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Research Article

Study of Stress and Deformation of Double Key Loop Orthodontic Archwire on the Finite Element Method

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Abstract

The present study evaluates and describes an orthodontic retraction archwire called double key loop, through the finite element method, visualizing the tensions and deformations generated by its activation. The objective of this study was to complement the clinical and laboratory analyses with simulations of the tensions in the arch and brackets during the process of the arch wire activation. Such information helps the orthodontist during treatment to minimize the side effects of retraction. The study based the geometry of the model used in a patient with orthodontic treatment finalized, the model was formed and brackets added virtually in the COMSOL® platform. The strain and stress distribution graphs show the tension of the arch being transferred to the incisor teeth and part of these tensions being stored in the loops in an unequal way, mainly in the distal loop and later in the mesial loop.

Keywords: *Finite Element Analysis; Orthodontics; Orthodontic Space Closure, Orthodontic Wires, Dental Stress Analysis*

Abbreviations

DKL: Double Key Hole Loop; mm: Millimetres; DKH: Double Key Hole; '': Inches; N/m2: Newton Per Square Meter; VOB: Virtual Orthodontic Bracket

Introduction

In orthodontics, an excessively disproportionate force applied to the dental structures generates serious side effects, such as reabsorption of the dental roots to tooth loss [1]. This study measures the forces applied to the arch and braces to perform the retraction of the anterior teeth [2]. This retraction is used when the size of the teeth is larger than the space in the arch, then the teeth are removed, and the anterior portion is retracted until space is completely closed [3]. This procedure requires force applied during the activation of the arch in its correct proportion, so the importance of knowing the limits of this force used, with the aim of eliminating or, at least, minimizing undesirable side effects with bone resorption of the teeth. In this way, the clinical practice is based on physical and mathematical tools, aiding treatment through biophysics [4].

The orthodontic archwire studied is the double Key Hole Loop (DKL) with four vertical loops 4 mm high by 5 mm wide. These loops are located on the proximal faces of the Canine in the shape of a lock [5] (DKH - Double Key Hole) in a rectangular stainless-steel arch 0.019'' X 0.025''[6] these loops are used in the Orthodontics to retract the anterior teeth after exodontia.

The study with finite element method simulated the opening of 0.5, 1 and 1.5 mm of each loop [7], an application up to 10 N force on the back of the arch in the direction of retraction of the dental arch wire. Through this, it was possible to visualize the tensions and deformations of the archwire. Thus, the calculation of the distribution of the forces of each bracket on the orthodontic apparatus [8] was performed.

Materials and Methods

In the initial phase of the study, a three-dimensional dental arcade of a patient was designed through a computerized tomography. The brackets structure and the DKL orthodontic arch wire were modeled. The characteristics correspond to the features of the arch wire of stainless steel, and its geometry is 0.019'' by 0.025''. The slots of the brackets have a geometry of 0.022'' by 0.027'' with supports the measurements of Arici [9], as shown in figure 1.

Figure 1: *Initial model, built to measure brackets and archwire dimensions, as well as distances inter-brackets and the space distribution of the structures.*

In a second step, we constructed the mesh of the model with 71,359 tetrahedral elements (4 knots) of mesh knots, and a volume of 3,398 mm3. The model has 74,494 degrees of freedom, assuming the symmetry of motion and linear isotropic elastic behavior of the model. Applying the force of 10 N in the period of 500 μs in the posterior portion of the arch wire, we observed an opening of 0.6 mm of the aperture between the DKL loops.

The contact between orthodontic arch-slot was configured with a coefficient of friction of 0.02 [10]. This interaction is described in the literature as a bracket-wire interaction with a small gap of 0.02 mm [11]. The A-B play of the bracket has approximately 7.2 degrees. Thus, the tests were conducted by applying horizontal 10N at the posterior extremities of the archwire in a lateral (Figure 2) and frontal (Figure 3) view of the arch.

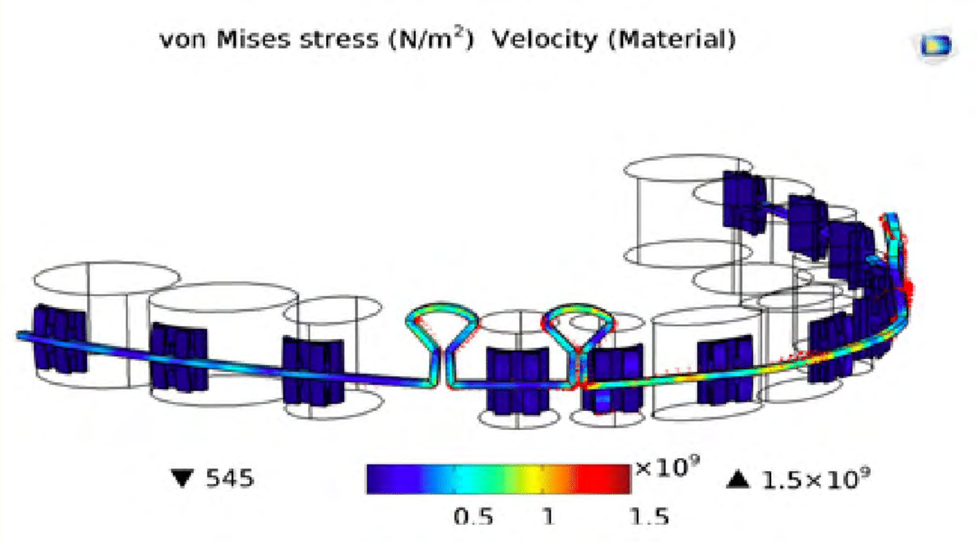

Figure 2: *Propagation of stress, with a tension of 10N, applied at each end of the arch wire.*

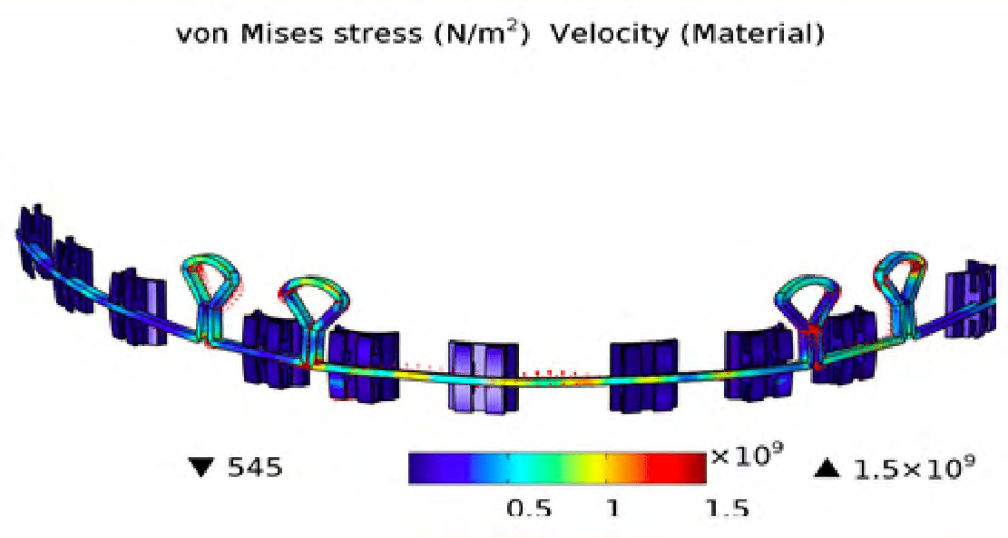

Figure 3: *Frontal view of the arch wire. Stress is concentrated in the loops.*

The tension in the arch is applied at its posterior extremities, so through equations, its distribution of stress (measured in Von Mises stress) in the body of the orthodontic archwire is calculated, as well as the displacement in the directions of vertical, horizontal and transversal axis.

Results and Discussion

During the first phase of activation, mechanical force waves were observed to propagate from the distal to the mesial loop until they met and reached the central portion of the arch and then returned and focused on the two loops, especially the Distal loop, where there is clearly greater storage of forces. As the test progresses towards the end, we also notice an increase of force in the anterior portion.

The results showed a disproportion in the opening of the loops. The distal loop presents the largest opening diameter during the entire test period, coinciding with the greatest tension area. The arch follows a predetermined path by the virtual orthodontic bracket (VOB), which prevents it from folding on itself, or from leaving the horizontal plane, however, clearly shows the tendency of displacement in the loops in several directions, especially in the anterior region, where the archwire presents a vestibular torque.

Despite the fact that the method of the finite elements is difficult to be considered an indeterminate system [11] since systems with more than two points cannot be analyzed theoretically nor directly solved in balanced forces. It is also true that the finite element representation is almost identical to the real one because it is within the deviation curve [12]. Thanks to the new software that provides the three-dimensional force system and the new range of studies [13,14] that have differentiated the dental and bone structures, approaching more and more of reality.

However, it is worth remembering that, whether it is a laboratory test, whether it is a predictive model or even a clinical case study, divergences will occur, since, in the biological system, no patient is the same as the other. Once you keep in mind that as close to reality as tests and results may be, these are still allegories, representations. We must remember that any analysis is complementary and that the junction of these makes us come closer to reality and relieve our limitations.

Conclusion

The use of more advanced techniques such as the finite element method allows us to refine the pre-existing dental conceptions through a more analytical analysis that allows us to treat orthodontic movement in a less empirical way. The ability to create these simplified visual representations but with complex mathematics also leads us to understand the biomechanics in the movements better and acquire information about the physics involved in a process previously seen as only clinical, adding a new dimension to dental research.

Conflict of Interest

No conflicts of interest.

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