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RESEARCH ARTICLE

Comparative Assessment of Efficacy of Four Different Designs of Retraction Loops made of Beta Titanium Archwire: A Finite Element Study

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ABSTRACT

Objective: To compare the forces, moments and moment/force (M/F) ratio and load deflection rate of T-loop, keyhole loop, teardrop loop and mushroom loop with the finite element method (FEM).

Materials and methods: FEM was used to compare 3D models of closing loops in rectangular (0.017 × 0.025 inch) beta titanium wire. The T-loop, mushroom loop, keyhole loop and teardrop loop were 7 mm in height. The forces, the moments and the M/F ratios at each tooth node were recorded with an activation of 2 mm.

Results: The highest force and moments was produced by the keyhole loop and the lowest force was produced by the mushroom loop.

Conclusion: All the four retraction loops exerted the greatest force levels at the molar node. The maximum value for M/F ratio is seen at the central incisor followed by lateral incisor, molar and canine node. The keyhole loop demonstrated the least load deflection rate making it the most efficient design.

Keywords: Retraction loops, M/F ratio, FEM, Beta titanium.

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INTRODUCTION

Closing loops have the ability to move teeth without friction and theoretically have the ability to translate a tooth. Two important characteristics of closing loops used for orthodontic space closure are the moment/force (M/F) ratio and the load-deflection (F/D) rate.[1,2] Controlled movements of the teeth depends largely on balancing the interplay between the orthodontic appliances, anatomic structures and delivering appropriate biomechanics. Mechanical properties of loops used in maxillary-incisor retraction arches should be determined by the balance necessary between forces and moments produced as the arch is activated.[3] The finite element method (FEM) is a mathematical method in which complex systems of keypoints or nodes are located on an accurate drawing of the structure to be modelled. This study intends to make an assessment of four designs of retraction loops: T- loop, Keyhole loop, Teardrop loop and Mushroom loop made of beta titanium wire, to determine the best retraction loop for orthodontic space closure, based purely on the design. Since the study would determine the force levels at each of the nodes, we would be able to determine the exact degree of preactivation that would be required in the retraction loop design that will best suit clinical application of mechanics for orthodontic space closure in cases needing extraction of 1st bicuspids.

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MATERIALS AND METHODS

The T loop (Fig. 1), keyhole loop (Fig. 2), teardrop loop (Fig. 3) and mushroom loop (Fig. 4) for 3D analysis with the FEM were made of 0.017 × 0.025 inch rectangular beta titanium wire.[1,4,5] A 3D beam element was used to construct the models. The loops were modelled without preactivation bends. The loops were standardized with 7 mm height. Accurate diagrams of the loops were prepared and the keypoints marked on each diagram. The keypoints were used to transfer the exact geometry of each loop to ANSYS Version 12.1 installed in a Pentium IV personal computer. The cross-sectional area of beta titanium orthodontic wire (0.017 × 0.025 inch) was then calculated. The Young's modulus of the beta titanium was assumed to be 66 + 1 GPa and the Poisson ratio was equal to 0.3. The boundary conditions were defined so that the terminal node in the alpha segment (anterior) was restrained (i.e. it was not able to move in the X, Y or Z axes, and it was not able to rotate around these axes). The terminal node of the beta segment (posterior) was restrained in a similar way to the alpha segment, except that it was free to move along the horizontal leg of the posterior segment. This movement simulated the wire sliding distally through the molar tube. In our study, 2 mm displacement was done in Fx direction, i.e. the horizontal displacement and moments calculated around the Z axis.

RESULTS

The horizontal forces (X axis) at the center of each tooth, and moments along the Z axis in the anterior and posterior segment were recorded after an activation of 2 mm. The forces are given in Newton's (N), moments in Newton millimeters (Nmm), and the M/F ratios in millimeters (mm). Load deflection rate (LDR) is represented in Newton/millimeters (N/mm). Master chart shows force, moment and M/F ratio acting on each tooth included, in four designs of loops, (keyhole loop, teardrop loop, mushroom loop and T-loop in beta titanium archwire). Table 2 shows the values obtained of load deflection rate in all the four loops.

The force values when noted in descending order of their magnitude followed a different trend at each node. But each node showed the same order for all four loop design.

The moment values when noted in descending order of their magnitude followed a different trend at each node.

DISCUSSION

The forces exerted by different designs of loops (T-loop, mushroom loop, teardrop loop and keyhole loop) made from beta titanium archwire was noted. The magnitude of force at similar nodes appeared to be in the same range for T-loop and Keyhole loop configuration (Table 1 and Graph 1). A similar tendency of comparable range in force levels was observed between the Mushroom and Teardrop loop configurations, however as expected the pure magnitude of the force levels at different tooth nodes varied considerably irrespective of the design of loop.

An interesting aspect which we observed while studying the levels of forces generated was that, the Mushroom and Teardrop loops developed greater force levels in posterior (molar) nodes as compared to other nodes, while the T loop and Keyhole loop seemed to exhibit larger force levels in the anterior segment (lateral and central incisor nodes) as compared to the other nodes (Table 1 and Graph 1). Hence, in cases with high anchorage requirement, Mushroom and Teardrop loops can be used. And cases in which it is essential

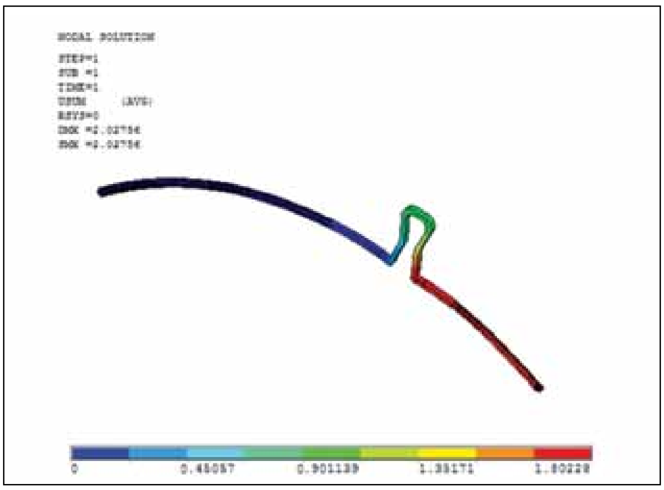


Fig. 1: Keyhole loop

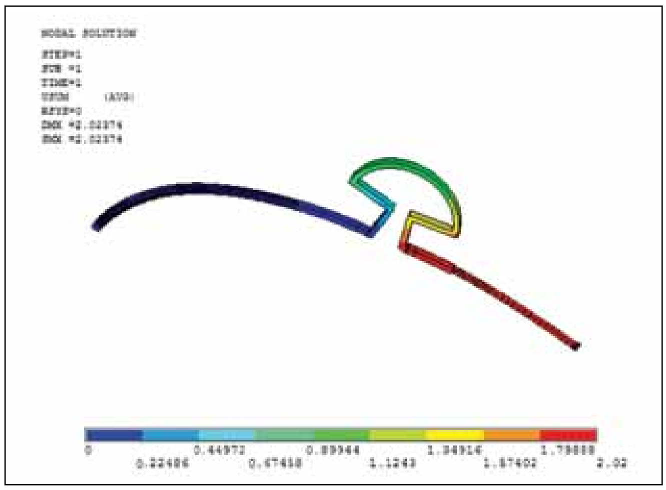


Fig. 3: Mushroom loop

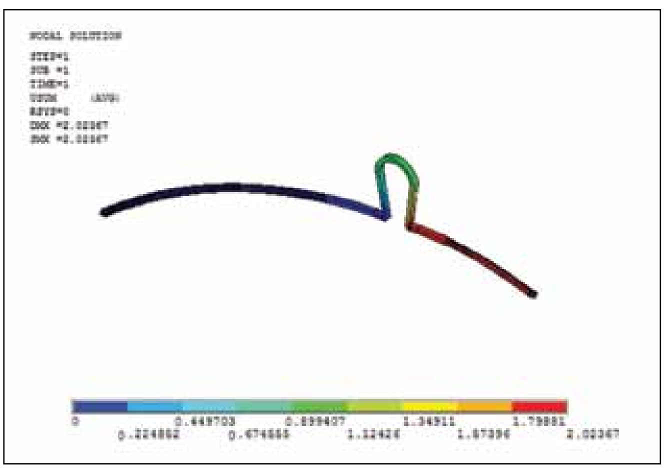


Fig. 2: Teardrop loop

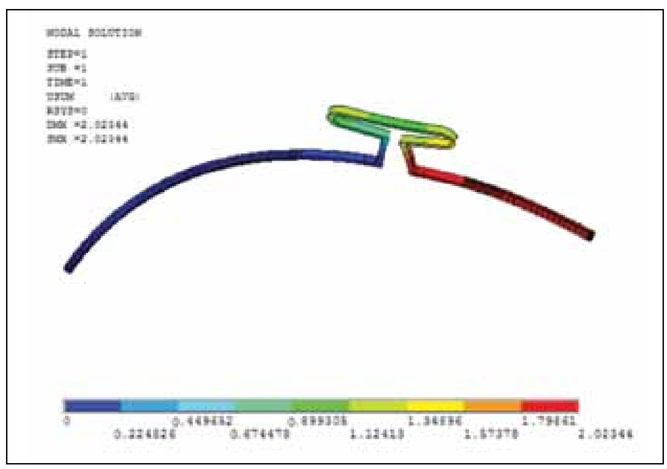


Fig. 4: T-loop

Table 1: Forces in Newtons, moments in Newton-millimeters and moment to force ratio in millimeters for all four designs of loops

		Teeth											
Sr. no.	*Loops*	*Molar node*			*Canine node*			*Lateral incisor node*			*Central incisor node*		
		Force (X)	*Moment (Z)*	*M/F ratio*	*Force (X)*	*Moment (Z)*	*M/F ratio*	*Force (X)*	*Moment (Z)*	*M/F ratio*	*Force (X)*	*Moment (Z)*	*M/F ratio*
1.	Keyhole loop	3.21	–19.63	6.10	–2.55	–2.54	0.99	–2.45	–16.85	6.85	–1.47	–13.47	9.15
2.	Teardrop loop	3.36	–19.78	5.87	–1.23	–0.99	0.80	–1.32	–9.63	7.25	–0.79	–7.30	9.16
3.	Mushroom loop	3.92	–19.80	5.83	–1.02	–0.74	0.62	–1.14	–7.86	6.84	–0.68	–6.32	9.16
4.	T-loop	3.26	–19.46	5.95	–1.99	–1.82	0.91	–2.00	–14.05	7.01	–1.20	–11.02	9.16

Table 2: The values of load deflection rate for all the four loops

Loop design	*Load deflection rate (Newton/mm)*
Keyhole loop	6.04
Teardrop loop	6.20
Mushroom loop	10.27
T-loop	11.29

to maintain torque in anteriors, T loop and Keyhole loop can be used.

A consideration of force magnitude experienced by individual tooth nodes demonstrated a decreasing magnitude of force levels from the posterior to anterior segment.

We aimed to observe the force system without the placement of any preactivation bends. The Moment to force ratios evaluated for each tooth node in this study indicate that the maximum value for the M/F ratios was experienced at the central incisor node, followed by the lateral incisor node, molar node and the canine node respectively (Table 2 and Graph 2).

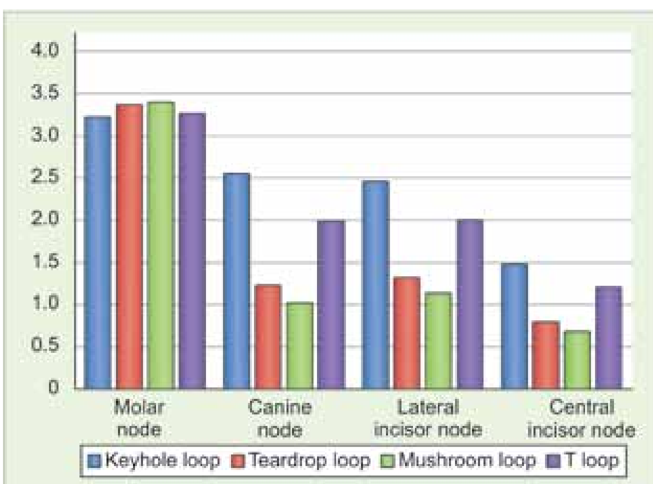
It was also noticed that when the force levels were studied, as one progresses anteriorly, the force levels showed a decreasing magnitude. This reduced force level and increased moment seemed to result in a high value of M/F ratio at central incisor. M/F ratio experienced at the central incisor node for all the different loop design seemed to be similar, for this reason in clinical scenario all these loops will help in achieving bodily movement of anteriors.

The loops used in our study showed that the T-loop and keyhole loop generated the force levels to near optimum values for physiologic tooth movements as suggested by Gjessing P,[6] Braun S,[7] Proffit WR,[8] Ricketts,[9] Smith and Storey.[10]

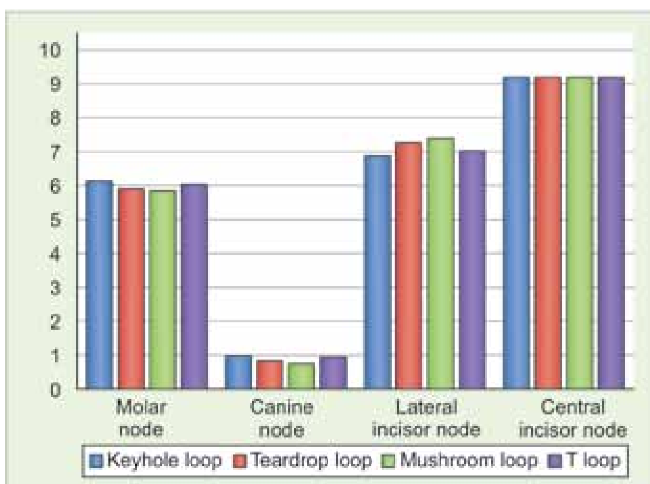
CONCLUSION

It is clear that the level and direction of forces and moments generated by loops depend on many confounding factors; they are the influences of loop material and shape, end conditions (ligation methods), activation direction and magnitude which make analysis difficult.

1. All the four retraction loops exerted the greatest force levels at the molar node. The level of these forces decreased as one moves anteriorly.
2. T-loop and Keyhole loop configuration generated comparable force magnitude at different teeth.
3. Teardrop and Mushroom loop configuration generated comparable force magnitude at different teeth.
4. The maximum value for M/F ratio is seen at the central incisor followed by lateral incisor, molar and canine node.



Graph 1: Forces in Newton's in recommended four types of loops



Graph 2: Moment to force ratios in millimeters in four types of loops at various nodes

5. The keyhole loop demonstrated the least load deflection rate making its design the most efficient for space closure.

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