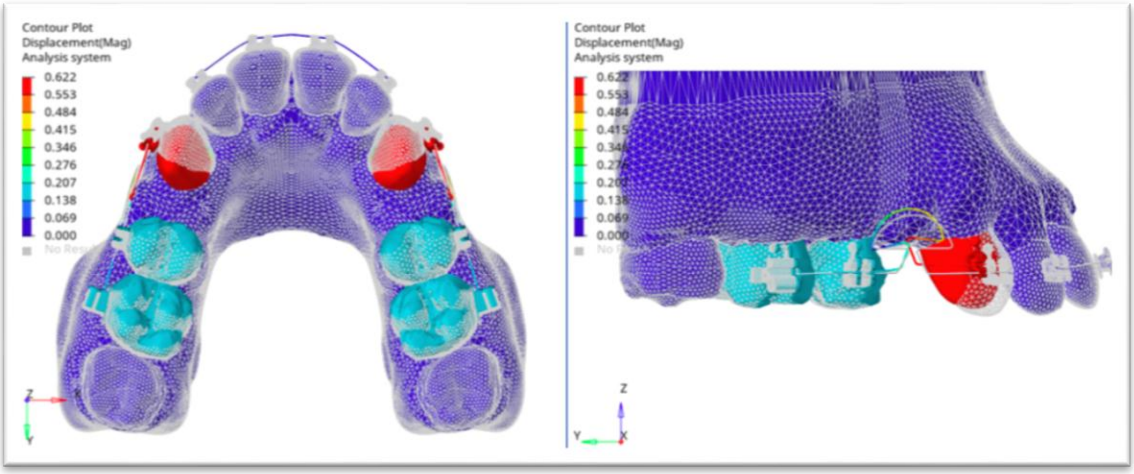


Figure 5- Displacement contours of maxilla ‘mm ’for Segmented Opus loop

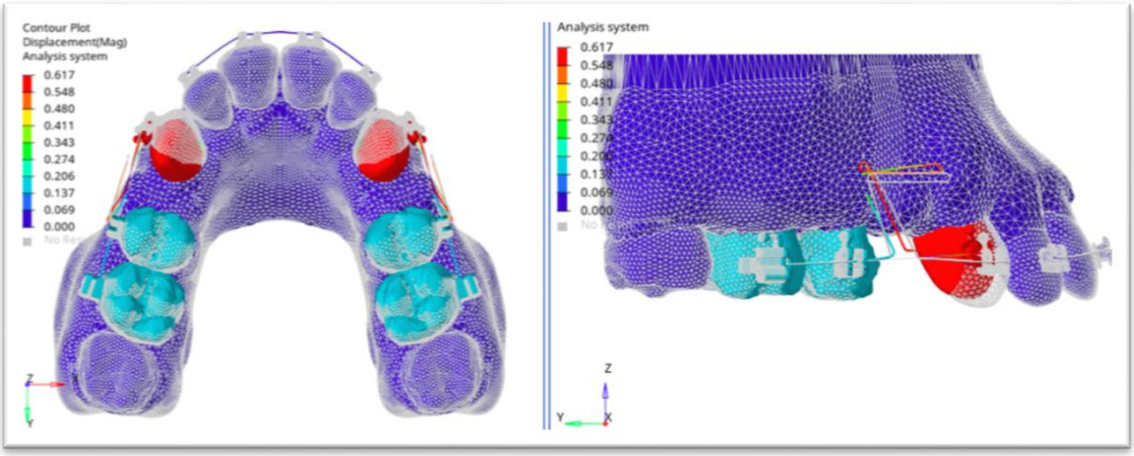


Figure 6- Displacement contours of maxilla ‘mm ’for Continuous T loop

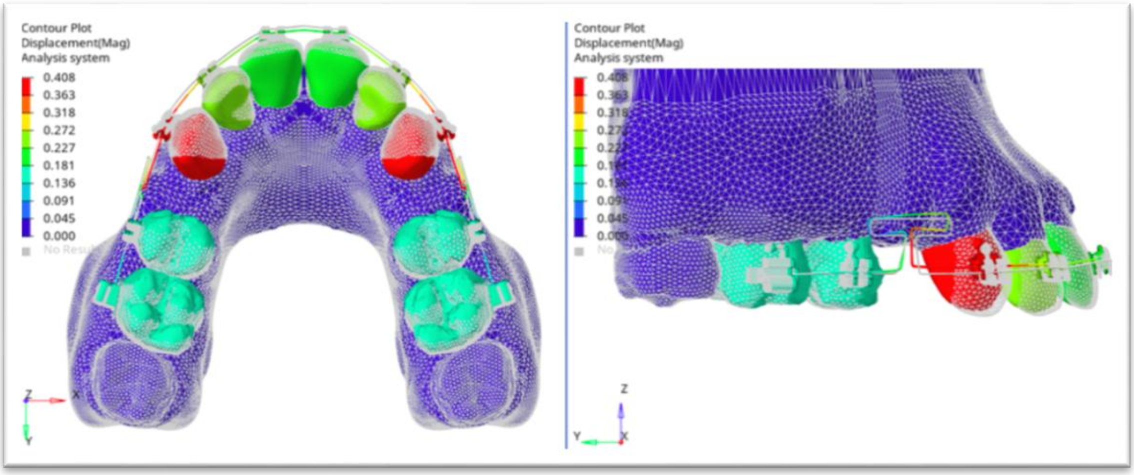


Figure 7- Displacement contours of maxilla ‘mm ’for Continuous Mushroom loop

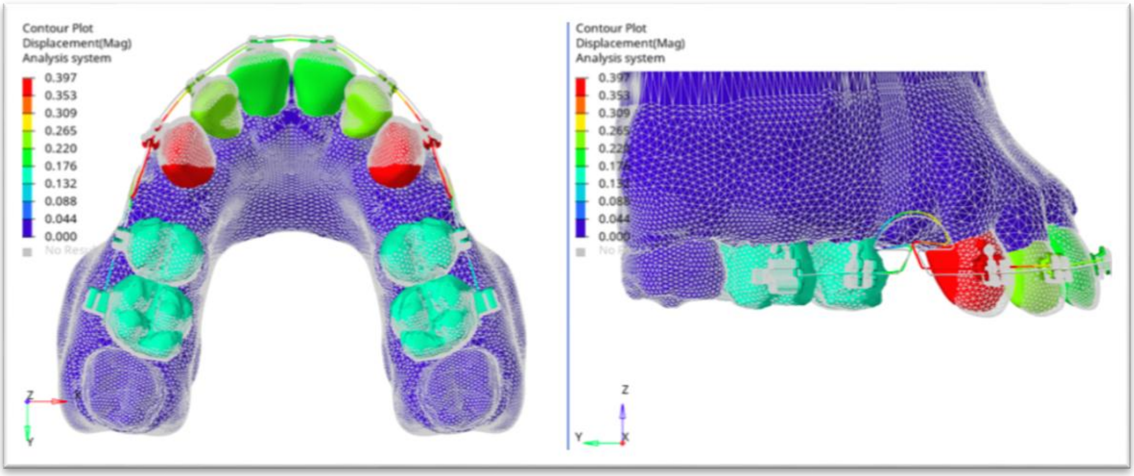
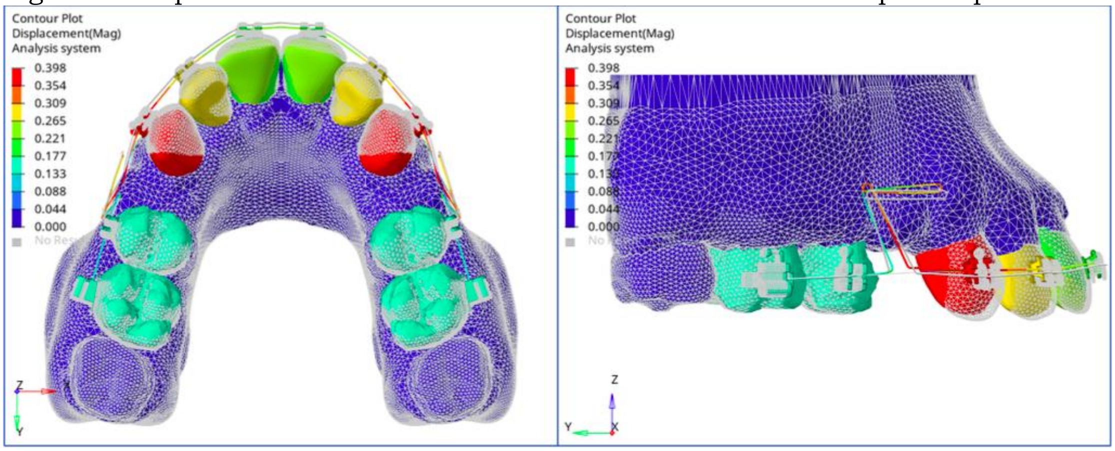


Figure 8- Displacement contours of maxilla ‘mm ’for Continuous Opus loop



Discussion

Space closure can be accomplished by friction and frictionless mechanics. Friction mechanics causes binding and swing effect of the archwire, thereby taxing the anchorage, increasing the force levels, resulting in unwanted tooth movement11. Thereby in this study frictionless mechanics was selected because the above given short comings of the frictional mechanics can be overcome the use of a frictionless system, in which the loop acts as the source of the applied force. Bending archwire loops of various configurations, sectionally is done to deliver the desired moment to force ratio to an individual tooth segmentally or in a continuous archwire. These arch wire loops when activated are friction free. As the teeth move, the loop gradually returns to its preactivated position. Since brackets are not sliding along the arch wire during the process, it is completely friction free. Individual tooth or groups of teeth can therefore be moved more accurately for more precise anchorage control to achieve treatment results. Space closure using frictionless/loop mechanics can be done either as segmental (two step retraction) or by en masse/one step retraction. Loop commonly employed in space closure is the T-loop.

The literature is replete with the studies done on T- loop with preactivation bend to determine various changes in moment to force ratio and its effect on anchorage and differential tooth movement after the activation of the loops and evaluating its efficiency for space closure**9,8,23-28**. But there has been few studies that suggests the activation of loops without the preactivation bends**25,26.** Braun and Garcia**23** stressed that both the addition of preactivation bends and their occlusal and gingival distribution alters the neutral position of a loop. In the absence of preactivation, activation can be easily quantified by measuring the space between the loops uprights. This advantage was given by Siatkowski**9** for Opus loop and confirmed with finite element method by Techalertpaisarn and Versluis**29**.

There has been no study for Mushroom and Opus loop being used for individual canine retraction and nor comparing the T-loop, mushroom loop and opus loop with regard to the force system delivered by these loops during en masse retraction. So this study has been done which evaluated the efficacy of T loop, mushroom loop and opus loop for individual canine and en masse retraction without preactivation bends using finite element analysis which included the initial displacement of the teeth and stress distribution in PDL, Cortical bone and Cancellous bone.

While comparing for individual canine retraction Segmented T loop(0.640) caused greater distal movement of the the canine followed by mushroom(0.622) and then opus loop(0.617). The result also showed a controlled tipping during retraction forces which is in accordance to the study done by melson el al. 199013. While comparing for en masse retraction Continuous T loop(0.408) caused greater distal movement of the canine followed by Mushroom(0.397) and least for Opus loop(0.398). This was in relation to the previous study done by Jeong et al. 200914. This finding suggests that the best loop to be used for individual canine retraction is the T loop as it shows minimum intrusion of canine and anchorage loss with maximum retraction of canine with single activation force fo individual canine as well as en masse retraction.

In the present study, stresses were mainly concentrated at cervical and apical areas, gradually reducing at mid root areas of anterior teeth. The maximum Von Mises stress was noticed in the lateral incisors and canines in continuous loop mechanics, which correlated to the direction of force application. The values of these stresses were far below the ultimate tensile strength of 135 MPa (Van eijden 2000)15. In all the models, maximum von Mises stress in PDL was found in cervical area, which was in accordance with the results of Bohara et al16 and these stresses were far below the ultimate tensile strength of 2.4 MPa (Ralph 1982)17. Thus, the PDL was safe during individual canine and en masse retraction in both the modalities.

In the present study, pattern of principal stresses in PDL changed from tensile in the cervical area to compressive at the root apex in both models. This was in accordance with the findings of previous studies (Zhang et al. 2010; Sung et al. 2010)**18,19**. Both the treatment modalities showed negligible compressive stresses and uniform distribution of tensile stresses in the incisors indicative of bodily tooth movement, as suggested in many studies (Jeon et al. 199920; Field et al. 200921; Jeong et al. 200914). The current study showed highest stresses on the lateral incisors for continuous loop mechanics, and this may be related to their short roots. Viecilli and Burstone 201522 stated that larger teeth have more PDL and root support than smaller teeth, and hence, when the same load is applied, stress magnitudes in PDL for larger teeth are smaller and larger for smaller teeth. Therefore, lateral incisors are more prone to root resorption compared to other teeth and great care should be taken before applying orthodontic forces to them.

Limitations of the study: FEM is an approximation technique and analytical results are highly dependent on models developed; therefore, they have to be constructed to be equivalent to real objects in various aspects. In the present study, periodontal ligament, tooth and the alveolar bone were treated as isotropic structures, even though they exhibit anisotropy and non-linear behaviour. However, there is limited data available that pertain to their anisotropic and non-linear properties. Another limitation of the study was inability to directly predict long-term tooth movement quantitatively through simulation. FEM can only calculate initial tooth displacement and stress distribution after force application. The biological and time-dependent reaction is still unpredictable and requires more clinical evidence.

Clinical Implications: A careful combination of correct treatment planning and treatment modality can help to achieve desirable results in correcting a malocclusion. In cases where individual canine retraction is indicated the Segmented T loop and in cases where en masse retraction is indicated Continuous T loop offers preferable mechanotherapy, as it is effective in controlled translation and minimum intrusive effect on the canine.

Conclusion

Within the limitations of the methodology of the present study, following conclusions can be drawn:

(1) Segmented and continuous loops, both treatment modalities had obvious effects on displacement and stresses on teeth, cortical bone, cancellous bone and PDL;
(2) A comparative evaluation of stress in cortical bone, cancellous bone and PDL revealed that the maximum amount of stress was observed for cortical bone and the stresses were more on laterals than centrals for continuous loops and
(3) FEM could not reflect actual biological response within the human body to orthodontic forces but based on present findings, Segmented T loop and Continuous T loop showed better stress distribution and controlled tooth movement compared to other segmented and continuous loops respectively.

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