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Evaluation of effects of various alpha and beta angulations for T-loop made of stainless steel and titanium molybdenum archwires during space closure – FEM study

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Abstract

Introduction: Space closure follows the initial stage of levelling and alignment in Pre-adjusted Edgewise treatment. There are majorly two methods of space closure, Loop mechanics and Sliding mechanics. Loop mechanics or frictionless mechanics is a preferred method because of its potential to produce pre-determined moment-to-force ratios which accurately achieve controlled movement of teeth.

Objective: The aim of this study was to evaluate the effects of three types of retraction loops with different moment bends (alpha and beta) made of 0.016”x0.022” stainless steel and TMA archwires with Finite Element Analysis.

Materials and Methods: A Finite element model of CAD geometric model of standard MBT prescription (0.018” slot), Stainless Steel and Titanium Molybdenum Alloy (TMA) wire (0.016” x 0.022”) and 3 loops (T-loop, Open Vertical and Closed helical loop) were constructed. A solid model of upper jaw with all permanent maxillary teeth except 1st premolar (extraction) with surrounding periodontal ligament and alveolar bone was prepared. Force, moment to force ratio, mesio-distal crown tipping, mesio-distal root tipping and vertical root movement (extrusion) were measured for different alpha and beta bends in anterior and posterior segments respectively.

Results: Force values without moment bends was found to be highest in open vertical loop in both anterior (SS- 414gms; TMA- 255gms) and posterior region (SS- 540; TMA- 370gms) with both SS and TMA wires. Moment to Force ratio (M/F) at both anterior and posterior segment was found to be highest in T-loop followed by closed helical loop and least in open vertical loop. Extrusion was found to be minimal in T-loop followed by closed helical loop and was maximum in open vertical loop.

Conclusion: T-loop showed maximal control in terms of minimal extrusion and maximum M/F ratio amongst the three loops.

Keywords: Space closure, Loop mechanics, Angulation bends (alpha and beta), M/F Ratio.

1. Introduction

Space closure is the second major step in Pre-adjusted Edgewise Appliance therapy after initial levelling and alignment has been completed. There are two major ways of space closure, frictional mechanics (sliding) and frictionless mechanics (loops). Frictionless mechanics is preferred because of several advantages like no resistance to friction and potential to produce predetermined moment-to-force (M/F) ratios to accurately achieve controlled movement of the teeth.[1]

In loop mechanics, the application of differential moments between teeth is recognized as an effective means for achieving desired tooth movement. These moments are termed alpha and beta moments for the anterior and posterior teeth, respectively. Differential moments are used for obtaining differential anchorage, intrusive or extrusive forces, and root movement and precise control of tooth movement during closure of extraction spaces in three dimensions is of paramount importance in meeting treatment goals. Variation in the force and moment magnitude and the moment-to-force ratio are important determinants of the resulting tooth movement.[2] various loop configurations and alloy materials are used for space closure. This study has used T-loop in Stainless Steel (SS) and Titanium Molybdenum Alloy (TMA) wires.

T-loop can be fabricated from various alloys like SS, TMA and even NiTi alloy.3 Stainless Steel alloy has high stiffness and greater resistance to deformation when compared with TMA.4 Initially, T-loop was fabricated using SS because TMA was not available at that time 3. Because of its high stiffness it has been shown that SS T-loop exerts greater force magnitude during space closure than TMA wire 5, but other properties important to en-masse retraction like M:F ratio, tipping and vertical root movement have not been compared between the two wires.

Therefore, the aim of this FEM study was to compare and evaluate the effects of T-loop with different angulation bends, made of SS and TMA archwires (0.016” x 0.022”) during en-masse space closure.

Materials And Methods

This study was conducted in the Department of Orthodontics and Dentofacial Orthopedics, of a tertiary care hospital. The finite element model used in this study was developed in conjunction with FEA Solutions - Nandanvan, Thane (Mumbai), India.

Materials

Computer configuration used for the study:

Hardware: A computer (DELL XPS System) with Intel i7 with 8-core processor, 8 GB RAM, 2 GB Graphics, loaded with Windows 7 operating system was used.

Software

Stage	Software
FEA Pre-processing	Altair HyperMesh
FEA Solver	Altair Optistruct
FEA Post-processor	Altair HyperView

Table 1: FEA Software

Methods

The finite element model involved construction of a solid model of upper jaw with all permanent maxillary teeth except 1st premolar (extracted) with surrounding periodontal ligament and alveolar bone **(Figure 1 and 2).**

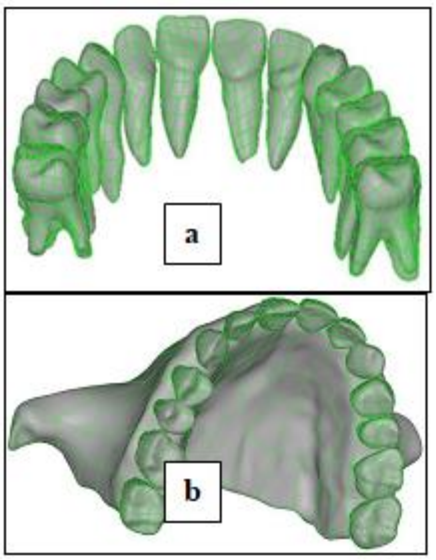

Figure 1: a, maxillary teeth in CAD model. b, assembly of maxillary teeth with maxilla.

ACAD geometric model of standard MBT prescription brackets and tubes of 0.018”x0.025” slot **(Figure 3)**, T-loopm**(Figure 4)** of Stainless Steel (SS) and Titanium Molybdenum Alloy (TMA) wire (0.016” x 0.022”) were also constructed.

The material properties of various components which are used in the study in order to stimulate the actual properties of the components are presented in **Table 2**.

Component	Density (g/mm^3)	Young’s Modulus (MPa)	Poisson’s Ratio (μ)
Teeth	1.7E-06	2.03E+04	0.3
Periodontal ligament (PDL)	1.7E-06	0.667	0.49
Alveolar bone	1.7E-06	1.37E+04	0.38
Stainless Steel	0.008	2.1E+05	0.3
Titanium	4.4E-03	1.1E+05	0.342

Table 2: Material properties.

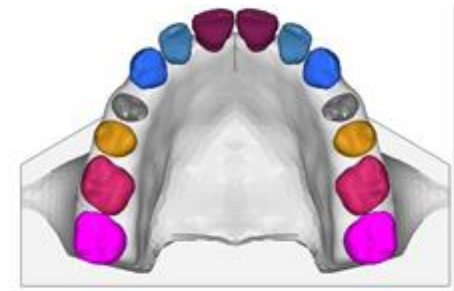

Figure 2: Final model with 1st premolar extraction (Occlusal view).

Anchorage situation (alpha and beta angulations) used in this study were as follows:

- Maximum anchorage: α=100; β=200
- Moderate anchorage: α=150; β=150
- Minimum anchorage: α=200; β=100

The parameters measured in the study with their units are summarized in **Table 3**.Final Stage

Parameters	Unit
Force (F)	Grams (gm)
Moment of force (M_f)	Gram millimetre (gm mm)
Moment of couple (M_c)	Gram millimetre (gm mm)
Crown tip (E^{-08})	Degrees (^{0})
Vertical root movement	Millimetre (mm)

Table 3: Parameters with their respective units.

Force

Continuous loop wire was engaged in the bracket slot (Figure 5) and ligation was done with the help of connectors. The loop was placed in the centre of extraction space. After engagement of loop arch wire without pre-activation bend in the bracket, 1mm activation was done bilaterally distal to 2nd molar tube. Force was then measured (in grams) at two points anteriorly and posteriorly on both the sides where the loop connects the archwire. Absolute values were compared among SS and TMA group.

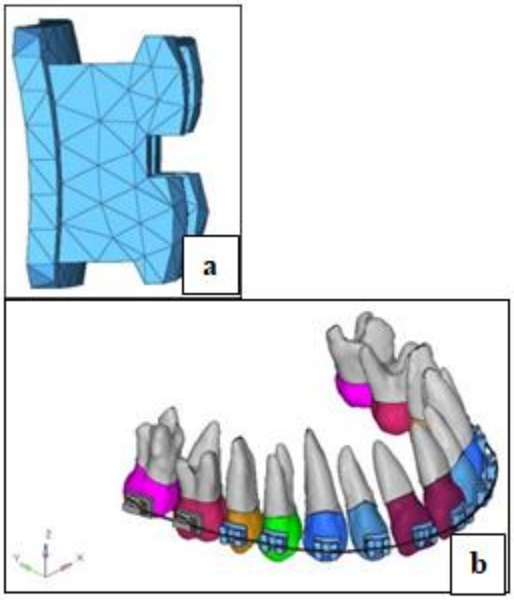

Figure 3 (a and b): a;FEM model of MBT prescription bracket (0.018”x0.025”). b; Brackets bonded to the teeth.

Moment of force

Moment to force = Force x Perpendicular distance from centre of resistance to point of force application. Centre of resistance of anterior segment was mesial to maxillary canine at 9.05mm distance, while that of posterior segment was between 2^{nd} premolar and 1^{st} molar at 6.50mm distance. **(Figure 6)**

Moment of couple: Continuous loop archwire was engaged with pre-activation bends and counter moment was measured in anterior and posterior segment.

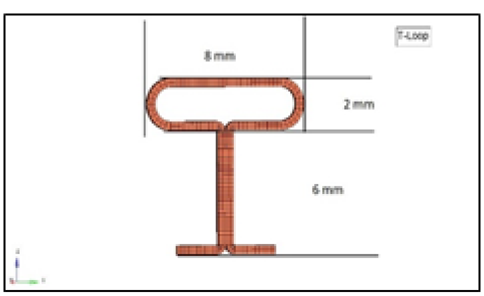

Figure 4: FE model of T-loop.

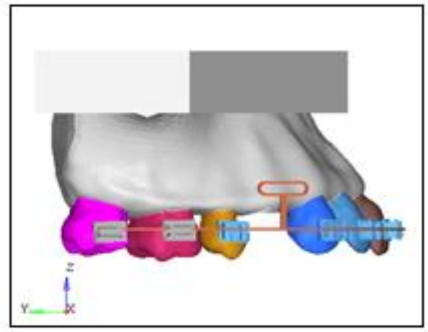

Figure 5: Continuous loop archwire engaging the brackets and tubes (right buccal view).

Moment to force ratio: It was calculated by dividing the moment of couple and force in anterior and posterior segments respectively. Absolute values were compared among SS and TMA group.

Figure 6:Centre of resistance of anterior and posterior teeth

Crown tip: It was measured before and after pre-activation bends. Angle of mesio-distal tipping of the crown was measured from the long axis of the tooth.Absolute values were compared among the SS and TMA group.If you are using Word, use either the Microsoft Equation Editor or the Math Type add-on (http://www.mathtype.com) for equations in your paper (Insert | Object | Create New | Microsoft Equation or Math Type Equation). “Float over text” should not be selected.

Vertical root movement: It was measured before and after pre-activation bends.Absolute values were compared among the SS and TMA group.

Statistics

Statistical analysis was done by using tools of descriptive statistics such as Mean, and SD for representing quantitative data. SPSS Inc. Released 2007. SPSS for Windows, Version 16.0. Chicago, SPSS Inc software was used to analyse the data and the statistically significance level was set at $p<0.05$ level and p-values 0.000 and 0.001 were considered to be Highly Significant.

Results

Force values: Force values without pre-activation bends were found to be higher in Stainless Steel when compared with Titanium Molybdenum Alloy in both anterior and posterior segments. The values are summarized in **Table 4**.

Wire (0.016"x0.022")	Force Anterior (gm)	Force Posterior (gm)
SS	293	424
TMA	146	211

Table 4: Comparison of force values in SS and TMA wire in anterior and posterior segments.

Moment to Force Ratio: Moment to force ratio are summarized in the **Table 5**. Moment to force ratio increases when the angulation bend increases and vice-versa.

In T-loop SS wire when alpha and beta angulation was kept 15-15^0, M/F ratio in anterior segment and posterior segment was 7 and 8 respectively. As the alpha increases by 5^0 M/F ratio in anterior segment increases up to 10, while as the alpha decreases by 5^0 M/F ratio in anterior segment decreases up to 5. As the beta increases by 5^0 M/F ratio in posterior segment increases up to 10, while as the beta decreases by 5^0 M/F ratio in posterior segment decreases up to 5.

Pre-activation bends (degrees)		α-β 10-20		α-β 15-15		α-β 20-10	
Loop	Wire	M/F Anterior	M/F Posterior	M/F Anterior	M/F Posterior	M/F Anterior	M/F Posterior
T-loop	SS	5.97	10.27	7.70	8.48	10.43	5.25
	TMA	5.50	10.69	7.89	8.47	10.53	5.33

Table 5: Comparison of Moment to Force Ratios with different angulation bends in SS and TMA wire.

In T-loop TMA wire when alpha and beta angulation was kept 15-15^0, M/F ratio in anterior segment and posterior segment was up to 7 and 8 respectively. As the alpha increases by 5^0 M/F ratio in anterior segment increases up to 10, while as the alpha decreases by 5^0 M/F ratio in anterior segment decreases up to 5. As the beta increases by 5^0 M/F ratio in posterior segment increases up to 10, while as the beta decreases by 5^0 M/F ratio in posterior segment decreases up to 5.

Crown Tipping

Anterior Segment (Stainless Steel): It was found highly significant difference among mean mesio-distal crown tipping at different angulations. Maximum distal crown tipping was seen in 0-0^0 followed by 15-15^0 and 10-20^0. Mesial crown tipping was seenin 20-10^0.

Posterior Segment (Stainless Steel): It was found highly significant difference among mean mesio-distal crown tipping at different angulations. Maximum mesial crown tipping was seen in 0-0^0 followed by 20-10^0 and 15-15^0. Distal crown tipping was seen in 10-20^0.

Anterior Segment (Titanium Molybdenum Alloy): It was found no significant difference among mean mesio-distal crown tipping at different angulations. Maximum distal crown tipping was seen in 0-0^0 followed by 15-15^0, 20-10^0 and least in 10-20^0.

Posterior Segment (Titanium Molybdenum Alloy): It was found significant difference among mean mesio-distal crown tipping at different angulations. Maximum mesial crown tipping in posterior segment was seen in 0-

0^0 followed by $10\text{-}20^0$, $15\text{-}15^0$ and least in $20\text{-}10^0$.**(Table 6)**

Pre-activation bends (degrees)		α-β 0-0		α-β 10-20		α-β 15-15		α-β 20-10	
Loop	Wire	Anterior	Posterior	Anterior	Posterior	Anterior	Posterior	Anterior	Posterior
T-loop	SS	4.17	-4.38	2.6	0.08	2.79	-1.57	-0.34	-3.34
	TMA	1.62	-2.79	1.23	-0.29	1.30	-0.68	1.26	-1.54

Table 6: Comparison of mesio-distal tipping of crown with different angulation bends in SS and TMA group

Vertical Root Movement:

Effects of vertical root movement showed high significance in both anterior and posterior segments of both SS and TMA. Maximum extrusion was noted with stainless steel wire in both anterior and posterior segment.**(Table 7)**

Pre-activation bends (degrees)		α-β 10-20		α-β 15-15		α-β 20-10	
Loop	Wire	Anterior segment	Posterior segment	Anterior segment	Posterior segment	Anterior segment	Posterior segment
T-loop	SS	3.99	4.93	4.57	4.44	5.05	3.87
	TMA	1.94	2.57	2.25	2.22	2.83	2.05

Table 7: Vertical Root Movement at different angulation bends in SS and TMA group

Discussion

Space closure in extraction cases is the second major step in pre-adjusted edgewise treatment after completion of levelling and alignment. In closure of an extraction space, it is necessary to generate both a force to move the teeth and a root-paralleling moment to move them bodily.[6]Both, the bodily repositioning of teeth and root torque are largely done with rectangular wires. With fixed appliance therapy, there are two major ways to do space closure: sliding mechanics and loop mechanics. Each method has its own advantages and disadvantages. Loop mechanics is preferred over sliding because of advantages like no frictional resistance and better control over M:F ratio.[1]

The mechanical performance of the loop depends on three characteristics, one of which is its spring properties. The spring properties of loop in turn depends on the material used (Stainless Steel or TMA). Depending on the material used for loop fabrication (keeping other factors constant), several parameters are changed that affect the treatment outcome. The purpose of this study was to compare those parameters between a stainless-steel T-loop and a TMA T-loop using Finite Element Method.

The parameters assessed in the study were force, moment to force ratio, crown tipping and vertical root movement (extrusion). The force values in this study suggested that the force exerted by SS T-loop is almost double of what is found to be exerted by TMA T-loop.This does not correlate with the study done by Orabi et. al. (2020)[4] where force exertion was shown to be greater with TMA loops. The moment to force ratio data depicted that TMA and SS loops have similar M/F ratio at different angulation bends and as the alpha and beta bend increases, the tooth movement changes from tipping to translation.Crown tipping at various angulation bend suggested that the mesial crown tipping can be controlled by increasing the angulation bend and maximum crown tipping is seen at 0-degree angulation bend. Data from vertical root movement showed that extrusion is more common with SS T-loop as compared to TMA. The extrusive effect of the loop increases as the value of angulation bend increases in both anterior and posterior segment.

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