L-loop characteristics: 3D analysis using finite element method

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Abstract

Introduction: An appropriate force system is a perquisite of desirable and predictable tooth movements during orthodontic treatment. Complete knowledge about the generated forces and moments by loops is essential to choose the best one for every situation.The aim of this study was to establish a mathematical equation to bring about a relationship between the L-loop height, width, activation and the produced force.

Materials and methods: Six 3D finite element models were designed for L-loop without pre-activation bends. Loops were designed with different widths (w) and heights (h). The cross section of wire was 0.016”× 0.022”. The distal end of each model was activated 1 mm in 0.1 mm intervals. The force produced by activation in a 0.1 millimeter increment was recorded.

Results: Force findings were different according to the loop parameters defined. The produced force varies from 0.106 to 0.228 N for a 0.1 millimeter of activation and increased from 1.07 to 2.27 N in 1.0 mm of activation.

Conclusion: The magnitude of force by L-loop can be estimated through adjustment of vertical part and activation as Increments of activation increased the delivered force while Increasing L-loop height decreased the generated force.

Keywords: Orthodontic loops, L-loop, Force, Moment, Finite element method

An appropriate force system is a perquisite of desirable and predictable tooth movements during orthodontic treatment.[1,2]

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Optimal dental movement needs some parameters like suitable levels of force, low load/deflection rate(L/D rate), high moment/force ratio(M/F ratio) and reasonable range of activation.[2] Incorporating loops are among the methods to reduce load-deflection rate.[3] Orthodontic wires are formed into loops to alter the elastic properties of the wire or serve as hooks or stops.[4] Delivering proper force system considering M/F ratio by adding loops is achievable through reducing stiffness and strength, increasing working range, decreasing the L/D rate and omitting friction.[4,5] The consistency of created force by certain loop is dependent on the load/deflection rate, as the lighter and more continuous force will be generated by the lower L/D rate.[6,7] Inappropriate force system due to improper use of loops may result in some undesirable dental displacements8,9, so complete knowledge about the generated forces and moments by loops is essential to choose the best one for every situation.[1,6,9,10] There are some parameters affecting spring characteristics like design and figuration, materials, ligation methods, amount of wire and rate of activation.[2,9,10,11,12] The orthodontist can handle the M/F ratio by changing loop dimension, angulation, amount of activation or alloy. There is no limitation for loop design and over the years several loop designs have been produced for better control of movements in any plane of space.[4,5],6The most practical loops are space opening, space closing or space holding loops, box loops, horizontal base loops, torqueing loops and loop-stop combination. L-loop, a kind of horizontal base loop, provide flexibility in all directions, but the length of horizontal base segment is crucial to provide flexibility for vertical and bucco-lingual actions.[4] By this time, several studies have been accomplished to determine load components of different loops by using 3D analytical and computational analysis like beam theory or finite element methods.8,10 The findings of these experimental studies will aid in better spring choice and design, but the most of these researches have been focused on T-loop [1,2,4,8,10,11,13-17]. The aim of this study was to establish a mathematical equation to bring about a relationship between the L-loop height, width, activation and the produced force.

Materials and Methods

Six 3D finite element models were designed for L-loop without pre-activation bends. Loops were designed with different widths (w) and heights (h). The cross section of wire was 0.016”× 0.022”.(Figure 1 to 6) SolidWorks 2006 (300 Baker Ave. Concord, Massachusetts 01742, USA) was selected for the modeling phase. The models were then transferred to the ANSYS Workbench Ver. 11.0 (ANSYS Inc. Soutpointe, 275 Technology drive, Cononsburg PA 15317, USA) for analysis. Young’s modulus (2e5MPa)and Poisson’s ratio (0.3) were applied. Models were meshed with10668 nodes; 5082 elements. The mesial part of the models was restrained so that all rigid body motions were prevented. The distal end of each model was activated 1 mm in 0.1 mm intervals.The force produced by activation in a 0.1 millimeter increment was recorded.(Figure 7)

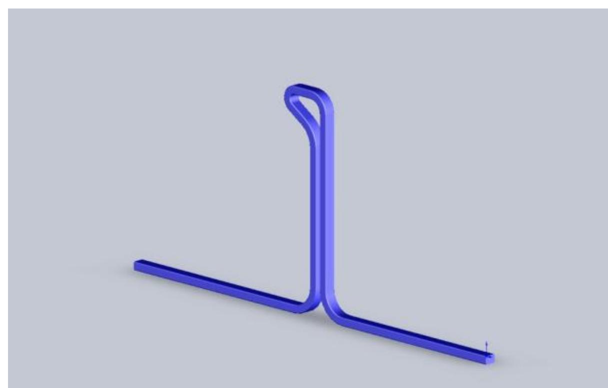

Figure 1: L11 (h=8 mm; w=1 mm)

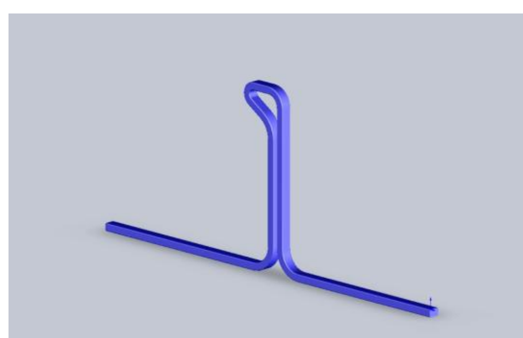

Figure 2: L12 (h=7; w=1)

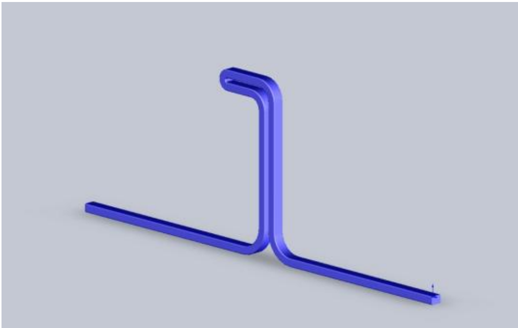

Figure 3: L21 (h=7; w=2)

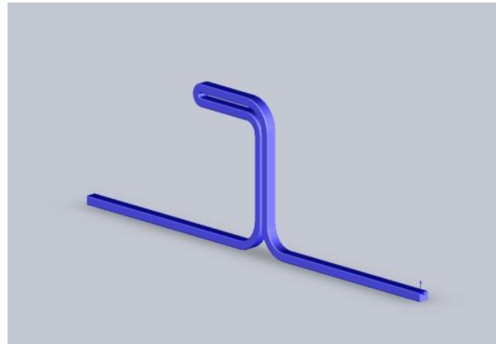

Figure 5: L32 (h=5; w=3)

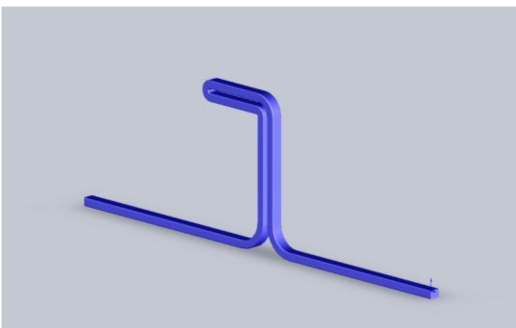

Figure 4: L31 (h=6; w=3)

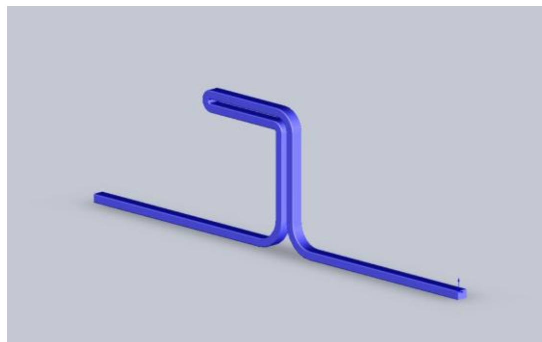

Figure 6: L41 (h=5; w=4)

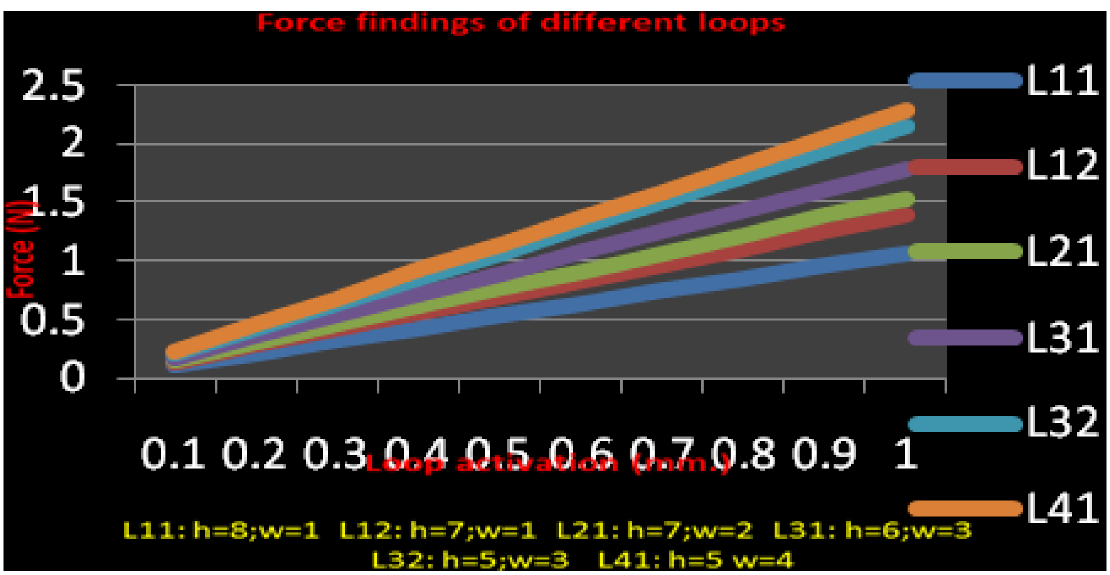

Figure 7: Force findings of different loop parameters

Statistical Analysis

In this study linear regression was used for evaluation of relationship between force and height, width and delta(amount of activation). For this purpose, the variable of force was placed in model by square root transformation. The correspondence of obtained results and findings of regression model were also estimated with calculation of ICC (Intra-class Correlation Coefficient). $P < 0.05$ was considered statistically significant.

Results

Force findings were different according to the loop parameters defined. The produced force varies from 0.106 to 0.228 N for a 0.1 millimeter of activation and increased from 1.07 to 2.27 N in 1.0 mm of activation. Numeric data is provided in Table 1.

1st Loop (h=8; w=1): The force findings were between 0.106 N in 0.1 mm of activation and 1.068 N in 1.0 mm of activation.

2ndLoop (h=7; w=1): The findings started with 0.138 Nin 0.1 mm of activation and increased to 1.389 N in 1.0 mm of activation.

3rd Loop (h=7; w=2): The lowest finding was 0.152 N and reached its highest value (1.542 N) in 1.0 mm of activation.

4th Loop (h=6; w=3):The force results were between 0.178 N in 0.1 mm of activation and 1.788 N in 1.0 mm of activation.

5thLoop (h=5; w=3): The findings started with 0.214 Nin 0.1 mm of activation and increased to 2.144 N in 1.0 mm of activation.

6thLoop (h=5; w=4): The lowest finding was 0.228 N and reached its highest value (2.28 N) in 1.0 mm of activation.

Using linear regression model showed a distinct relationship between force and height and delta.

$$Force=(1.063 - 0.105\times Height + 0.945\times Delta)2$$

The value of R2 for this model was 0.96 and the predicted results of model had an acceptable correspondence with observed findings.(ICC: 0.98)

Discussion

Control of tooth movement during orthodontic treatments is achievable by using suitable appliance to deliver an appropriate force and moment. The force system can predict the dental movement response. One way of improving force system is by insertion of different loops.Each loop design produce distinct forces and moments, so it would be easier to choose the best one and avoid inappropriate side effects by understanding 3D force system of loops. By this view, several studies have been done to estimate the generated force of different springs and loops. It was also reported that the force drive from a definite loop is influenced by their vertical and horizontal dimensions and amount of activations. This study determined how spring design(change in dimension) and activation can effect on the generated force in L-loop and if there is any relationship between these variables or not?

In this study the finite element method was applied to estimate the generated force in various designs of L-loops and activations. The findings showed that there is a direct relationship between loop height and amount of activation and generated force [$F= (1.063-0.105h+0.945\Delta)2$]. According to this formula, altering of loop dimensions by changing the vertical parts, influenced the produced forces, as increasing the height with the same amount of activation, decreased the generated force. This is in agreement with Jie Chen10 who revealed that increasing the vertical part of T-loop decreased the amount of force delivered at any activation level. Similar results were also obtained by Faulkner18 in which the increments of height in T-loop were related to the reduction of delivered forces. In the other research, Dong19 found that increasing of height in vertical loops was associated with a decrease in generated forces. Blaya9also showed that the producing force by teardrop loop and circle loop decreased when the height increased. Although direct comparison may not be possible because of different loop designs,it might be concluded that loop height is more important than loop design.

In a different investigation,Vanderby1 reported that increasing the gingival dimension in both T-loop and L-loop, decreased the forcesand mechanical behavior of L-loop being strongly affected by geometric nonlinearity. But in present study no significant relationship was found between the width and force.

According to this study, there was also a direct relationship between amount of activation and produced force. This result was in agreement with our previous study and some others. Geramy20 showed that generated force by L-loop increased by activation increments. In similar study, Jie Chen10 reported that raising activation in T-loop resulted in increasing the delivered force. He also found in his other study8 a linear relationship between activation and force with T-loop, as increasing activation, increased the force. This is also in agreement with Maia21 who reported that generated force by T-loop increased by increasing the activation. Different loop designs in these studies make it difficult to compare, but all of them showed a direct relationship between activation and force.

As a result, understanding the force system of different loops and determining an affecting factor on generated force can be so helpful for use. In present study we found that delivered force by L-loop is influenced by vertical dimension and also amount of activation.According to obtained formula, increase of loop height had an adverse effect on produced force, while activation showed a direct relationship with force. So it would be possible to control the magnitude of force through the adjustment of vertical dimension and amount of activation. Although there are many affecting factors, by this way tooth movement can be predictable to some extent.

Conclusions

- Increasing L-loop height decreased the generated force.
- Loop activation and the delivered force are in direct realtion.
- The magnitude of force by L-loop can be estimated through adjustment of vertical part and activation.

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