COMPARATIVE EVALUATION OF THE EFFICIENCY OF CANINE RETRACTION WITH T LOOP, K LOOP, SNAIL LOOP AND BULBOUS LOOP, USING TMA AND STAINLESS-STEEL WIRES: A FEM STUDY.

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Abstract

Introduction: Present FEM study evaluates and compares the efficiency between stainless-steel and titanium-molybdenum-alloy in terms of canine retraction, canine angulation, canine rotation, stress distribution evaluation of the periodontal-ligament in the mandibular canine region and anchorage loss during canine retraction using 4 different loop designs.

Methods: Four replicas of a pre-existing three-dimensional finite element model of the craniofacial skeleton from CBCT data of a patient were used. The 1st premolars were extracted from the left and right sides of the mandibular model and the loops were simulated between the canine and 2nd premolar region and activated. The four loop designs simulated were-T loop, K loop, Snail loop and bulbous helical loop. TMA loops were simulated on the left and SS loops were simulated on the right. The amount of canine retraction, canine angulation, canine rotation, stress distribution at the PDL in the mandibular canine region and anchorage loss were measured in each case.

Results: Increased canine displacement, canine rotation and anchorage loss was seen in the SS loops when compared to the TMA loops. Slightly increased stress at the PDL was seen with SS loops when compared to the TMA loops. Maximum tipping was shown by the K loop in TMA wire and minimum tipping was shown by K loop in SS wire, indicating that the stainless-steel loops had better control.

Conclusion: The SS loops offer more canine retraction and tipping control whereas the TMA loops provide better rotational control, low anchorage loss and slightly decreased stress at the PDL.

Keywords- Cone-beam computed tomography; Finite element method; Periodontal ligament; Stainless steel; Titanium Molybdenum Alloy.

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INTRODUCTION:

Based on the diagnosis and treatment plan, Orthodontists close spaces through various methods. Those methods used to close space without friction are preferable than systems that close space through friction. Greater control over tooth movement is possible when using a frictionless appliance for space closure.[1]

When teeth are moved using frictionless mechanics, the brackets do not slide along the arch wire. Loops or springs are used for retraction because they provide more regulated tooth movement than sliding mechanisms. Pulling the distal end of a retraction spring through the molar tube and pulling it back tightens it to exert force. The wire arrangement and the existence of pre activation or gable bends, which create an activation moment, are what determine the moment.[2]

Closing loops are typically employed in loop mechanics for extraction space closure and can be created in frictionless mechanics as either sectional or whole arch wire loops. The main benefit of loop mechanics is the absence of friction during space closure between the bracket and arch wire. The unintended tooth rotations in the transverse and sagittal planes and the time-consuming fabrication of the loops are drawbacks of this method.[3]

According to Burstone and Koenig[4], the segmented arch approach has a number of additional benefits, including improved force management and more effective tooth movement over extended distances with small, consistent forces (1976). Beta titanium molybdenum alloy (TMA) wire, which has 11% molybdenum, 6% zirconium, and 6% beta titanium alloy, was first introduced by Burstone and Goldberg in 1980. It exhibits twice the deflection and delivers half the force of stainless-steel wires.

In order to achieve the treatment objectives, precise control of tooth movement during closure of extraction gaps in three dimensions is crucial. Control of the root positions, rotations, vertical forces, and anchorage units are all included in this.[5]

Planning the treatment and choosing the right mechanics depend on an accurate estimation of the amount of anchorage loss during extraction space closure. Tweed[6] emphasised anchorage preparation as the first phase in Orthodontic therapy to reduce anchorage loss and increase tooth movement effectiveness. Storey & Smith[7], and Raymond Begg all recommended using low force values, and Begg[8] stressed the benefits of using differential force to allow for the fastest possible movement of the teeth.[9]

Periodontal ligament phenomenon is the main cause of Orthodontic tooth movement. Long-term pressure causes bone remodelling as well as tooth movement within the bone. The periodontal ligament experiences a large amount of stress, which is passed to the alveolus and causes bone remodelling and subsequent tooth movement.[10]

It is crucial to look into the levels of stress caused by Orthodontic forces in the periodontal tissue because it is well known that stress in the tissue serves as the catalyst for biologic changes. The finite element method (FEM), which was first used for numerical analyses, has proven to be an effective way for analysing stress in biological systems.[11]

The purpose of this study is to evaluate and compare the efficiency between stainless steel and titanium molybdenum alloy (TMA) in terms of canine retraction, canine angulation, canine rotation, stress distribution evaluation of the periodontal ligament in the maxillary canine region and anchorage loss during canine retraction using 4 different loop designs using FEM.

METHODOLOGY:

A patient's CBCT was used to create four copies of an existing three-dimensional finite element model of the craniofacial skeleton.

Images from the scan were chosen, and they were then transformed into a stereolithographic (STL) format using 3-D Slicer. GOM was used to convert the brackets, archwire, screws, and loops into STL format. Additionally, this was transformed using the SOLIDWORKS programme into a geometric model. In this study, this model was replicated four times.

Material property data representation was done on the model. The teeth, alveolar bone, periodontal ligament, TMA wires, stainless steel wires and stainless-steel brackets were assigned their respective material properties (Table 1).[12,13] The teeth, alveolar bone and periodontal ligament were assumed to be isotropic and homogenous structures individually.

Table 1: Mechanical properties of each material used in this study has been mentioned in the table below-

MATERIAL	YOUNGS MODULUS(MPa)	POISSON'S RATIO
Teeth	2×10^4	0.3
Bracket	2×10^5	0.3
Periodontal ligament	5×10^2	0.3
Alveolar bone	2×10^3	0.3
Stainless steel wire	2×10^5	0.3
TMA wire	81 +/- 6	0.3

ANSYS (Analysis of Systems) software was used for the study, and ALTAIR HYPERWORKS was used for meshing. The domain was divided into parts using the meshing software, each of which represented an element. These finite elements were loaded with boundary conditions using the analysis programme ANSYS. In order to specify how the model was limited and to prevent free body motion, the boundary conditions were defined.

All mandibular teeth were fitted with 0.022 X 0.028 slot stainless-steel MBT brackets and molar tubes modelled with specified tip and torque values, and they were positioned on the aligned teeth in accordance with the MBT's standard bracket positioning guidelines so that the archwire rested passively through the bracket slots.

The 1st premolars were extracted from the left and right sides of the mandibular model and the loops were simulated between the canine and 2nd premolar region and activated.

Loops made with TMA wire was simulated on the left side and loops made with Stainless steel wires were simulated on the right.

The 4 loop designs simulated in the four different models were-

1. T-loop
2. K-loop
3. Snail-loop
4. Bulbous-helical loop

The variables included in the study has been mentioned below-

1) Canine retraction- The distance that the canine has moved distally from its original position.
2) Canine rotation- Change in the angle between the median plane of the mandible and the mesio-distal cuspal surface of the canine.
3) Anchorage loss- The distance that the first molar has moved mesially from its original position.
4) The magnitude of stress generated in PDL- were calculated and represented with different colors.
5) Canine angulation- Change in the angle between the mid-sagittal plane of the mandible and the long axis of the canine.

The finite element analysis was carried out using ANSYS software. The results were visualized as von Mises stress maps.

RESULTS:

Amount of canine retraction using 4 loop designs in 17*25-inch TMA wire on the left side and S.S wire on the right side during canine retraction. (Table 2 and Figure 1)

Increased canine displacement was seen with S.S loops when compared to the TMA loops.

Among the SS loops, bulbous loop showed the maximum canine displacement (2.0 mm) whereas the K loop showed the least canine displacement (1.27 mm).

Among the TMA loops, T loop showed the maximum canine displacement (1.2 mm) whereas the K loop showed the least canine displacement (0.8 mm).

K loop showed the least amount of canine displacement when compared to the rest of the loop designs.

Table 2: Amount of canine retraction using 4 loop designs in 17*25-inch TMA wire on the left side and S.S wire on the right side during canine retraction.

LOOP DESIGN	LEFT SIDE (TMA)	RIGHT SIDE (S.S)
T-loop	1.2 mm	1.3 mm
K-loop	0.8 mm	1.27 mm
Snail loop	1.19 mm	1.5 mm
Bulbous loop	1.0 mm	2.0 mm

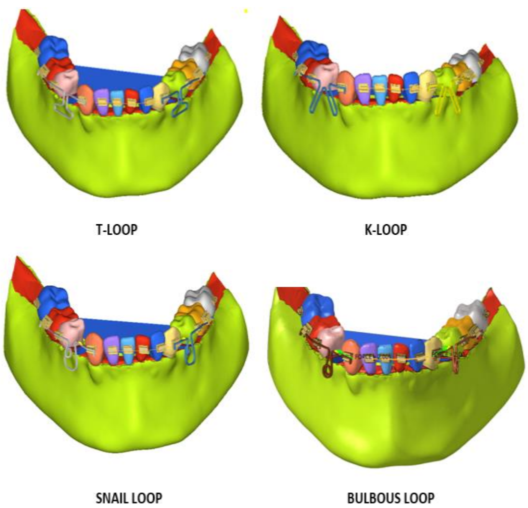

Figure 1: Canine retraction using 4 loop designs in 17*25-inch TMA wire on the left side and S.S wire on the right side during canine retraction.

Degree of canine rotation using 4 loop designs in 17*25-inch TMA wire on the left side and SS wire on the right side. (Table 3 and Figure 2)

Increased canine rotation was seen with S.S loops when compared to the TMA loops.

Among the SS loops, bulbous loop showed the maximum canine rotation (0.23^0) whereas the snail loop showed the least canine rotation (0.14^0).

Among the TMA loops, bulbous loop showed the maximum canine rotation (0.13^0) whereas the K loop showed the least canine rotation (0.07^0).

Bulbous loop showed the maximum amount of canine rotation when compared to the rest of the loop designs.

Table 3: Degree of canine rotation using 4 loop designs in 17*25-inch TMA wire on the left side and SS wire on the right side.

LOOP DESIGN	LEFT SIDE (TMA)	RIGHT SIDE (S.S)
T-loop	0.1^0	0.15^0
K-loop	0.07^0	0.17^0
Snail loop	0.08^0	0.14^0
Bulbous loop	0.13^0	0.23^0

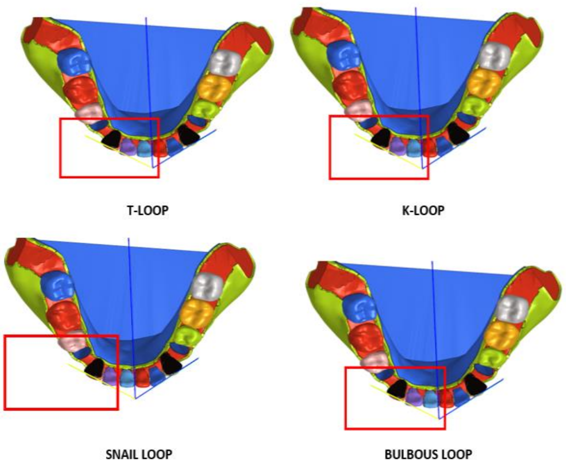

Figure 2: Degree of canine rotation using 4 loop designs in 17*25-inch TMA wire on the left side and SS wire on the right side.

Anchorage loss using 4 loop designs in 17*25-inch TMA wire on the left side and S.S wire on the right side during canine retraction. (Table 4 and Figure 3)
Increased anchorage loss was seen with S.S loops when compared to the TMA loops.

Among the SS loops, bulbous loop showed the maximum anchorage loss (0.56 mm) whereas the T loop showed the least anchorage loss (0.14 mm). Among the TMA loops, bulbous loop showed the maximum anchorage loss (0.22 mm) whereas the T loop showed the least anchorage loss (0.08 mm). Bulbous loop showed the maximum amount of anchorage loss whereas T loop showed minimum anchorage loss when compared to the rest of the loop designs.

Table 4: Anchorage loss using 4 loop designs in 17*25-inch TMA wire on the left side and S.S wire on the right side during canine retraction.

LOOP DESIGN	LEFT SIDE (TMA)	RIGHT SIDE (S.S)
T-loop	0.08 mm	0.14 mm
K-loop	0.14 mm	0.40 mm
Snail loop	0.11 mm	0.15 mm
Bulbous loop	0.22 mm	0.56 mm

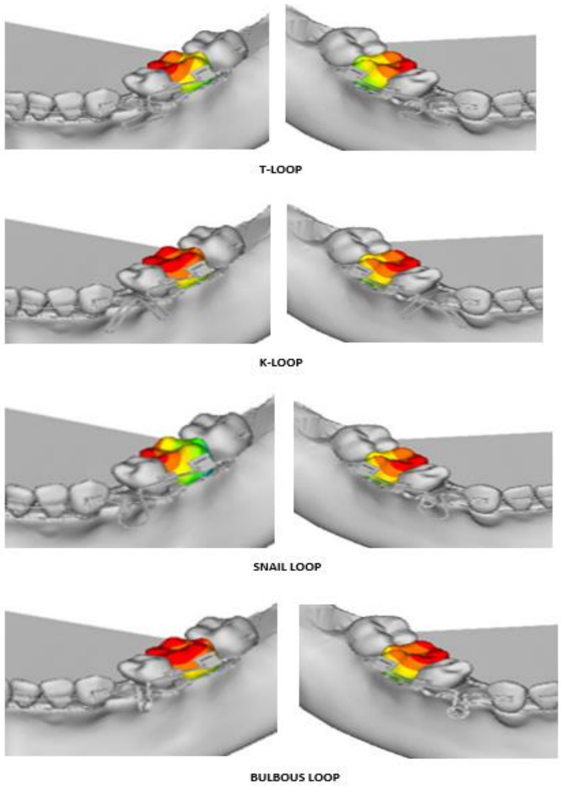

Figure 3: Anchorage loss using 4 loop designs in 17*25-inch TMA wire on the left side and S.S wire on the right side during canine retraction.

Stress distribution at the PDL in the mandibular canine region using 4 loop designs in 17*25-inch TMA wire on the left side and S.S wire on the right side during canine retraction. (Table 5 and Figure 4)
Increased stress at the PDL was seen with S.S loops when compared to the TMA loops.

The PDL at the alveolar crest level produced the highest amount of stress.

Bulbous loop showed the maximum amount of stress at the PDL (0.911 MPa) whereas snail loop showed minimum stress at the PDL (0.89 MPa) when compared to the rest of the loop designs.

Table 5: Stress distribution at the PDL in the mandibular canine region using 4 loop designs in 17*25-inch TMA wire on the left side and S.S wire on the right side during canine retraction.

LOOP DESIGN	LEFT SIDE (TMA)	RIGHT SIDE (S.S)
T-loop	0.902 MPa	0.903 MPa
K-loop	0.89 MPa	0.89 MPa
Snail loop	0.88 MPa	0.89 MPa
Bulbous loop	0.911 MPa	0.912 MPa

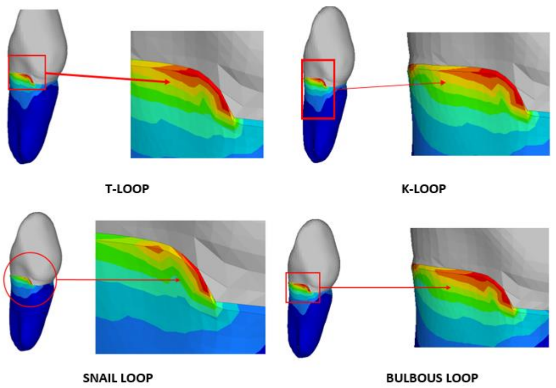

Figure 4: Stress distribution at the pdl in the mandibular canine region using 4 loop designs in 17*25-inch TMA wire on the left side and S.S wire on the right side during canine retraction.

Change in canine angulation using 4 loop designs in 17*25-inch TMA wire on the left side and S.S wire on the right side during canine retraction. (Table 6 and Figure 5)

Maximum change in canine angulation was shown by the K loop in TMA wire (1.27^{0}) and minimum change in canine angulation was shown by K loop in SS wire (0.39^{0}).

Table 6: Change in canine angulation using 4 loop designs in 17*25-inch TMA wire on the left side and S.S wire on the right side during canine retraction.

LOOP DESIGN	LEFT SIDE (TMA)	RIGHT SIDE (S.S)
T-loop	0.71^{0}	0.5^{0}
K-loop	1.27^{0}	0.39^{0}
Snail loop	0.4^{0}	0.45^{0}
Bulbous loop	0.42^{0}	0.77^{0}

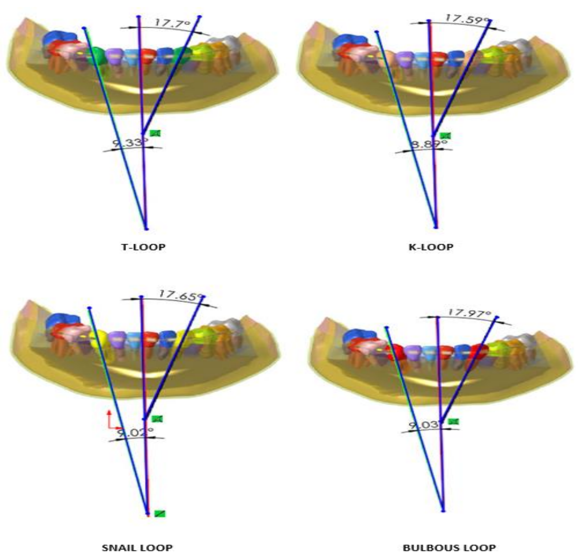

Figure 5: Change in canine angulation using 4 loop designs in 17*25-inch TMA wire on the left side and S.S wire on the right side during canine retraction.

DISCUSSION:

Space closure in extraction scenarios is accomplished through the careful application of frictionless, sliding, or loop mechanics. Frictionless mechanics, which employs retraction loops in continuous arch wire or in segmental form, enables more controlled tooth movement than friction mechanics, according to Staggers et al.[14]

FEM provides the following benefits: the study may be performed as often as the operator desires, it is highly accurate, non-invasive, and can model the actual physical properties of the materials involved, imitating the oral environment in vitro. Young's modulus and Poisson's ratio are the crucial factors that are needed as mathematical inputs to create the finite element model in a FEM study for tooth movement; any change would have an impact on the outcomes.[15] FEM can freely replicate the Orthodontic force system utilised in practise, enables examination of the dentition's reaction to the Orthodontic load in three-dimensional environments.[16-20]

Similar to the study by Eduardo et al.[21], who found that beta-titanium loops produced less horizontal force and a lower load/deflection ratio than stainless-steel loops, higher canine displacement by the SS loops was seen in the present study. In contrast, the study conducted by Mehta K R et. al[4] found that the TMA T-loop caused greater canine retraction (5.46 mm) than the stainless-steel T-mean loop's retraction (4.20 mm). In the current investigation, the bulbous helical loop among the SS loops demonstrated the greatest canine displacement, whereas the K loop showed the least canine displacement. Increasing the wire length in the loop design reduces the force delivered at the same activation. A smaller loop increases the force and stiffness, but reduces the M/F(moment/force) ratio. The length of bulbous helical loop is small when compared to that of K loop, thus the M/F ratio is less and the horizontal force produced is high during deactivation in the bulbous helical loop which could account for its increased canine displacement.

In contrast to the study conducted by Mehta K R et. al[4], where it was reported that canine rotation was higher for the TMA T-loop group (50.82%) as opposed to the stainless-steel T-loop group (39.44%), enhanced canine rotation by the SS loops was observed in the present study. This rotation was greater because TMA had a weaker control and is more flexible than stainless steel, which has a more solid structure. In the current study, the bulbous helical loop among the SS loops displayed the highest canine rotation, whereas the snail loop displayed the lowest canine rotation.

According to Woo Heo et al[6], no significant differences existed in the degree of anchorage loss of the upper posterior teeth and the amount of retraction of the upper anterior teeth associated with en masse retraction and two-step retraction of the anterior teeth. In the present study, single canine retraction was attempted and it was found that S.S. loops showed higher anchorage loss when compared to TMA loops. The bulbous loop among the SS loops demonstrated the greatest anchorage loss, whilst the T loop demonstrated the least anchorage loss. The T loop had the least anchoring loss among the TMA loops, while the bulbous loop had the most. When compared to the other loop designs, the bulbous loop demonstrated the greatest anchorage loss, whilst the T loop shown the least anchorage loss.

When compared to TMA loops in the current study, S.S loops caused somewhat more stress at the PDL. When compared to the other loop designs, the bulbous loop demonstrated the greatest level of stress at the PDL, whilst the snail loop had the least.

According to Stephanie R. Toms et al[22], the PDL's maximum primary stresses for the uniform linear model tapered more at the linguocervical margin than the buccocervical edge for extrusive and tipping forces. These stresses were highest at the apex. High stress concentrations are found at the apex and cervix of the PDL. These outcomes are consistent with the histologic findings, which demonstrate that the cervix or apex is frequently the site of induction of the cell-free area and hyalinization of the PDL.[23-25]

In the current study, the PDL at the alveolar crest level produced the highest amount of stress, which was similar to a study by Kazuo Tanne[11] et al that found that when a tooth is tipped with a single lingual force, the PDL at the lingual alveolar crest level produces roughly four times as much stress as translation if stress is measured at the middle of the root.

On a 2-D model of an incisor with a parabolic-shaped root, Hack et al.[26] had examined the distribution of force in the periodontal ligament. A mandibular premolar was modelled using finite elements in a 2-D plane by Toms.[27] The produced models heavily influence the logical outcomes of the FEM, so they must be carefully built to be analogous to real objects in various ways. When intrusive force was applied to both 0.15 mm and 0.24 mm PDL thickness in his study, Maynak Gupta et al[10] reported that the maximum concentration of stress was found to be at the alveolar crest and minimum at the apex in a healthy alveolar bone. His research also revealed different stress distribution patterns at two layers of alveolar bone (alveolar crest and apex). When compared to the alveolar crest in periodontal ligament thicknesses of 0.15 mm and 0.24 mm, the apical region showed the highest stress value.

In contrast to the study conducted by Mehta K R et al[4], who concluded that the TMA loop had better control in their study, the K loop in the present study demonstrated maximum tipping in the TMA wire and minimum tipping in the SS wire, indicating that SS loops had better control.

These findings provide light on this crucial and fascinating element of segmented loop mechanics and its relationship to the loops' cross-section, resistance centre, and material of construction. Poor rotational control of canines was provided by both SS and TMA loops.

In situations when quicker, more customised canine retraction is required while also minimising the strain on the posterior anchorage, segmented loop mechanics may be frequently utilised.

CONCLUSION:

The following conclusions were drawn from the study

1. Greater amount of maxillary canine displacement was seen with the Stainless-steel loops when compared to the TMA loops. The SS bulbous loop showed the maximum canine displacement whereas the TMA K-loop showed the least.
2. The TMA loops offered better rotational control over the stainless-steel loops. The TMA K Loop showed better rotational control and the SS bulbous loop showed the least.
3. Increased anchorage loss was seen with the stainless-steel loops when compared to the TMA loops. Bulbous loop showed the maximum amount of anchorage loss whereas T loop showed minimum anchorage loss when compared to the rest of the loop designs.
4. Increased stress at the PDL was seen with S.S loops when compared to the TMA loops. Bulbous loop showed the maximum amount of stress at the PDL whereas snail loop showed minimum stress at the PDL when compared to the rest of the loop designs.
5. Maximum tipping was shown by the K loop in TMA wire and minimum tipping was shown by K loop in SS wire, indicating that the stainless-steel loops had better control.
6. The SS loops offer more canine retraction and tipping control whereas the TMA loops provide better rotational control, low anchorage loss and decreased stress at the PDL.

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Conflict of Interest
Authors has no conflict of interest.

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