Journal of Research in Medical and Dental Science
2022, Volume 10, Issue 10, Page No: 185-192

Available Online at: www.jrmds.in
eISSN No. 2347-2367: pISSN No. 2347-2545

Finite Element Analysis for Canine Sliding Using Different Arch Wire Sizes

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ABSTRACT

This study aimed to predict the amount of canine displacement in two axes of space movement, rotation vector, and stress distribution on the retracted canine with a sliding method using different sizes of stainless steel rectangular archwire. Materials & methods; the wires of (0.017 × 0.025, 0.017 × 0.022, 0.016 × 0.025, and 0.016 × 0.022 inch) sizes were used in a two-dimensional analysis of a numerical dental model that represents the retracted mandibular canine, extraction space, anchoring teeth (mandibular molar and premolar) constructed using ANSYS software. Subsequently, the analysis adopted the application of 1.5 N for the retraction procedure, and the data have been processed to develop a more practical finite element mesh for the analysis procedure. Results; showed large displacement in the two axes of movement when the smaller diameter of archwire sizes was used. According to this study, the rotation vector and stress distribution on the retracted tooth will have minimum or no apparent differences when using different retraction archwire sizes. Conclusion; the finite element analysis for sliding canines using different archwire sizes illustrates that the amount of canine displacement will be increased with small archwire sizes compared with the larger size, with minimum or no effect on rotation control.

Key words: Sliding canine, Finite element analysis, Archwires

HOW TO CITE THIS ARTICLE: Rasha Y Al-Darzi, Finite Element Analysis for Canine Sliding Using Different Arch Wire Sizes, J Res Med Dent Sci, 2022, 10 (10): 185-192.

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Received: 14-Sep-2022, Manuscript No. JRMDS-22-77213;

Editor assigned: 16-Sep-2022, PreQC No. JRMDS-22-77213(PQ);

Reviewed: 03-Oct-2022, QC No. JRMDS-22-77213(Q);

Revised: 07-Oct-2022, Manuscript No. JRMDS-22-77213(R);

Published: 14-Oct-2022

INTRODUCTION

Basic facts of canine retractions using multiple techniques along the history of orthodontic treatment and space closure biomechanics may offer several clues about the influence of the tooth movement characteristics by the applied force in concern to the magnitude, and the direction of the moment, and force ratio [1,2]. Accordingly, the force application during canine retraction may also be affected by the type of the orthodontic appliances in one way or another. Regarding the enormous techniques and appliances that have been used since 1974, e.g. (Ricketts technique) passing to the recent methods for retraction frictional and frictionless, and with or without Temporary Anchorage Devices) TADs) for maximum anchorage properties [3]. Using the finite element procedure in analyzing orthodontics is reliable and helpful in avoiding any harm caused by unexpected stress in that process [4].

The Finite element analysis is considered an essential computerized simulative method that may solve stress-strain mysterious mechanics of many structures, including teeth under orthodontic treatment, and retraction when the systems were conducted via FEM into a set of elements connected simply by nodes [5,6]. Subsequent structural (dental) responses, force application, and boundary condition simulation will be computed and presented to be displayed and analyzed [7,8]. The dynamic analysis using finite element analysis was used to investigate the stress distribution pattern in the tooth due to orthodontic processes [9]. The finite element used a numerical simulation of the problem by defining the element and giving a suitable boundary condition with a substantial degree of freedom [10]. The ANSYS program is one of the most powerful tools used in Finite Element analysis; therefore, it was adopted for simulation and analysis of the orthodontic process [11]. The aim of the present study is to predict the amount of canine displacement in two axes of space movement, rotation vector, and stress distribution on the retracted canine with a sliding method using different sizes of stainless steel rectangular archwire.

MATERIAL AND METHODS

The construction of the two-dimensional numerical dental model that represents the right canine retraction and space closure using different orthodontic retraction archwire sizes (Table 1), model is based on the digital panoramic radiograph belonging to a female chronic orthodontic patient after taking her agreement for using the data illustrated by the following panoramic view on the Figure 1. The finite element ANSYS software was used to construct the dental model and the related surrounding tissue after omitting the lower first premolar to guide the canine for space closure with the application of 1.5N for the retraction procedure.

The method of statements includes the simulation of the digital x-ray in the AutoCAD program. The x-ray with an initial scale was added to the AutoCAD program file, where the mesh identifies the coordinates of the teeth' boundaries. The adopted mesh size was measured in (mm), as shown in Figure 2.

The four nodes' three-dimensional Shell181 element with six degrees of freedom in each node (Translations in X,Y, and z and rotation about X, Y, and Z) was used to model the teeth body and the Brackets, as shown in Figure 3A. The orthodontic archwires were modeled using the two-nodes three-dimensional Link180 element, as shown in Figure 3B. The bracket is contacted with the teeth by six nodes using two elements per tooth.

The model contains 960 nodes, and 836 elements, as shown in Figure 4. The meshing size was about 3mm to 4mm. The coordination data collected from AutoCAD was used to initiate the ANSYS model by creating "keypoints" to connect all the boundaries. Areas were then drawn with the aid of the "keypoints". The data have been processed using a personal computer version (Core-I7) to develop a more practical finite element mesh for the

Table 1: Wire size properties.

Item	Wire size inch x inch (mm x mm)	Area (mm2)
1	0.017 x 0.025 (0.4318 x 0.635)	0.27419
2	0.017 x 0.022 (0.4318 x 0.5588)	0.2413
3	0.016 x 0.025 (0.4064 x 0.635)	0.25806
4	0.016 x 0.022 (0.4064 x 0.5588)	0.2271

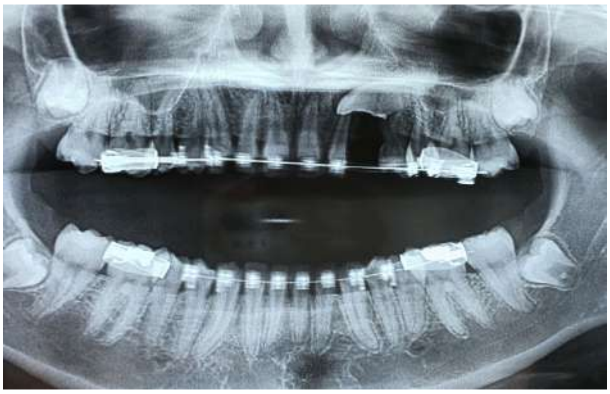

Figure 1: Panoramic radiograph of a female patient with a sectional illustration of the lower dentition used to construct the two-dimensional finite element numerical dental model.

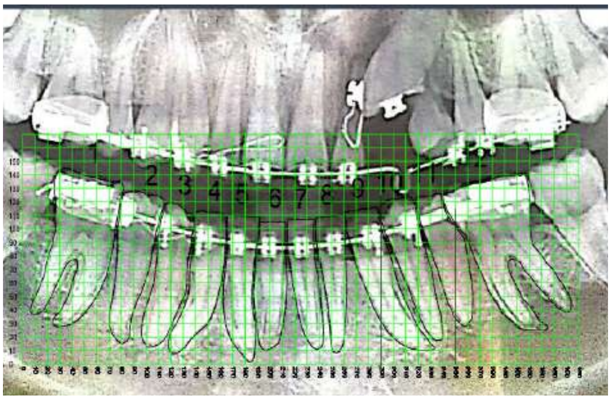

Figure 2: The Image simulation and scaling using Auto CAD program (Mesh size in mm).

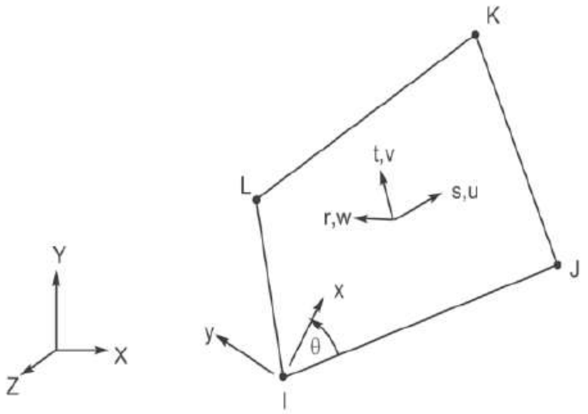

Figure 3A: The shell181 and link180 elements: 4-nodes Shell181 element.

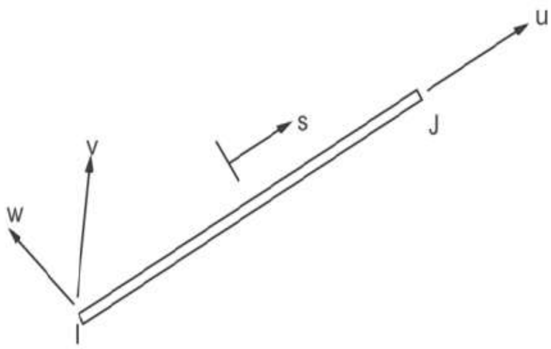

Figure 3B: The shell181 and link180 elements: 2-nodes link180 element.

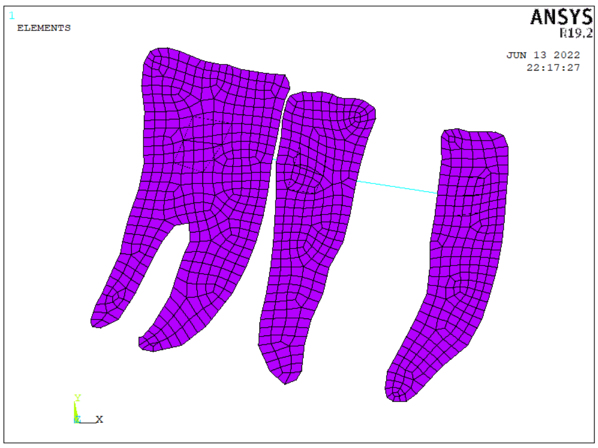

Figure 4: The finite element simulation of the three teeth.

dental model. The shell 181 element was used in meshing the areas created. Again the dimensions obtained from the AutoCAD program and the coordinates recorded were used to simulate the bracket elements added lately with the dentition for a proper analytical expression in simulating the numerical orthodontic model, as shown in Figure 4.

The ANSYS program used the stored elements in its library to create and give the boundary condition and solution options for the teeth model and analyze the orthodontic actions [12]. The connection between each bracket and wire was conducted through two nodes using the full connection method, so the archwire size was considered the same as the bracket slot when the archwire was securely connected to the bracket [13]. The boundary condition used to simulate the bone and tissue surrounding the teeth roots is shown in Figure 5. The translation in X-direction, Y-directions, and the rotation around X are constraints [11].

To verify the finite element model, a displacement in the X-direction of the sliding canine compared with the measured value obtained by the researcher by retracting the lower canine with 1.5N using 0.016 × 0.022 in steel wire and shown to be about 2.5mm in the extraction space. The numerical results of X-displacement obtained by the ANSYS model were 2.6mm with percentage differences of about 4%. The retraction forces (1.5 N) were applied to the right lower canine by using four different sizes of steel wires in the analysis, as shown in Table 1. The modulus of elasticity and Poisson's ratio used for the study are shown in Table 2 [7,14,15].

RESULTS AND DISCUSSION

The applied load on the teeth model was spread through the orthodontic archwires, then transmitted to the teeth by the brackets. The program gave the results regarding displacements and stresses in six axes by conducting the numerical analysis method and the rules of the finite element method. The overall behavior of the model can be shown by tracing the results obtained from the analysis.

The main parameter was to investigate the differences in movement (displacement of the retracted lower right canine in X and Y directions) are shown in Figures 6 and 7 and Tables 3 and 4 for the X and Y directions, respectively. The X displacement results shown in Figures 6 indicate the mesiodistal movement; in addition to the Y directions (displacement) results shown in

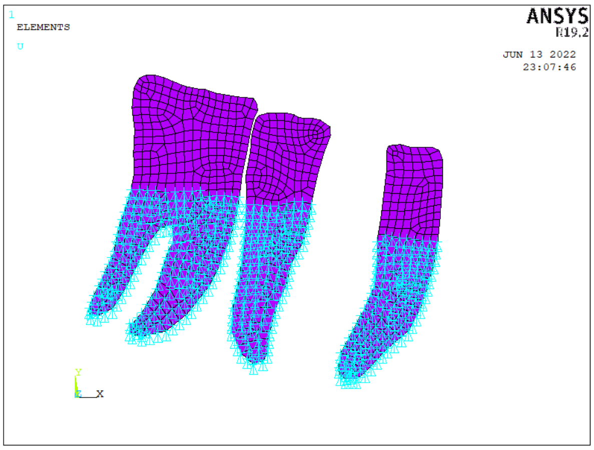

Figure 5: The finite element boundary conditions of the three teeth.

Table 2: Wire properties.

Part	Modulus of Elasticity (N/mm2)	Poisson's Ration
Teeth	18600	0.31
Steel Wire	200000	0.3
Brackets	210000	0.3

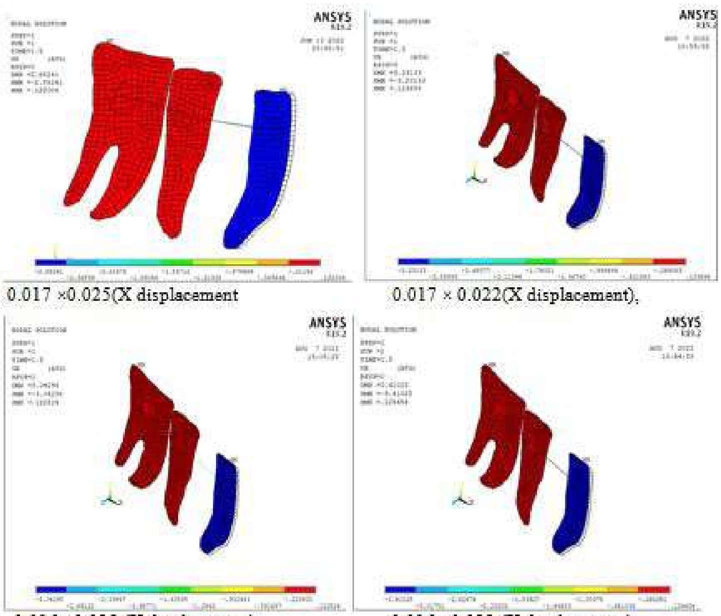

Figure 6A: Finite element X-displacement results for different wire sizes: ANSYS X-displacement results (mm).

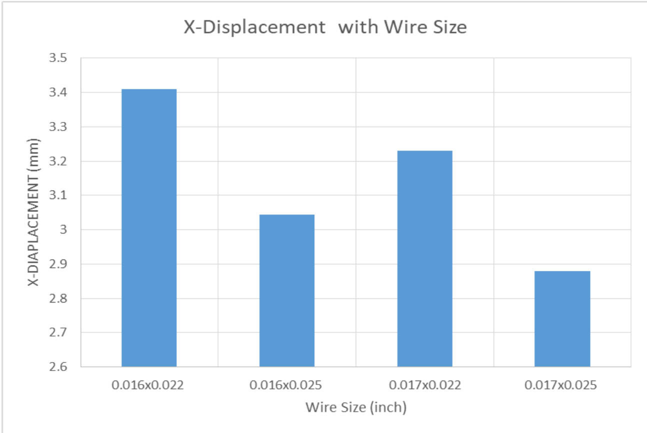

Figure 6B: Finite element X-displacement results for different wire sizes: X-displacement with wire size relation.

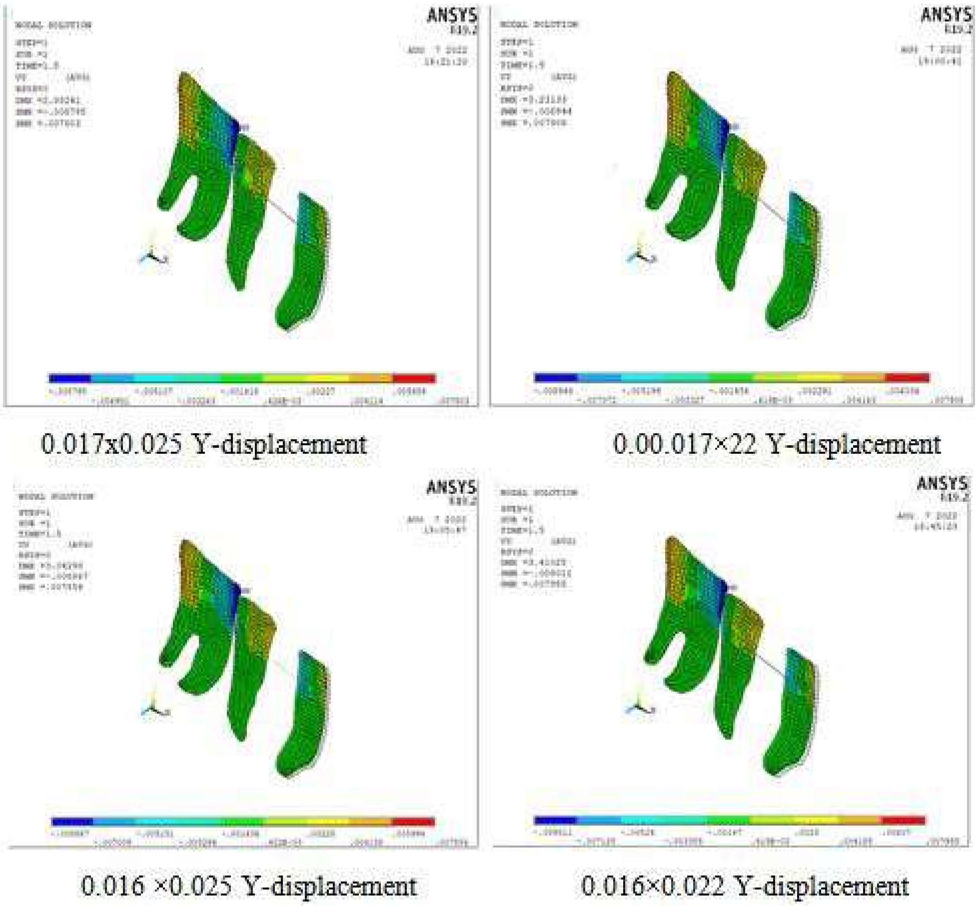

Figure 7A: Finite element Y-displacement results for different wire sizes. ANSYS' Y-displacement Results (mm).

Table 3: Displacement of the retracted canine in the X-direction.

Item	Wire size inch x inch (mm x mm)	x -Displacement (mm)
1	0.017 x 0.025 (0.4318 x 0.635)	2.882
2	0.017 x 0.022 (0.4318 x 0.5588)	3.231
3	0.016 x 0.025 (0.4064 x 0.635)	3.041
4	0.016 x 0.022 (0.4064 x 0.5588)	3.41

Table 4: Displacement of the retracted canine in the Y-direction.

Item	Wire size inch x inch (mm x mm)	Y-Displacement (mm)
1	0.017 x 0.025 (0.4318 x 0.635)	0.00879
2	0.017 x 0.022 (0.4318 x 0.5588)	0.00894
3	0.016 x 0.025 (0.4064 x 0.635)	0.00886
4	0.016 x 0.022 (0.4064 x 0.5588)	0.00901

Figures 7 indicate the occluso-alveolar direction of the sliding canine. The rotational effect on the sliding canine was also investigated by reviewing Figure 8 and Table 5, showing clearly the differences in tooth response. The results of stress distribution are shown in Figure 9 and Table 6 giving an idea about the reaction of the teeth against the applied load. The percentage differences in X-displacement, Y-displacement, and Rotations of teeth by using four types of archwires were drawn in Figure 10.

Table 6 and Figure 10 show that the X-displacement compared with wire size 0.017 × 0.025 inch was increased by 12.2% and 18.4% for wire sizes 0.017 × 0.022 inch and 0.016 × 0.022 inch, respectively. However, less displacement increase of about 5.7% gained when wire size 0.016 × 0.025 was used. It was also shown that the Y-displacements were too small and represented approximately 0.2% compared with X-displacement. However, the wire size decrease may also increase the Y-displacement amount. The use of the four types of wires causes minimal teeth rotation, as shown in Table 6 and Figure 10.

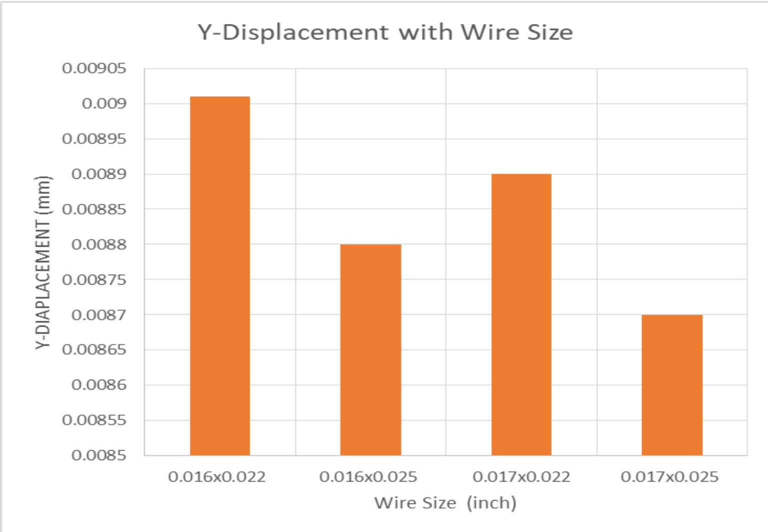

Figure 7B: Finite element Y-displacement results for different wire sizes. Y-displacement with wire size relation.

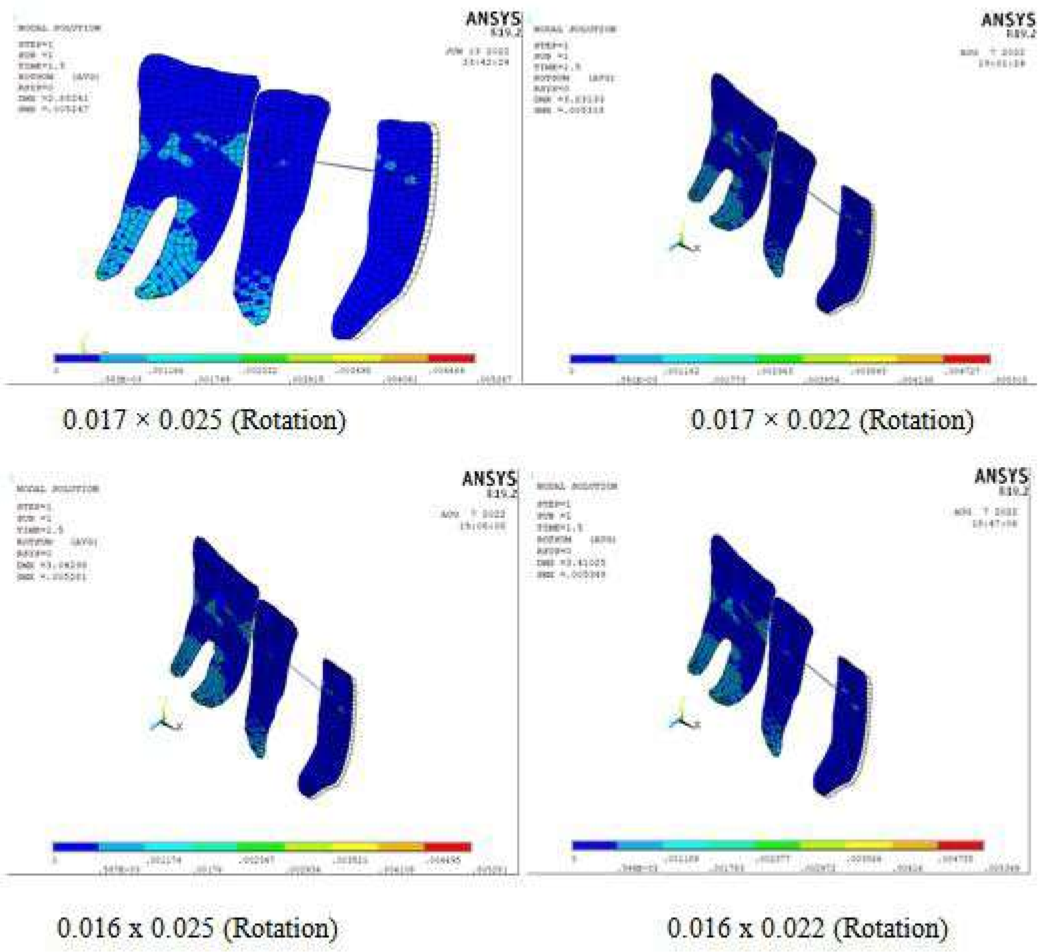

Figure 8A: Finite element rotation results for different wire sizes: ANSYS' rotation results (Degree).

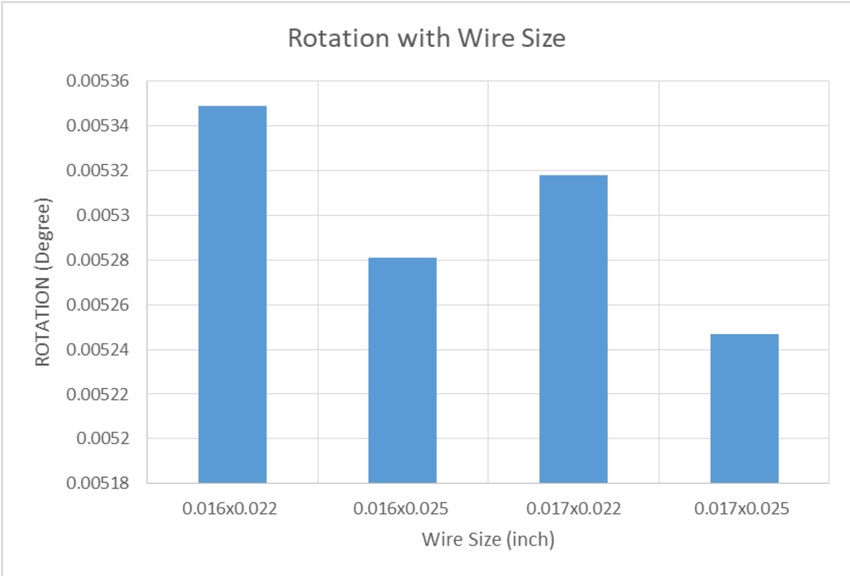

Figure 8B: Finite element rotation results for different wire sizes: Rotation with wire size relation.

Table 5: Differences in the analysis records of the retracted canine in the X-direction, Y-direction, rotational differences, and stress distribution differences.

Wire size (inch)	X-Displacement mm	X Displ. % Diff.	Y-Displacement mm	Y DISPL. % Diff.
0.017x0.025	2.88	-	0.0087	-
0.017x0.022	3.23	12.2	0.0089	2.3
0.016x0.025	3.043	5.7	0.0088	1.1
0.016x0.022	3.41	18.4	0.00901	3.6

Table 6: Rotational differences and stress distribution differences in the analysis records of the retracted canine.

Wire Size (inch)	x -Displ. mm	x -Displ. % Diff.	Y-Displ. mm	Y-Displ. % Diff.	Rotation	Rotation % Diff.	Stress MPa*10-4
0.017 x 0.025	2.88	-	0.0087	-	0.0052	-	0.223
0.017 x 0.022	3.23	12.2	0.0089	2.3	0.00532	1.4	0.223
0.016 x 0.025	3.043	5.7	0.0088	1.1	0.00528	0.6	0.223
0.016 x 0.022	3.41	18.4	0.00901	3.6	0.00535	1.9	0.223

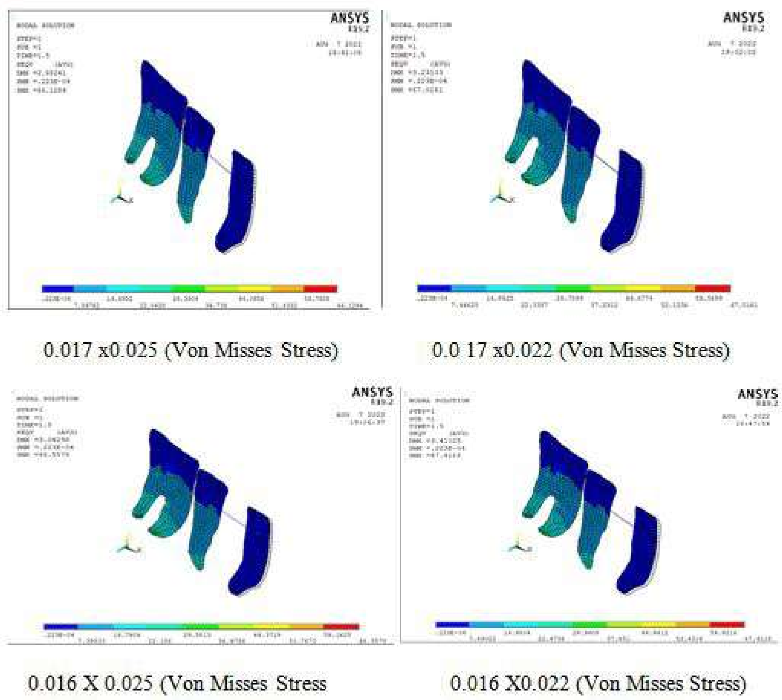

Figure 9A: Finite element canine von misses stress results with different wire size. ANSYS' von misses stress results (MPa).

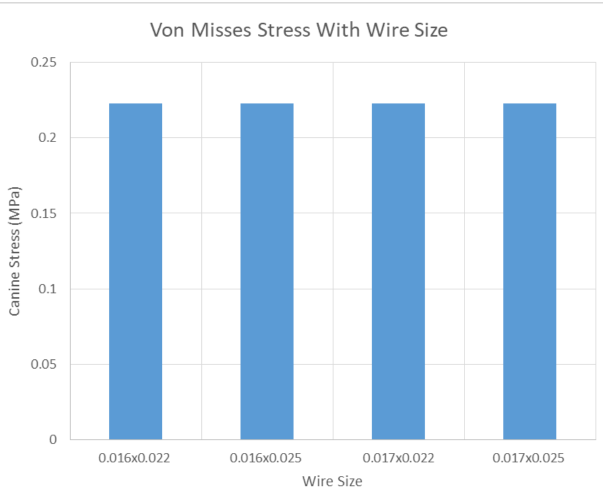

Figure 9B: Finite element canine von misses stress results with different wire size. Canine stress with wire size relation.

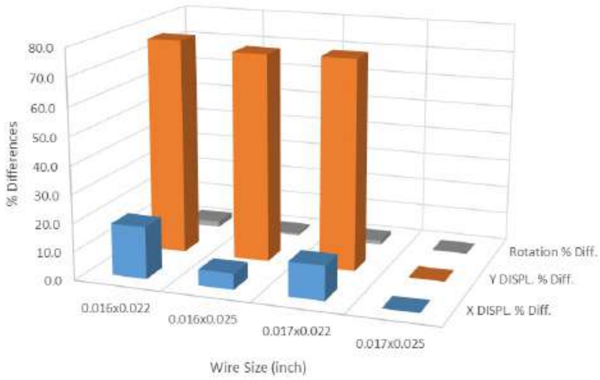

Figure 10: Differences of X-Displ., Y-Displ., and von misses stress results with different wire size.

Although, relatively high stress near the roots of the teeth was shown in Figure 9, which might be due to support resistance. The stresses obtained from finite element analysis are too small in canine for all wire sizes adopted in the study, and no fundamental differences were noticed between them.

Finite element analysis results gave a sliding of the right mandibular canine to the extracted space, which is truly represented on the X-displacement records (mesiodistal direction). It was clearly shown from the results that the X and Y displacement of the retracted canine and especially in the mesiodistal direction gives an excellent clue about the rapid canine sliding movement related to the smaller stainless steel wires, these findings comply with the results obtained by Laohahaiaroon, et al. [16]. The movement behaves slower in proportion to the increase in the wire size. That may be related to the higher elastic properties of the small-size wires, which offer great freedom for the sliding tooth and subsequent faster space closure under the effect of 1.5N applied retracted force for the different orthodontic archwires.

These results perfectly match the analysis records of Kawamura, et al. [8], even though they have made more play connections between the wire and the bracket in their dental model. While in this study, the archwire is perfectly secured as a fixed connection to the underlying bracket design of the dental model. The present study illustrates that the extrusion of the sliding canine will increase by using a small cross-section wire size. It is distinguished with the sliding on (0.016 × 0.022 inch) wire in comparison to the larger archwire sizes used in the same model analysis, which may also agree with the study of Kawamura, et al. [8].

On the other hand, neither the rotational differences nor the Von Misses stress distribution has been shown to have enormous effect on the archwire size differences. However, the distribution of Von Misses stresses also complies with results obtained by Laohahaiaroon, et al. [16]. The results show differences from those obtained by Laohahaiaroon, et al. [16] at the root of the teeth. In contrast, more stress concentration was noted when boundary conditions were used in the analysis compared with periodontal ligament (PDL) simulation.

CONCLUSIONS

The results obtained by the analysis of the orthodontic process using the Finite Element ANSYS program give a good guide for the dentist regarding the effect of different archwire sizes on the movement and rotations of the sliding tooth. Where an excellent movement was recorded for the smaller size wire (0.016 × 0.022 inch).

The stresses obtained from finite element analysis are too small in canine for all wire sizes adopted in the study, and no fundamental differences were noticed between them. The analysis results indicate that higher stress might be obvious on anchored teeth's roots with different wire sizes during the orthodontic sliding method.

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