The effects of height and width in L-loop characteristics: 3D analysis using finite element method

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Abstract
Desirable tooth movements need optimal force systems. Loops are employed to move teeth properly. L-loop is used frequently due to its ease of fabrication. The aim of this study is to assess the expected forces and moments when a definite length of wire is bent to form L-loop. In other words, the effect of loop height and width on the produced force and moment is evaluated by the finite element method (FEM).
Materials and methods: Six 3D finite element models were designed of an L-loop without pre-activation bends keeping the total lengths of wire equal to 24.34+/- 0.5 mm. The cross section of wire was 0.016”× 0.022”. The force produced by activation in a 0.1 millimeter increment was recorded.
Results: In model L1, the findings start with 0.086 N in 0.1 mm of activation and increased to 0.88 N in 1 mm of loop opening. The pattern of findings was almost the same for other loop designs (L2 through L6) with an increase in findings. M/F ratios were almost constant in a loop design along its activation starting with 3 in L1 and reaching about 1.9-2 in L6.
Conclusions:Moment to force ratios were almost constant in a loop design along its activation. increasing width and decreasing height with almost the same length of loop wire can increase force and therefor reduce M/F ratio.
Keywords: Orthodontic loops, L-loop, Force, Moment, Finite element method
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Using optimal force system during orthodontic treatment is necessary to achieve desirable and predictable tooth movements.[1,2]
There are some requirements for optimal dental movement including appropriate level of force, low load/deflection rate (L/D rate), high moment/force ratio(M/F ratio) and reasonable range of activation.[2]

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One method of reducing L/D rate and producing predetermined force system is to add loops into wires.[3,4] Loops can be incorporated into any orthodontic wire to change their elastic properties and produce the necessary activation for a special force system.[4,5] There is no limitation for loop design except the imagination and skill of the operator, so they can be used in many forms and applications.[5] Loops have some effects like reducing stiffness and strength, increasing working range,decreasing the L/D rate, omitting friction and delivering appropriate force system considering the M/F ratio.[4,5] These effects of loops are

accomplished by altering the bending moment arms and the length of wire.[2,5,6,7] The load/deflection rate in orthodontics determine the consistency of generated force by certain loop in which the lower L/D rate, the lighter and more continuous force will be produced.[8,9] Inability to manage force system due to improper use of loops can lead to some undesirable tooth movements and selecting the most suitable type for every cases is crucial.[9,10,11] The use of loops requires complete knowledge of force systems, so understanding the forces and moments generated by loops is necessary.[1,12] There are some parameters affecting spring properties like loops design and figuration, materials, ligation methods, amount of wire and rate of activation.[2,9,11,12,13]The orthodontist can change the moment/force ratio produced by loops through altering spring dimension, angulation, type of activation(vertical or horizontal) or alloy for better control or selecting different type of movement.Over the years several loop shapes have been developed for different goals, thus they can be used whenever we need a major correction in any plane of space.[4,9] Horizontal base loops like delta-shape loop and L-loop provide flexibility in all directions, but the important is that the horizontal base segment has to be long enough to provide flexibility for vertical action and bucco-lingual movements.[5] up to now various studies have been done to measure load components by using 3D analytical and computational analysis like beam theory or finite element methods.[10,12] The results of these studies will be useful in effective appliance selection and design. The effect of these variables on T-loop have been reported in different studies [1,2,4,6,7,10,12-18] but about L-loop there is just a few information [1,2,4,8].The aimof this study was to evaluate the effects of L-loop characteristics in its force production

Materials and Methods

Six 3D finite element models were designed of an L-loop without pre-activation bends. Loops were designed with different widths (w) and heights (h), keeping the total lengths of wire equal to 24.34+/- 0.5 mm. The models were designed in an order of decreasing height by 1 mm (h-1 mm) and increasing the width by 1 mm (w+1 mm) simultaneously step by step starting from L1(h=9 mm; w=1 mm) reaching L6 (h=4mm; w=6 mm).The cross section of wire was 0.016”× 0.022”. (Figure 1a-f)

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.The corresponding elastic properties such as Young’s modulus 2e11 Pa and Poisson’s ratio 0.3 were applied. Models were meshed with 61254 nodes; 34019 body elements. All nodes at the mesial side of the models were restrained so that all rigid body motions were prevented. The force produced by activation in a 0.1 millimeter increment was recorded.

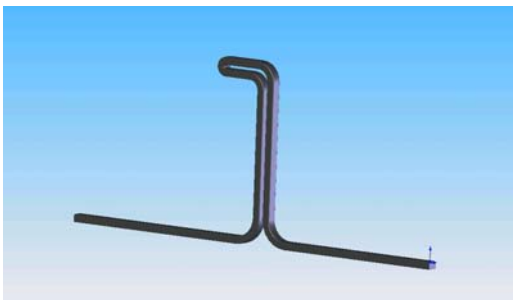
Results

Force findings are presented in Table 1. In model L1, the findings start with 0.086 N in 0.1 mm of activation and increased to 0.88 N in 1 mm of loop opening. The pattern of findings was almost the same for other loop designs (L2 through L6) with an increase in findings. These findings started with 0.11 N and reached 1.198 N in model L2. The starting point was 0.13 in L3 and increased to 1.395 N. Force findings started with 0.16 in L4 and ended up with 1.713N. In L5 findings were between 0.2N and 2.21N. The highest findings were in L6 (0.29 - 3.09).(Figure 2)

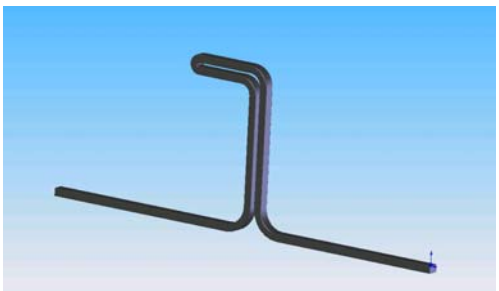
M/F ratios were almost constant in a loop design along its activation starting with 3 in L1 and reaching about 1.9-2 in L6. The

pattern shows an almost straight line and the common point about all designs is their inability to produce bodily movement. (Figure 3)

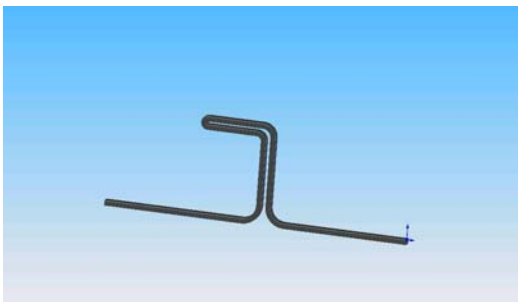
a)L_1 loop design (h=9 mm; w=1 mm)



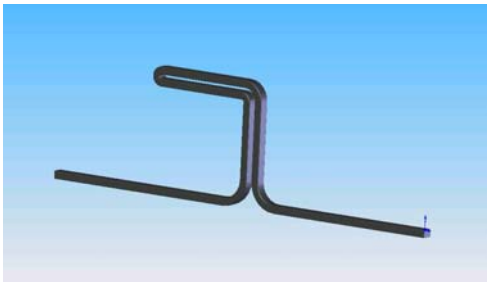
b) L2 loop design (h=8 mm; w=2 mm)



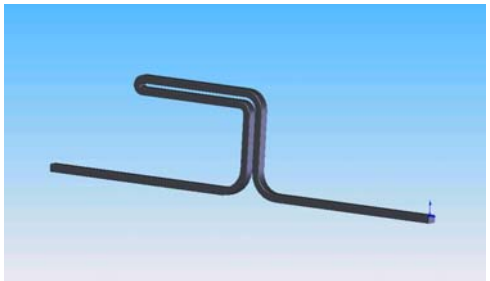
c)L3 loop design (h=7 mm; w=3 mm)



d) L4 loop design (h=6 mm; w=4 mm)



e) L5 loop design (h=5 mm; w=5 mm)



f) L6 loop design (h=4 mm; w=6 mm)

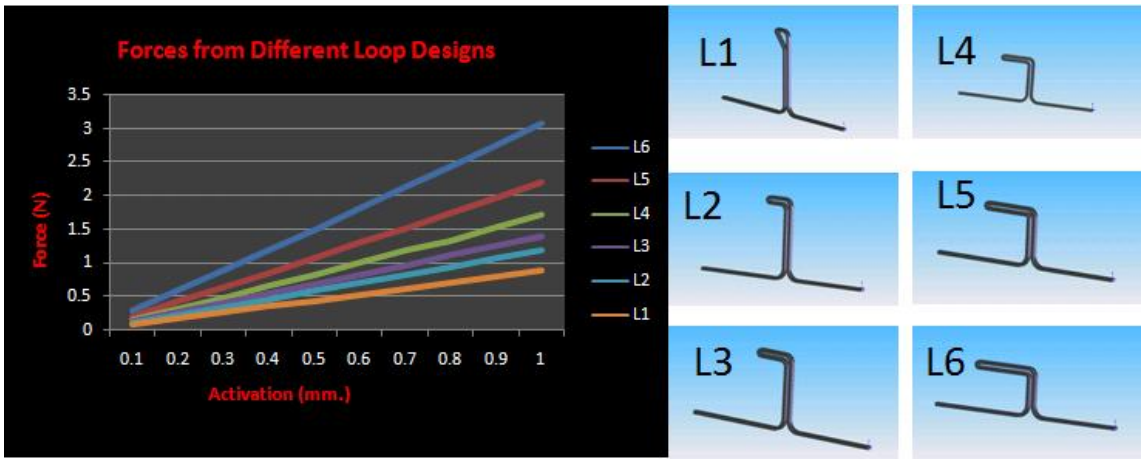


Figure 2: Force findings of L-loop with various shapes keeping the wire length constant.

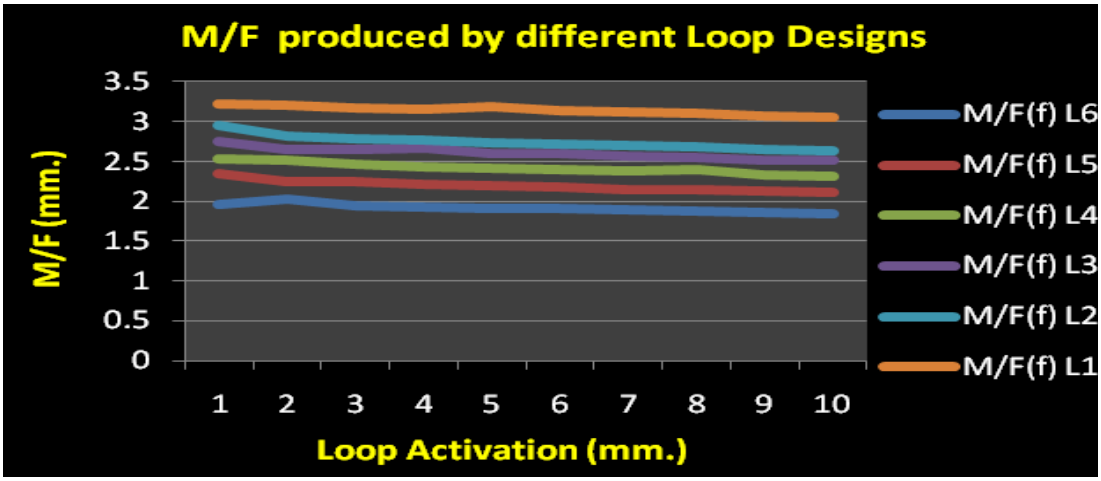


Figure 3: M/F ratio findings of different loop designs

Discussion

Clinical management of tooth movement is determined by the design of appliance which require knowledge of M/F ratio in all plans. The magnitude of force should also be restricted within appropriate range for the best results, although it has to be high enough to induce dental displacement without causing damage. The ability of a spring to cause a certain movement is dependent on the M/F ratio which can produce, so the critical spring has a low L/D rate and a high M/F ratio. This study shows how spring design (change in dimension) influences the generated force and M/F ratio in an L-loop. Understanding the 3D force system makes it easier to choose a suitable appliance with predictable clinical results and then decrease side effects.

In this study the finite element method were used for evaluating the generated force by

different design of L-loop. The findings showed that altering of vertical and horizontal dimension of loop with almost the same length of loop can effect on delivering force and moments. Decreasing the height associated with increasing the width, raised the generated force and therefore reduced the M/F ratio. Our results also demonstrate that although the force increased linearly with the activation, the M/F ratio did not changed and each design of loop showed a constant and almost straight line pattern of M/F ratio along its activation. This was in agreement with Jie Chen's finding12 that the amount of activation had insignificant effect on M/F ratio. Safavi et al19 also reported that T-loop had constant M/F ratio in every amount of activation. In our study, each type of loop design had a distinct force system while increasing in vertical dimension, increased the M/F ratio. (Figure 3) These results confirm Burstone's report20 who believed that raising the length of the loop in an apical direction is one method to increase the M/F ratio. Dong YS21 also revealed in his studythat increasing the height of vertical loop would increase the M/F ratio. JieChen12also demonstratethe same results that increasing the length of T-loop by increasing of horizontal dimension can decrease M/F ratio. In the other studyFaulkner22 showed that raising the height of T-loop caused reducing in force much more rapidly than the moment and result in increasing of M/F ratio. These results are not directly comparable with ours because of difference in loop design.We also found that although M/F ratio improved by raising the loop height (from 1.92 in L6 to 3 in L1), these values were not enough for bodily movements. If desired tooth displacement is translation which is a common requirement for space closure, we need to increase this ratio to the optimum of 10/1. Another manner to achieve this optimal ratio is by incorporation of compensatory bends. Burstone23 reported that introducing angulation in the loop could increase M/F ratio of a appliance. Jie Chen10 also confirms this idea in his study and suggested that M/F ratio can be adjusted by using gable bends.

As a result, insertion of loops can lead to development of a force system by altering the force and the moment delivered, but using an appropriate design is very critical to achieve final goal. Changing the vertical and horizontal dimensions of loop can improve the M/F ratio to an optimal range, but in many instance we need to add some angulation as a gable bend to reach desired value.

Conclusions

-Moment to force ratios were almost constant in a loop design along its activation

-increasing width and decreasing height with almost the same length of loop wire can increase force and therefor reduce M/F ratio

- L-loop in each design and activation failed to produce an optimal M/F ratio for bodily movement.

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