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FINITE ELEMENT STRESS ANALYSIS OF TWO ROTARY SINGLE FILES IN DIFFERENT CANAL CURVATURES

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ABSTRACT

BACKGROUND: Proper biomechanical preparation of root canals is fundamental to successful endodontic therapy. Curved canal resulted in endodontic intricacy. Formation of step, root canal deviation, and instrument separation are the most common complications during preparation of curved root canals.

AIM OF THIS STUDY: The aim of this work is to use finite element analysis to evaluate the effect of different degrees of canal curvature on the stresses falling on two different single rotary files.

METHODS: Three finite element models were designed to simulate three canal curvatures (2°, 30°, 45°), then each of the two file systems were used to simulate the filling motion on each curvature forming six models. Group Ⅰ (Wave One Gold models) that divided into GⅠ(N), GⅠ(M), GⅠ(S) and GⅡ (One Curve) that divided into GⅡ(N), GⅡ(M), GⅡ(S)according to degree of canal curvature. Using COMSOL software 2020 to simulate the motion and the applied stress. VON MISES stress values were obtained to analyse the difference in studied groups.

RESULTS: The highest stress was 515.36 Mpa with Group ⅠS, 435.13 Mpa with Group ⅠM and 375.42 Mpa with Group ⅠN. While it was 565.17 Mpa with GⅡS, 472.87 Mpa with GⅡM and 405.71 Mpa with GⅡN. Thus, the stress generated in the group Ⅰ was lower than group Ⅱ.

CONCLUSION: Wave One Gold revealed lower Von Mises stress values than One Curve. Increased canal curvature resulted in generation of more amount of stress.

KEYWORDS: Finite elements analysis, Root curvature, Wave one gold file, One curve file

RUNNING TITLE: Finite element stress analysis in different canal curvatures

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INTRODUCTION

Successful endodontic treatment involves carefully cleaning and shaping the root canal structure, most root canals have several curves that make instrumentation very complex (1). Clinically, procedural mistakes such as the creation of ledge, canal blockage, root perforations and zipping are the unintended mishaps that can happen when curved canals are being prepared (2).

Understanding internal root anatomy is necessary for root canal treatment to be successful. Appropriate focus was placed on radiographic evaluation that aided in navigating the canal shape and root curvature (3). Schneider's method is used to measure the curvature of root canals, and the outcomes are categorised into three groups: straight root canals (0–10 degrees of curvature), moderately curved root canals (10–30 degrees of curvature), and severely curved root canals (more than 30 degrees of curvature) (4).

Torsional overload or fatigue from flexure can cause rotary instruments to fracture (5). A torsional fracture happens while the instrument's tip or another component binds to the canal walls as the handpiece keeps rotating. The instrument will inevitably break when this binding takes place and the metal's elastic limit is exceeded (6).

Rotary Ni-Ti instruments made root canal therapy easier. However, they are able to impair the tooth's structure, especially in canals that are curved. One of the main issues is the use of rotary Ni-Ti devices to straighten curved root canals, which can result in ledge formation, file fractures, and even perforation during the root canal preparation process (7,8).

Lately, manufacturers have produced a new generation of Ni-Ti rotary instruments with a variable cross-sectional design and various working movement that makes canal preparation by only one tool (9). Single-file technique was developed to improve instrumentation procedure, by decreasing stresses and prevent cross-contamination. However, root canal shaping by only one file exposes it to a great deal of torsional and flexural stresses. Each file is not subjected to additional strains because it is not utilised for additional canals and does not need to be thermally sterilised in an autoclave (10,11).

In order to prepare root canals, reciprocating single file systems like Wave One Gold (Dentsply Sirona) use reciprocating movement. It poses reversed taper, varying helix angle and a non-active edge. Wave One comes in a variety of tip sizes and tapers, including 20/0.06, 25/0.08, and 40/0.08, and is used with 170° anticlockwise rotation (the direction of cutting) and 50° clockwise rotations at a speed of 300 rpm (12).
One curve file, a different single file system, is utilised in a conventional continuous rotating movement at a speed of 300 rpm and torque of 2.5 N.cm direct downward movement to the working length. It is manufactured by Micro-Mega, Besancon Cedex, France (13).

Finite Element Analysis (FEA) has revolutionized dentistry (14). Any given physical phenomena could be simulated utilising the Finite Element Method (FEM), a numerical technique that divides an object's structure into small parts called elements and then reconnects the elements at nodes. From there, the FEM applies partial differential equations (PDEs) to each element, which then used to generate comprehensive predictions of the object's behaviour (15).

Finite element analysis is being used more and more in endodontics to assess fracture resistance, stress distribution characteristic in the root canal structure and surrounded dentin, and to model and assess the biomechanical behaviours of teeth, root canal systems, and obturation materials (16).

In order to better understand the single role of canal curvature in stress generation, the current research has begun to isolate the canal curvature as a single factor and investigate its effect on the amount of stress produced on the files, given the potentials of FEA and the significance of canal curvature in endodontics.

The aim of this work is to use finite element analysis to evaluate the effect of different degrees of canal curvature on the stresses falling on two different single rotary files.
Null hypothesis: No changes of stress values were recorded by the two rotary single files with different canal curvatures.

MATERIAL AND METHOD

The present in vitro study was piloted in the department of endodontics in the Faculty of Dentistry at Alexandria University and approved by the Research Ethics Committee. The approval code of this study is (Ethics code number: 950-8/2024-IORG 0008839).

Schneider's classification of root canal curvature has been considered to develop 3D root models with different degrees of canal curvatures. Three experimental models were designed in SolidWorks using Sketcher and Part Design modules having 2°, 30°, and 45° of canal angulations, representing straight, moderate, and severely curved canals. The radius of curvature was kept constant at 4 mm for all the designed models, the root canal orifice dimension was considered to be 0.30 mm and the 3D finite model was constructed for a root length of 14 mm. (Figures 1-3), then layer of cementum covering the root was neglected and the wall of the root was assumed to be dentin only. The elastic modulus of dentin which is 2.00×10^4 N/mm^2 and poisson's ratio which is 0.310 used to set up finite element analysis models (17).

Cross-sectional shape of the two file systems (Wave One Gold, One Curve)were recorded using digital caliper device and commercial file information like tapering of the files and the pitch. The computerized creation of the file model was accomplished at the convergence of two distinct geometries. The former was the raw material, whereas the latter was the machined. Presuming the rotary file was manufactured using NiTi alloy, the Young's modulus is 36GPa and Poisson's ratio is 0.3. The critical stress at the beginning of the forward phase transformation was 504 MPa and at the end of the recoverable strain was 755 MPa. (Figures 4,5).

After preparing all required designs for stress analysis, a two groups according to file system were obtained either group I wave One Gold or group II One Curve, so that in each group there were three designs according to canal curvature degrees (2° =N), (30° =M) and (45° =S), each design containing the tooth with a degree of curvature and inside it the file on which the effect of curvature was to be measured, group Ⅰ (Ⅰ N, Ⅰ M, Ⅰ S) group and Ⅱ (Ⅱ N, Ⅱ M , Ⅱ S).

The finite element models were designed using the SolidWorks software package 2020 and COMSOL Server 2020. Mesh generation is the process of splitting the analytic continuum into several distinct or finite components. The file was placed inside the root canal. The virtual rotation had a torque of 2.0 Nm and a speed of 250 rpm at all the curvatures. Simulation was performed once in each canal. The final model subjected to analysis is discretized into 337,064 nodes and 242,835 elements.

Boundary conditions were used to measure the stress applied on One Curve and Wave One Gold files in different root canal curvatures 2°, 3° and 45°. Then the experiment was done and Von Mises stress values were noted. Colour map was used to describe the values as red colour revealed the maximum stress values and the blue colour revealed the minimum stress values.

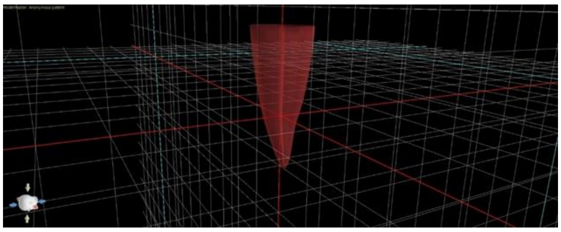

Figure 1: Model of root with 2° curvature

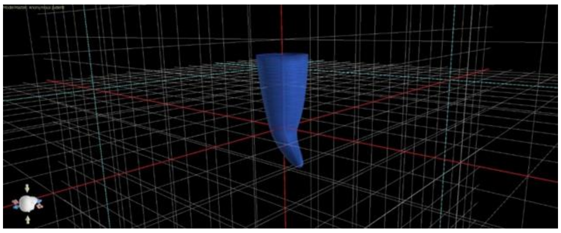

Figure 2: Model of root with 30° curvature

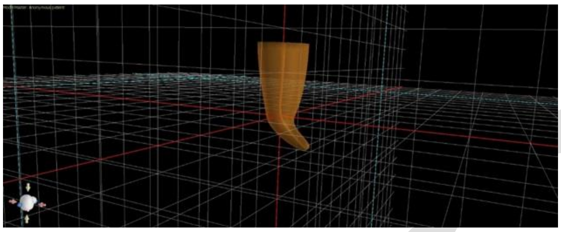

Figure 3: Model of root with 45° curvature

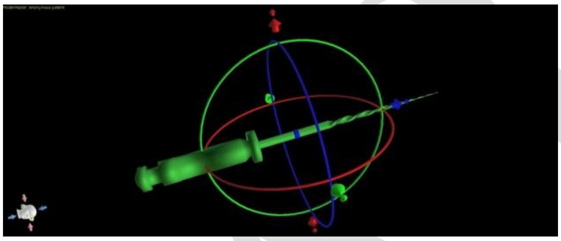

Figure 4: Three-dimensional (3D) finite element model of rotary file Wave one gold file.

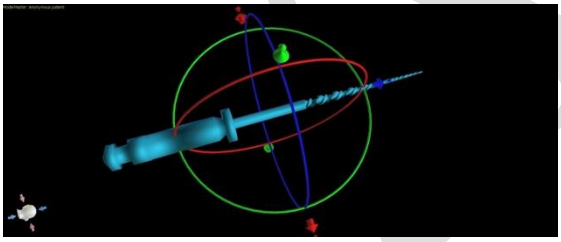

Figure 5: Three-dimensional (3D) finite element model of rotary file One curve file.

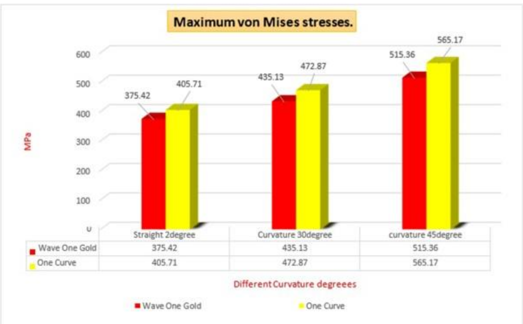

Figure 6: Maximum von Mises stresses.

RESULTS

In the present analysis, the least stress values observed within GROUP Ⅰ than group Ⅱ at the three different degrees (N, M, and S) that exhibited 375.42 MPa at group Ⅰ N and 405.71 MPa at group Ⅱ N, 435.13 MPa at group Ⅰ M and 472.87 MPa at group Ⅱ M, and 515.36 MPa at group Ⅰ S and 565.17 MPa at group Ⅱ S . As displayed in figure 6.

DISCUSSION

Numerous factors, including the handling technique, the manner of usage, and the complexity of the root canal architecture, might cause stress on the file during root canal instrumentation, which could result in fracture (18). According to certain reports, the fracture incidence among NiTi rotary files ranges from 1.04% to 13.54% (19). Work hardening of the alloy due to repetitive extension and compression of an instrument inside a curved canal can result in cyclic fatigue and an elevated chance of fracture (20).

Finite element (FE) models have been used to mimic the process of assessing the stresses imposed by root curvatures on Niti files to identify, evaluate, and address possible structural or performance problems (21), FEA approach simulates a structure with loads and boundaries in a virtual setting (22).

There is a list of notable software packages that implement the finite element method for solving partial differential equations. The present study used COMSOL software as it known by its exceptional ability in multi-physics simulations, making it a favourite in academia and research, it provides a flexible environment for modelling and meshing, especially beneficial for complex geometries. COMSOL has a comprehensive library of material properties, beneficial for diverse simulations (23,24).

The parallelogram cross section of Wave One Gold versus One Curve, which has an S-section closer to its shank and a triple-helix portion towards its tip, explains why Wave One Gold showed less stress than One Curve. An innovative off-centred cross-section, where only one cutting edge touches the wall—reduces the screw's force while also increasing the amount of space needed to remove debris. By reducing the instrument's contacts with the tooth's canal wall (25), which is confirmed by Webber J et.al. Who stated that off centered parallelogram-shaped cross-sectional design augments its torsional resistance (26).

Wave one gold showed less stress values than One Curve demonstrating that the reciprocating file structure has a higher cyclic fatigue tolerance than the rotating motion file system. Reciprocating motion improves endodontic files' resilience to cyclic fatigue, reducing the likelihood of instrument breakage within the root canal, and enables improved debris removal compared to continuous rotation (27). Which verified with Berutti et al. who showed that preparation systems with reciprocating motion outperform those with rotating motion (28).

Among the studied groups an increase in canal curvature resulted in higher stress values along the instruments. This result is explained that any point of a rotating file inside a curved root canal experienced continuous compressive and tensile stresses and strains (29).

Those findings rejecting the null hypothesis, thus there was difference in stress values between the two-file systems in addition to there was an increase in stress values as the angulation of curvature increased.

Even though the study's virtual simulation of the geometry and mechanical characteristics of endodontic files and root canals was accurate, it does not replicate the real clinical environment. As a result, accessibility during the filing of natural dentinal walls in various canal configurations influences the stresses and strains created, potentially requiring additional processing.

CONCLUSION

Wave One Gold (Dentsply Maillefer) revealed lower Von Mises stress values with different canal curvatures than One Curve (Micro-Mega, Besancon Cedex, France). During biomechanical preparation, increased canal curvature has definitely resulted in the generation of a greater amount of stress.

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