

## To compare and evaluate friction V/s frictionless mechanism for individual canine retraction: A Finite element method study

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### ABSTRACT

**Objective:** This study aims to compare and evaluate friction and frictionless mechanics-NiTi closed coil spring versus T-loop-for individual canine retraction using the finite element method (FEM).

**Materials & Methods:** A three-dimensional finite element model of the maxillary arch was developed using Solid Edge v19 software. Simulations were conducted using ANSYS 18.1 software to analyze stress distribution, anchorage loss, canine movement, and rotation under both friction and frictionless mechanics.

**Results:** The T-loop model demonstrated greater overall stress and cortical stress compared to the NiTi closed coil spring model. However, the NiTi closed coil spring showed more canine distal movement and less anchorage loss.

**Conclusion:** Both friction and frictionless mechanics have their advantages and limitations. The FEM results suggest that segmented T-loop mechanics provide better control over tipping and anchorage, whereas the NiTi closed coil spring provides greater distal canine movement with reduced anchorage loss.

**Keywords:** Semaglutide; Polymeric nanoparticles; Oral drug delivery; Encapsulation efficiency; Controlled drug release; PLGA.

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### 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.

The biomechanical basis of space closure enables clinicians to determine anchorage and treatment options, reach the

prognosis of various alternatives, as well as decide specific adjustments that can improve the outcomes of the treatment.

In order to achieve good treatment outcomes, it is important to understand the principles behind space closure. Regulation of space closure is ultimately determined by the biomechanical forces applied to the teeth, variation in force and moment magnitude, moment-to-force ratio (M/F), force-to-deflection rate, and anchor unit.<sup>1</sup>

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Two basic biomechanical strategies can be used to close spaces: frictionless (loop) mechanics and frictional (sliding) mechanics. In spite of the variety of appliance designs available to the orthodontist, the techniques of both, loops or sliding mechanics have their advantages and disadvantages.

In Frictionless mechanics, retraction is accomplished with forces and couples built into the loops or springs, which offer more controlled movement than friction mechanics. In frictionless mechanics, teeth are moved without the brackets sliding along the arch wire. Retraction is accomplished with loops or springs, which offer more controlled tooth movement.<sup>2</sup>

A required amount of force is delivered to the teeth and spaces are closed with the help of loops with forces and couples built into it. Moreover, the loops incorporated in the arch wire increases the flexibility and springiness thereby producing optimal force for different types of tooth movement.<sup>3,4</sup>

In Friction mechanics, resistance to sliding has little to do with friction and instead, is largely a binding and release phenomenon that occur. In orthodontic tooth movement, friction (static or kinetic) results from the interaction of an archwire with the sides of an orthodontic bracket or a ligature. Friction is only a part, and usually a small part, of the resistance to movement as a bracket slides along an archwire.

Kusy and Whitley divided resistance to sliding (RS) into 3 components: (1) friction, static or kinetic (FR), due to contact of the wire with bracket surfaces; (2) binding (BI), created when the tooth tips or the wire flexes so that there is contact between the wire and the corners of the bracket (when a force is applied to a bracket to move a tooth, the tooth tips in the direction of the force until the wire contacts the corners of the bracket, and binding occurs); and (3) notching (NO), when permanent deformation of the wire occurs at the wire-bracket corner interface. Tooth movement stops when a notched wire catches on the bracket corner and resumes only when the notch is released.<sup>5</sup>

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.<sup>1</sup>

There has been various studies done on friction and frictionless mechanics 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 movements, anchorage loss and stress distribution can be measured at any point of force application.<sup>6</sup>

There has been a study designed to explore the differences between friction and frictionless mechanics for maxillary canine retraction with the use of a new typodont simulation

system, the Calorific machine system that has evaluated and compared the biomechanical response and the different tooth movements that occurs during the individual canine retraction with friction and frictionless mechanism. Results achieved from this study was friction mechanics were superior to frictionless mechanics for rotational control and arch dimensional maintenance. Frictionless mechanics were more effective than friction mechanics at reducing the tipping and extrusion. There was no significant difference in anchorage loss between the 2 methods. This study could not establish the superiority of 1 of the 2 methods over the other.<sup>7</sup>

So we are performing the study under a new medium i.e. finite element method which will help us to analyse and give accurate results. Hence this study has been taken up.

#### **Need for the study**

This study is basically the virtual form of treatment procedure that enact in software which will behave accurately the same as in oral cavity, as the software will deliver the same oral environment as in human.

Study is done with finite element method, so we can conduct two different mechanisms i.e. friction and frictionless for space closure in the same arch simultaneously & comparison of various parameters between these two mechanisms of space closure.

By performing this study, we will get to know the better method for individual canine retraction among this two different mechanisms applied.

#### **AIM AND OBJECTIVES**

##### **AIM OF THIS STUDY :**

The aim of this study is to compare and evaluate friction and frictionless mechanism i.e. NiTi Closed coil spring Vs T loop for individual canine retraction using finite element method

##### **OBJECTIVES OF THIS STUDY :**

- To evaluate and compare rotational control
- To evaluate and compare tipping control
- To evaluate and compare anchorage loss
- To evaluate and compare amount of canine retraction

#### **MATERIAL & METHOD**

##### **Inclusion Criteria:**

Increased Overjet  
First premolar extraction  
Maximum anchorage case

##### **Exclusion Criteria:**

Systemic diseases  
Facial or skeletal deformity  
Temporomandibular joint disorder

#### **MODELING**

The first step involved in construction of three dimensional finite element model is modeling. The modeling will be done using a software called Solid Edge v19 .

Solid Edge v19 is a medical modeling software used for the visualization and segmentation of CT/MRI images. Using the software, models can be created and edited with ease.

##### **Three Dimensional Modeling of Maxillary Dentition:**

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Computerized tomography (CT) image acquisitions in the DICOM (digital imaging communications in medicine) format of an adult human skull was obtained using 120 kV, 150 mA, 512 x 512 matrix, field of view 14 x 14 cm and slice thickness of 0.5 mm.

These CT images consisted of 165 sections along the axial axis and 123 sections along the coronal axis, was then imported into the software program Solid Edge v19 and a geometric model was generated that could be manually adjusted to get the exact shape and curves in different sketch planes. These models represent geometry in terms of points, lines, area and volume. The constructed complicated smooth object can be represented geometrically as simple pieces called Elements.

All elements and nodes were numbered so that a setup of matrix connectivity was established. This greatly affects the computing time. The elements could be one, two or three-dimensional and in various shapes and should not overlap each other but are connected only at the key points termed as nodes. The joining of elements at the nodes and eliminating duplicate nodes was termed as 'Meshing'

**Construction of arch wires:**

For arch-wire mechanics:

- Segmented wire, no connection between canine and lateral.
- 0.019x0.025-inch TMA wires are used for loop and 0.019x0.025-inch SS wire anterior segment.
- MBT brackets with 0.022-inch slot is used.
- TMA wires is used for loop and SS wire is used for anterior segment.
- NiTi closed coil spring, 0.009x0.030-inch wire is used for it
- Cone Beam Computed Tomography of skeletal and dental class I malocclusion with increased overjet

After placement of archwire in geometric model, as described above the force applied on space closure on both mechanism will be 200 grams each quadrant.

This study was done using Ansys 18.1 a recent version of Ansys which can import models with 100% data Transfer or with 0% data loss. Once imported the software can do an automatic meshing with defined material properties. The software establishes contacts automatically and defines them as bonded contact. This is of great use as less time is required in selecting surfaces to define contacts especially when there are lots of components between which contact need to be defined.

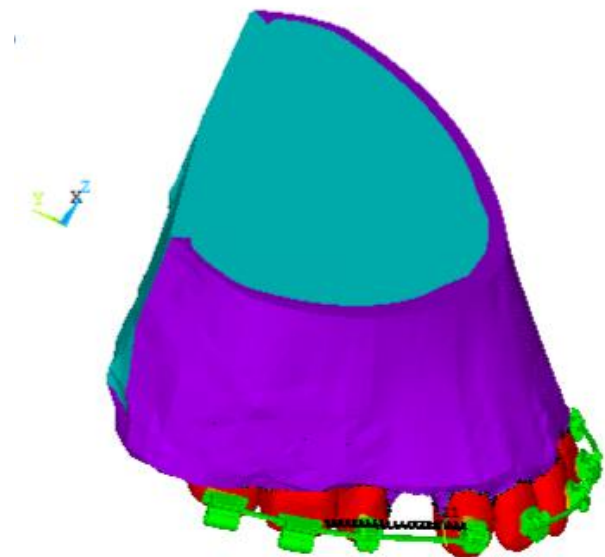
The constructed modeled Images of maxillary arch with dentition, brackets and archwire was imported to work bench ANSYS software and relevant material properties were assigned. The material properties required are Poisson's ratio and Young's modulus of each component as given in below table. Then the periodontal ligament is extracted as surface from the root of the tooth and thickness is assigned.

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

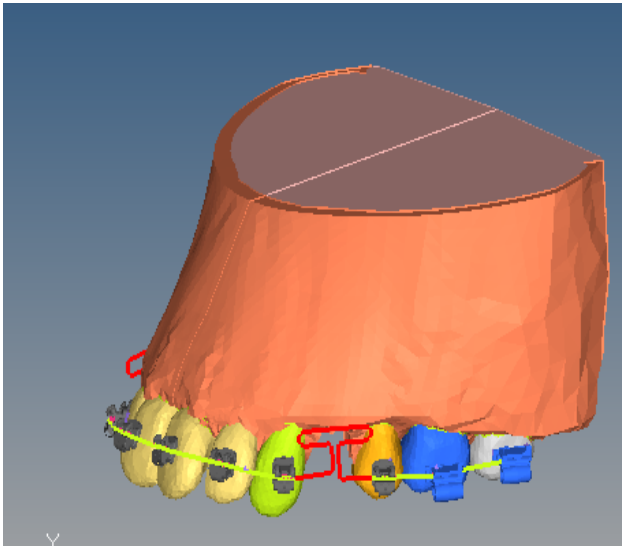
All these components were individually modeled and then assembled to create 3D finite element models of the maxilla and the mandible depicting en- masse retraction of six anterior teeth with ANSYS 18.1 . Once all the images were imported the software can do an automatic meshing with defined material properties. Then the models were converted to elements and nodes.

Therefore, the type of Element used in our study was mid noded Tetrahedron and the total number of elements and nodes established were 275283 and 377968 respectively. 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 coil spring and T Loop arrangement (Figure 1 & 2) respectively.



**Fig 1: Three dimensional finite element model of maxilla with Coil Spring arrangement in one of the quadrant**



**Fig 2: Three dimensional finite element model of maxilla with T Loop arrangement in one of the quadrant**

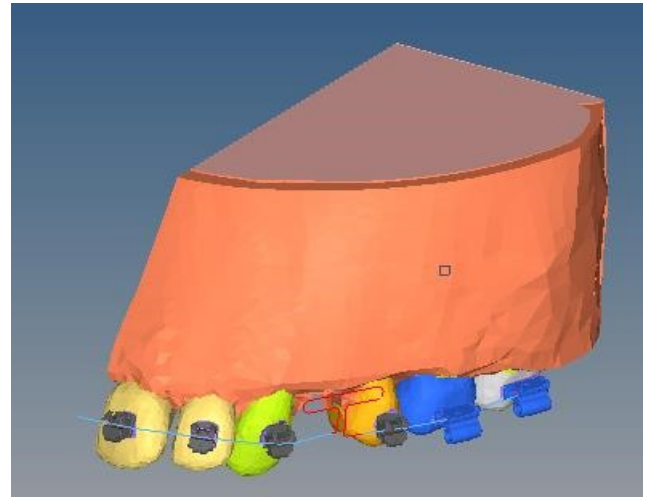
**RESULT**

Title : To compare and evaluate friction v/s frictionless mechanism for canine retraction : (NiTi closed coil spring and T-loop)

Aim: To aim of this study is to compare and evaluate friction and frictionless mechanism i.e. NiTi closed coil spring V/s T loop for individual canine retraction using finite element method

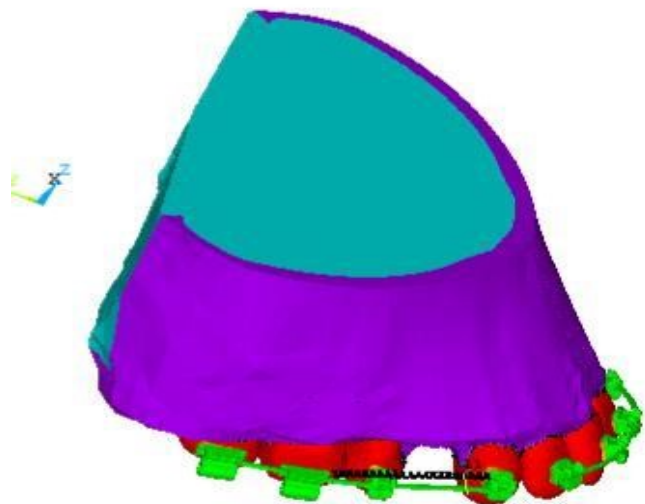
Objectives:

- To evaluate and compare rotational control
- To evaluate and compare tipping control
- To evaluate and compare anchorage loss
- To evaluate and compare amount of canine retraction

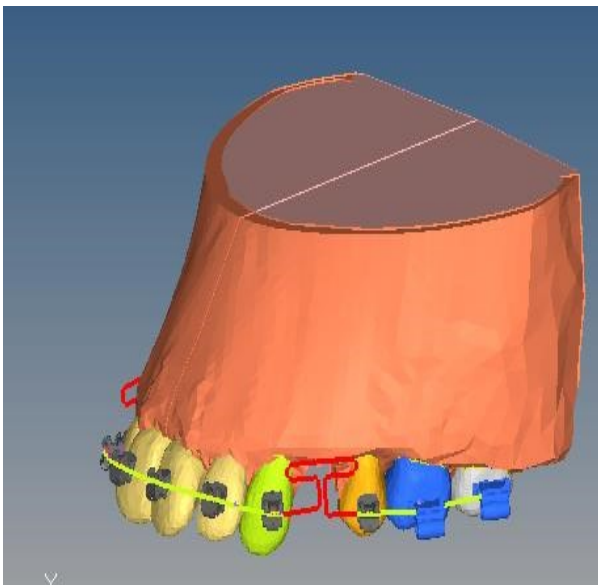


(B)

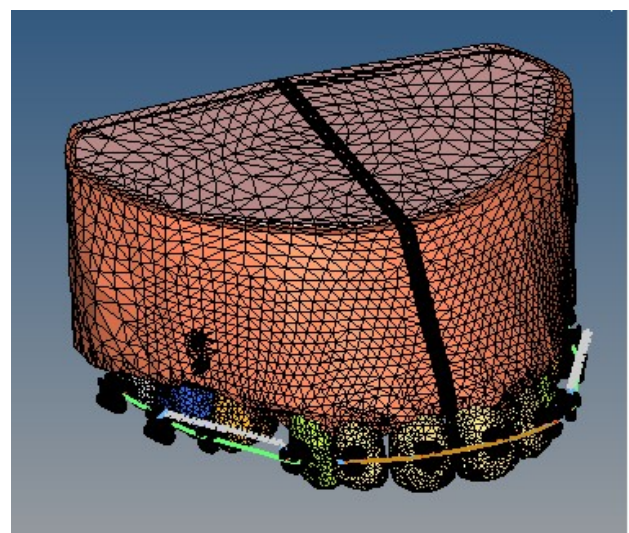
**Fig 1 (A & B) : T-Loop Arrangement**



(1 A)



(A)



(1 B)

**Fig 1 (A & B): closed coil spring arrangement**

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	Number of elements	Number of nodes
T-Loop	274708	377262
Closed Coil Spring	275283	377968

Cancellous Stress (MPa)	0.020976	0.014606
Teeth Stress (MPa)	0.40848	0.216741
Anchorage loss(mm)	0.000228	0.000199
Peri Stress (MPa)	0.000000355	0.00000023
Canine distal movement	0.0000941	0.0000983
Canine intrusion	0.0000301	0.0000318
Canine tipping movement	0.00000272	0.00000355
Canine rotation	0.00000277	0.00000295

	T-Loop	Closed Coil Spring
Overall deformation (mm)	0.000228	0.000199
Overall Stress (MPa)	0.40848	0.216741
Cortical Stress (MPa)	0.265589	0.196885

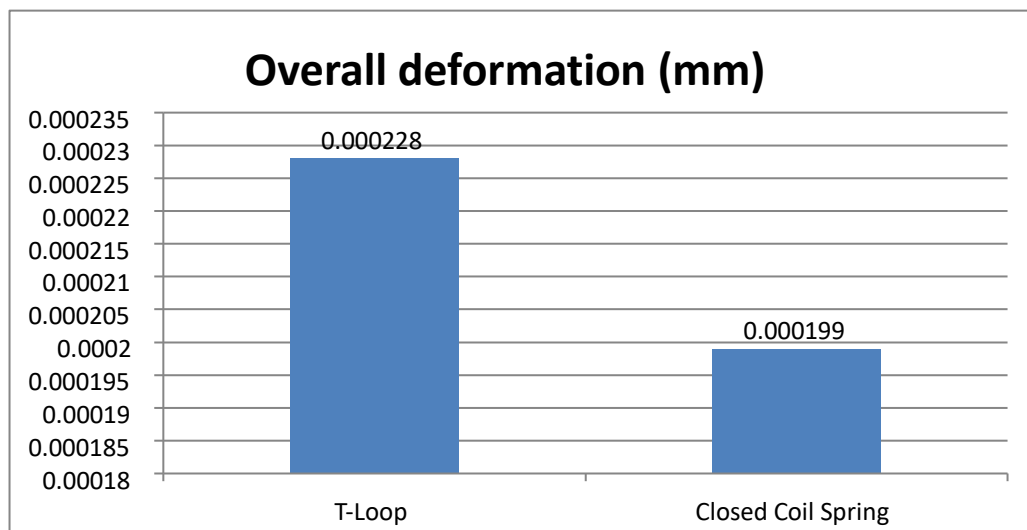


Table No. 1 : "Overall deformation" comparison in both mechanism

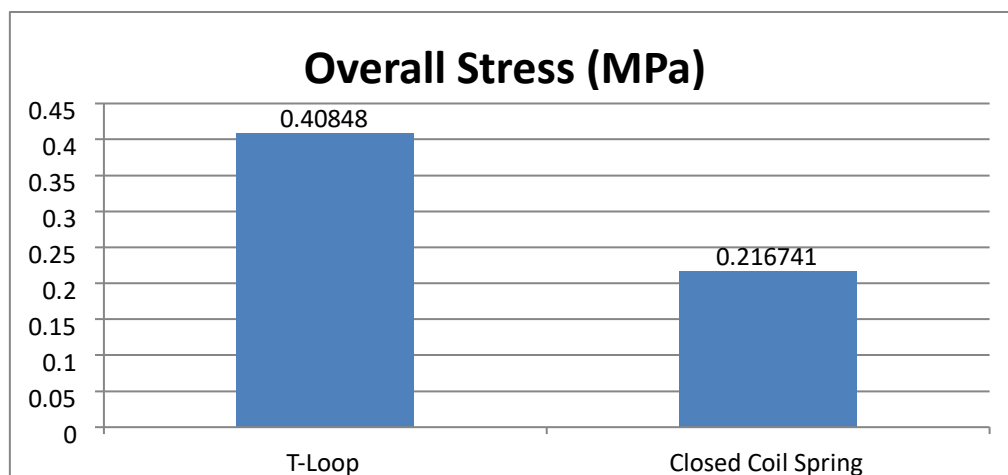


Table No. 2 : "Overall stress" comparison in both mechanism

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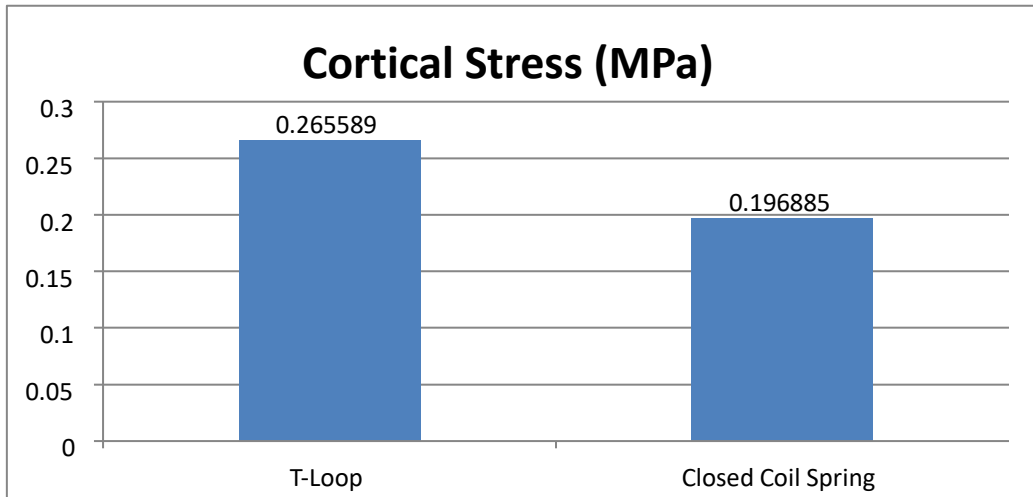


Table No. 3 : "Cortical stress" comparison in both mechanism

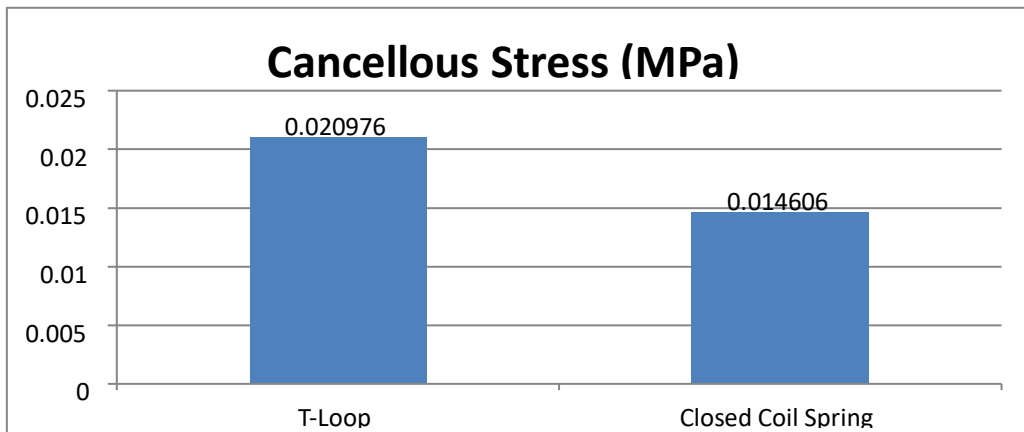


Table No. 4 : "Cancellous stress" comparison in both mechanism

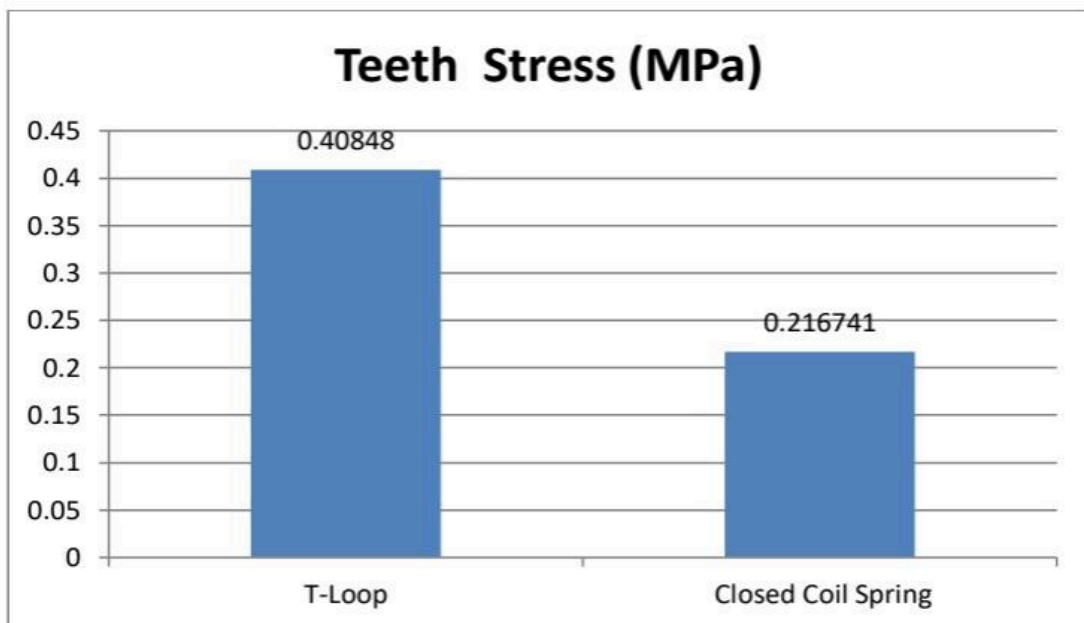


Table No. 5 : "Teeth stress" comparison in both mechanism

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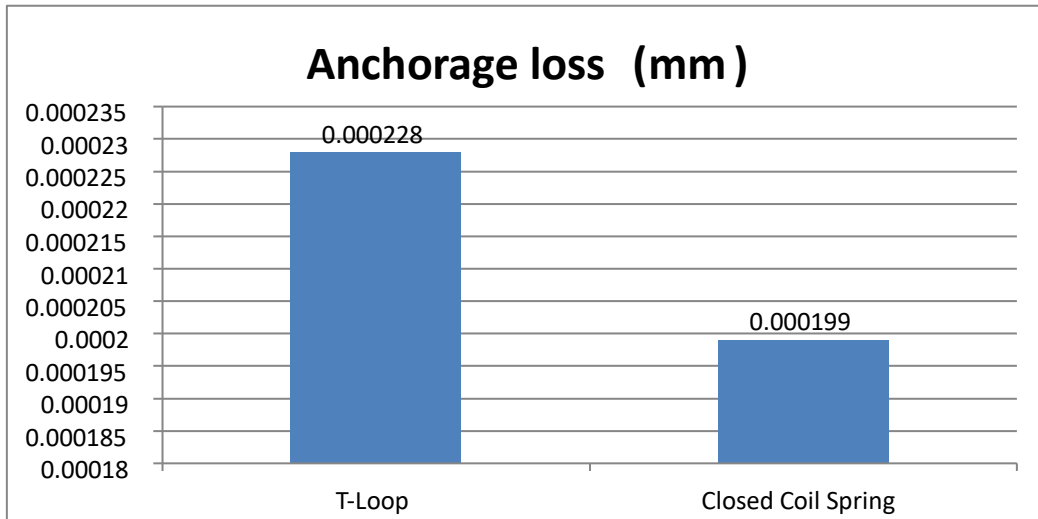


Table No. 6 : “Anchorage loss” comparison in both mechanism

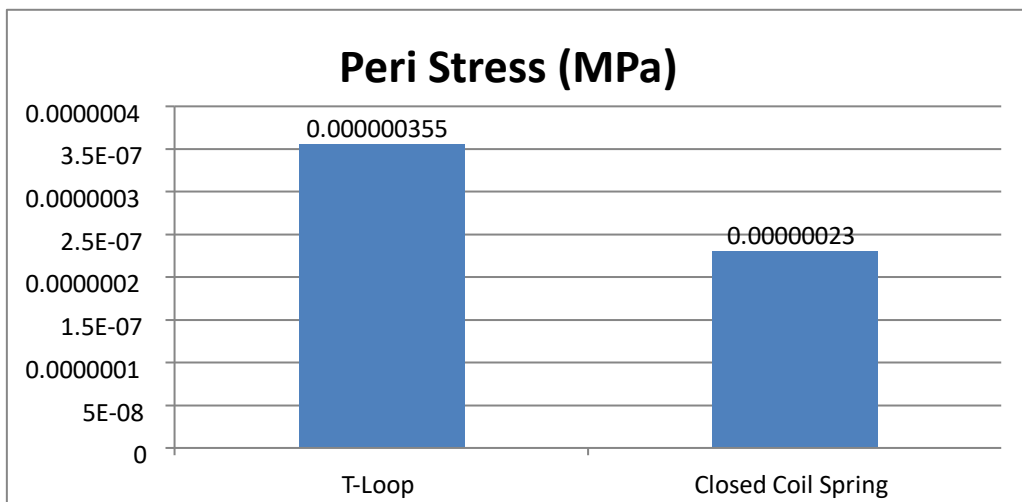


Table No. 7 : “Peri stress” comparison in both mechanism

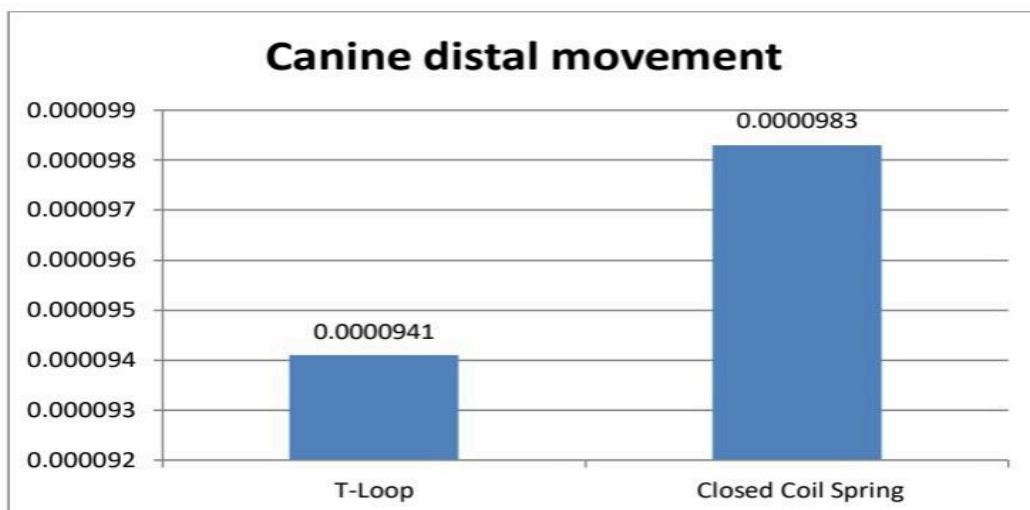


Table No. 8 : “Canine distal movement” comparison in both mechanism

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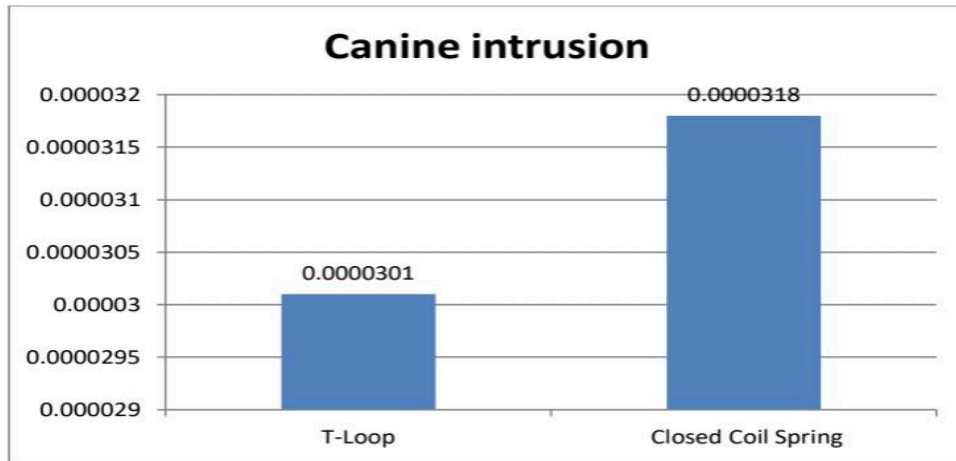


Table No. 9 : “Canine intrusion” comparison in both mechanism

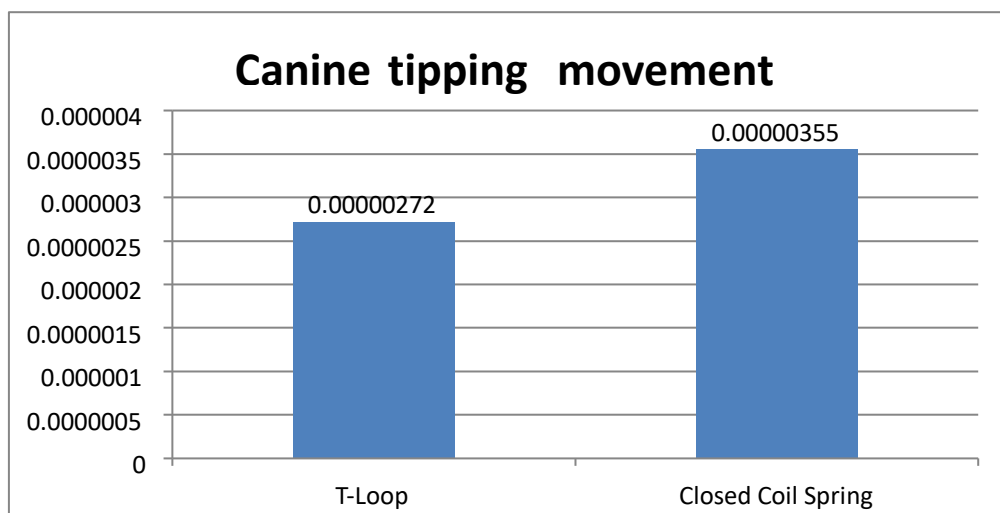


Table No. 10 : “Canine tipping” comparison in both mechanism

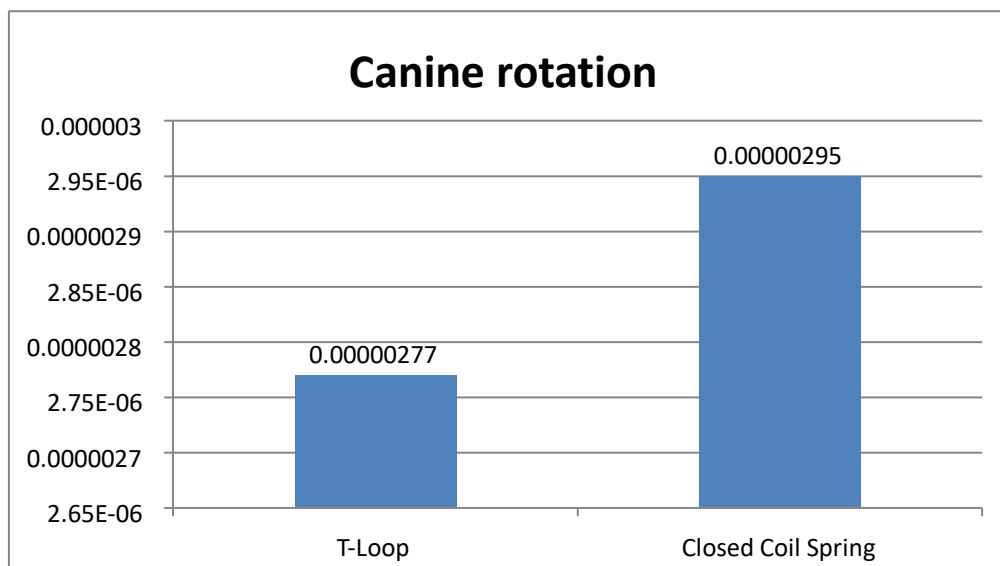


Table No. 11 : “Canine rotation” comparison in both mechanism

## DISCUSSION

Over the years, there has been a constant debate on the different methods of space closure depending on the relative merits of friction and frictionless mechanics. However, much of this could not be resolved without the knowledge of the optimal force levels involved. Storey and Smith developed the concept of optimal force as the minimum force that results in the maximum rate of tooth movement within the limits of biologic response.<sup>1</sup> Quinn and Yoshikawa conducted a critical review on the different theories that relate the orthodontic force to tooth movement and concluded that the rate of tooth movement increases with increasing force up to a point, after which increasing the force further no longer results in increase in tooth movement. Nikolai defined optimum orthodontic force as that which produces the most desirable biologic response and tooth movement with minimum tissue damage and maximum patient comfort.<sup>3</sup>

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 movement.<sup>4</sup> In this regard, loop/frictionless mechanics is more beneficial in that a known force system is delivered to the teeth and spaces are closed with the help of loops with forces and couples built into it. Therefore, while selecting the loop design for space closure, variables such as loop design, thickness and properties of the wire used, type of tooth movement desired and amount of force necessary must be taken into consideration.

Space closure using frictionless/loop & friction mechanics done segmental (two step retraction) respectively, where the canines are first distalized followed by anterior retraction that is supposed to be less detrimental to anchorage. However, the treatment time is prolonged. Loop mechanics commonly employed in space closure is the T-loop, whereas Closed Niti coil spring is used in friction mechanism for space closure. Thus in the present study we have evaluated the efficacy of T loop and Closed Niti coil spring using finite element analysis.<sup>8</sup>

The finite Element Analysis (FEA) is a modern tool for numerical stress analysis, which has the advantage of being applicable to solids of irregular geometry that contain heterogeneous material properties. It provides the orthodontist with quantitative data that can extend the understanding of physiologic reactions that occur within the dento-alveolar complex. Finite element method allows for exact modeling of the tooth, periodontal ligament and mechanical properties of the tissue in three dimensions.<sup>9</sup> Several studies have demonstrated that the FEM provides a solid, workable foundation for modeling the system.<sup>10 11</sup> The greatest strength of the FEM model is that it can be magnified infinitely both in terms of the actual volumetric construction itself and the mathematical variability of its material parameters. In biomechanics of tooth movement it is commonly used in describing the reactions of dental and facial structures to orthodontic forces and solving stress-strain problems in the mechanics.<sup>12</sup>

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,<sup>13 14</sup> But there has been few studies that suggests the activation of loops without the preactivation bends Braun and Garcia 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.<sup>15</sup>

In the friction method, a NiTi closed-coil spring with a force of 160 to 200 g was used instead of the elastomeric module because the spring delivers a relatively constant force. However, the NiTi closed-coil springs are temperature sensitive and are known to produce force variations. Nevertheless, in this study, there was no evidence that the heated root influenced the force delivered by the coil spring to the bracket bonded to the tooth crown. So this study has been done which evaluated the efficacy of T loop, without preactivation bends & Closed NiTi coil spring, with relative constant force for individual canine retraction respectively 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 between both mechanism, closed Niti coil spring model caused greater distal movement of the canine than Segmented T loop model. The result also showed a controlled tipping during retraction forces which is in accordance to the study done by melson et al. 1990, efficacy of Segmented T loop is better. Segmented T loop shows less intrusion of canine and more anchorage loss with maximum retraction of canine with single activation force to individual canine in comparison to Closed NiTi coil spring. For comparison of canine rotation in case of individual canine retraction in both the models, observation shows more rotation in Closed NiTi coil spring model. While evaluating both the treatment modalities it was observed that their was no significant movements in the anterior teeth.

While evaluating the stress in the tooth, more stress was observed for segmented T loop model in comparison to Closed NiTi coil spring model of anterior teeth. For canine maximum stress was observed at bracket attachment region for segmented loop model and for premolar and molar the stress at bracket attachment was similar in both the models. Evaluating the stress in PDL, no significant difference in stress was observed for both models. For Canine it was observed that maximum stress was at apical region for the Closed NiTi coil spring model and for premolar and molar maximum stress was observed on the medial side and was similar in both the models.

Evaluating the stress in cortical bone it was observed that maximum stress is observed for Segmented T loop case model against Closed NiTi coil spring model. For segmented loop model maximum stress is observed at canine and second premolar cervical regions. On the buccal aspect of the quadrant. Evaluating the stress in cancellous bone it was observed that maximum stress is observed for

Segmented T loop case model against Closed NiTi coil spring model. For segmented loop case maximum stress is observed at apical region of canine. So the amount of overall stress and deformation delivered in both mechanisms, Segmented T loop model showed more overall stress and deformation than Closed NiTi coil spring model.

Tissue reaction to orthodontic tooth movement is known to occur either through bone or with bone. So, it is essential to study stresses in the alveolar bone to understand tooth movement.<sup>16</sup> In the present study, stresses in cortical bone were greater than cancellous bone, which is in agreement with previous data.<sup>13</sup> A previous clinical study involving osteotomy on the cortical layer leaving the inner spongiosa intact, increased tooth movement was noticed suggesting that higher stresses in cortical bone are favourable for tooth movement.<sup>17</sup> In the present study, stresses were mainly concentrated at cervical and apical areas, gradually reducing at mid root areas of the anterior teeth. The values of these stresses were far below the ultimate tensile strength of 135 MPa.<sup>18</sup>

Orthodontic tooth movement is primarily a periodontal phenomenon, where a bony response is mediated by the PDL corresponding to a prolonged pressure exerted on the teeth. On force application to a tooth initial displacement is produced, and then, orthodontic tooth movement starts. Thus, it is of utmost importance to study the forces applied on the teeth and stresses produced in PDL at initial movement.<sup>19</sup> In all the models, maximum stress in the PDL was found in the cervical area, which was in accordance with the results of Bohara et al and these stresses were far below the ultimate tensile strength of 2.4 MPa.<sup>20</sup> Thus, the PDL was safe during individual canine retraction in both the modalities.

In the present study, the pattern of principal stresses in PDL changed for tensile in the cervical area to compressive at the root apex in both models. This was in accordance with the findings of previous<sup>21</sup>, Segmented T loop model showed better compressive stresses and uniform distribution of tensile stresses on the canine indicative of bodily tooth movement, as suggested in many studies.<sup>22</sup> During translatory tooth movement, a uniform distribution of tensile stress opposite to the direction of tooth movement occurs, with very mild compression in the direction of tooth movement<sup>15</sup>. A balanced low compressive stress distribution in the PDL leads to less chances of root resorption and is more physiologic.<sup>23</sup>

#### Limitations of the study

FEM is an approximation technique and analytical results are highly dependent on the models developed; therefore, they have to be constructed to be equivalent to real objects in various aspects. In the present study, the 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 the 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 in the Segmented T loop and Closed NiTi coil spring models respectively, it offers preferable mechanotherapy, on the basis of results achieved in the models. Gives a better understanding of the use correct and better mechanism for individual canine retraction purpose.

#### CONCLUSION

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

- Friction and frictionless mechanism, both treatment modalities had obvious effects on displacement and stresses on teeth, cortical bone, cancellous bone and PDL. 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 was most on canine region.
- FEM could not reflect actual biological response within the human body to orthodontic forces but based on present findings, Segmented T loop model showed better controlled tipping of canine during individual canine retraction i.e. frictionless mechanism. Canine distal tooth movement compared in both models respectively & Closed NiTi coil spring model i.e. friction mechanism showed more movement in the result we got.
- As far anchorage loss is concerned more of that was seen in Segmented T loop model than Closed NiTi coil spring model. Where as canine rotation was more observed in Closed NiTi coil spring model rather than the other model during individual canine retraction process.

So it can be conclude that the null hypothesis has been overcome, we can observe difference between friction and frictionless mechanism during individual canine retraction process on the basis of objectives measured in FEM study.

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