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STRESS ANALYSIS IN ROOT DENTINE USING THE SINGLE CONE VERSUS THE CONTINUOUS WAVE OBTURATION TECHNIQUE: A FINITE ELEMENT STUDY

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ABSTRACT

Introduction: The maximum stress distribution in radicular dentin was assessed during root canal obturation while using the continuous wave compaction (CWC) and single cone (SC) techniques. Limited information regarding the stresses induced on root dentine during employing the SC technique is currently present in the literature.

Materials and Methods: Two different root canal obturation techniques; the CWC and the SC obturation technique were simulated. Mathematical analysis of the stress distribution patterns and maximum von Mises (VM) stresses after load application to all tooth models were assessed at one, five millimeters from the root apices, at the apex and at the orifice by finite element analysis (FEA) using the Cosmos software package (Solid works, Dassault Systems, Cedex, France).

Results: In stage one of the CWC the maximum stresses were expressed at the apex (6.3 MPa), while in the second stage the maximum stresses were at the orifice (29.3 MPa). In the SC technique, the maximum stresses were at the orifice (27.2 MPa).

Conclusion: Gentle forces should be employed during compaction in the first stage of the CWC technique, due to the greater force concentration at the apex. The stresses generated during obturation in both the CWC and SC techniques are less than that required to fracture root dentine.

KEYWORDS: Single cone obturation, Continuous wave obturation, Finite element study, root stresses

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INTRODUCTION

Endodontic treatment procedures result in weakened dentinal walls that in time may give rise to root fractures (1). Rotary files can result in fine cracks in the root canal walls during instrumentation (2,3), which when coupled by obturation forces may result in tooth fractures (4). Stress distribution in radicular dentin during root canal obturation is believed to vary according to the obturation technique employed (5). Nowadays, both the warm vertical and lateral compaction techniques are regularly utilized, with the former being more frequently employed in favor of its superior adaptation. Both compaction techniques create stresses in the root during obturation, however the warm vertical compaction was postulated to create greater stresses compared to the lateral compaction(6). Vertical root fractures can occur in radicular dentin under masticatory loads due to the excessive pressure employed during obturation (7). Recently, the single cone obturation technique with the use of bioceramic sealers has been advocated as a readily used method for obturation. Limited information regarding the stresses induced on root dentine during employing the single cone obturation technique is present (8,9). Finite element analysis (FEA) is an engineering method for the mathematical assessment of complex structures based on their material properties to determine the stress distribution when the structure is subjected to force. Studies investigating the stresses falling on the teeth during and after using the single cone obturation technique with bioceramic sealer compared to the vertical and lateral obturation techniques is scarce. Hence, the present study was conducted to assess the stress distribution during obturation with the single cone and continuous wave obturation techniques by using a finite element analysis model (10).

MATERIALS AND METHODS

In the current study, the stress distribution in the root of a 3D mathematical model simulating a maxillary second premolar tooth was assessed using Solidworks software (Dassault Systems, Cedex, France) a structural analysis program. The solidworks software simulated two different root canal obturation techniques; the continuous wave compaction technique and the single cone obturation technique.

Plugger force measurement for compaction during obturation:

For measurement of the index finger and plugger pressure during obturation, ten endodontists with a minimum of ten years of clinical experience and of ages ranging from thirty-five to forty years of age were tested to measure the index finger force. Each of the ten endodontists was sitting in an upright position with the elbow flexed ninety degrees. The index finger of the endodontist was placed on the head of a size 50 (0.5mm) hand plugger (S Condenser Sybron endo, California, USA) and the plugger tip was then placed on a pinch gauge (Fabrication Enterprises, New York, USA), and an examiner was standing in front of the endodontist to stabilize the pinch gauge. The endodontist then applied pressure on the gauge. The force measurement for each endodontist consisted of three pinch tests with rest in between. The examiner then recorded each test and recorded the average of the series. The mean force reading in pounds of the ten endodontists was recorded (2.7 pounds) to obtain the mean force which was 12 Newtons (N).

Model generation:

An intact sound human maxillary second premolar tooth with a single canal, without any cracks, resorption, caries, calcifications or fillings was scanned using a high-resolution cone beam computed tomography (CBCT) (Cranex 3D, Soredex, Helsinki, Finland). The CBCT was with a current of 10mA, voltage of 90kvp, field of view of 5cmx5cm and a voxel resolution of 0.085mm generating 668 images that were saved in a Digital Imaging and Communications in Medicine (DICOM) format. The MIMICS software 19.0 (Materialise, Leuven, Belgium) then extracted the preliminary 3D models of enamel, dentine, and pulp space from the CBCT images by forming masks and automatically growing threshold regions. The data was enhanced using a 3-Matic Medical 11.0 (x64) software (Materialise NV) . The software SolidWorks combined enamel and dentin, but the cementum layer was neglected, assuming that the hard tissue of the root is only dentine. The surrounding periodontal ligaments were modeled starting 1.5 mm apical to the cemento-enamel junction with a uniform thickness of 200μm.

Simulation of access cavity design and root canal preparation:

After the solid model was created (Fig. 1a), the simulated access cavity was designed by removal of the entire roof of the pulp chamber to create a straight-line from the root canal orifice to the access opening (Fig. 1b). Virtual root canal preparation was simulated by projecting a line through the central axis of the root canal, then creating a conical shape around it with the simulated root canal size #30 and 0.06 taper (Fig. 1c). The volumes of the root canals after root canal preparation were 16.43 mm^3 .

Root canal filling:

To simulate the two designated root canal obturation techniques, three experimental models were created by the Solidworks software. Two models for the continuous wave technique (as it is a two-step technique) and one model for the single cone obturation technique.

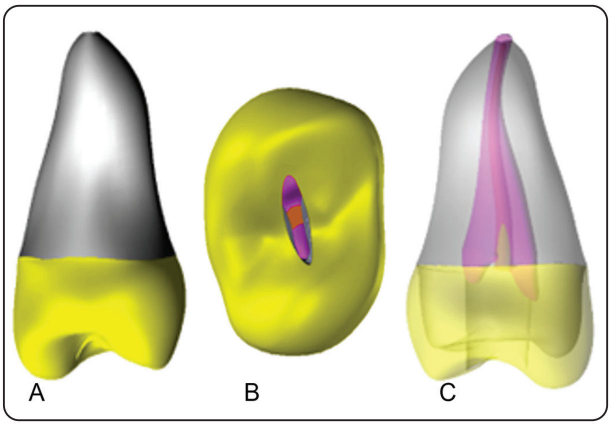

Fig. (1) Showing (a) solid model (b) simulated access cavity (c) Virtual canal preparation

1. Continuous wave compaction technique:

Stage one of continuous wave compaction technique:

In the first stage of the continuous wave compaction model, after removing the volume created by canal preparation, a gutta-percha model filled the empty canal volume up to 5mm from the apex (Fig. 2a). The temperature of this gutta percha model was calculated to be 55°C. Then a plugger with 0.5mm diameter was applied to this gutta percha model to virtually compact it with a force equivalent to 12N (Fig. 2b).

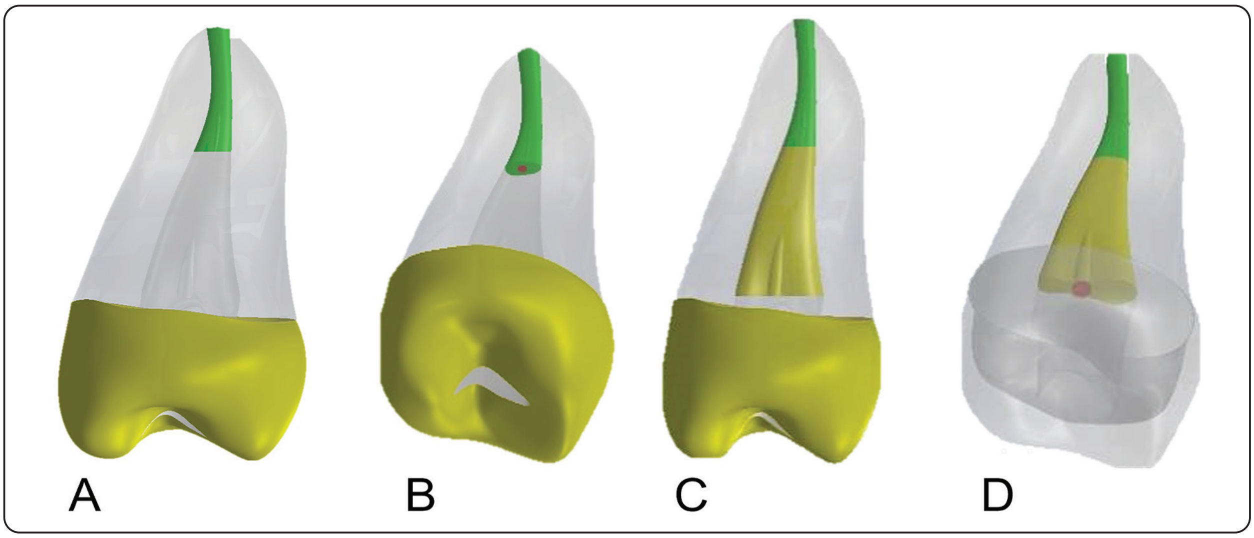

Fig. (2) Showing the two steps of the continuous wave obturation technique

Stage two of continuous wave compaction technique:

In stage two of the continuous wave compaction model, the gutta percha was assumed to reach temperature equilibrium with the rest of the tooth. The remaining coronal two-thirds of the canal volume was filled with gutta percha heated at 55ºC (Fig.2c), then a 1mm plugger was used to compact the hot gutta percha at the canal orifice at 12N as a final step (Fig. 2d).

2. Single cone technique:

For the single cone modeling, gutta-percha filled the whole root canal(Fig. 3a), and only the upper face of the gutta percha had the temperature of 55ºC to simulate the searing by a heated plugger at the orifice (Fig. 3b). A 1mm plugger was then used to compact the hot gutta-percha at the orifice at a force of 12N (Fig. 3c).

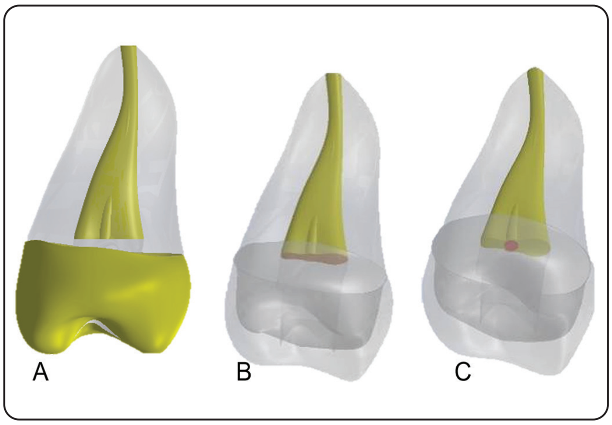

Fig. (3) Showing the Single cone obturation steps

Meshing and set material properties :

All models were imported into Cosmos software package (Solid works software package, Dassault Systems, Cedex, France) for meshing (Fig. 5). This resulted in an element size range from 0.2135 - 1.0674 mm according to the complexity of the models. Teeth, as well as all materials used, were considered homogeneous, linear, and isotropic. Mechanical and thermal properties of different materials used to set up the FEA models are listed in Table 1.

TABLE (1) Mechanical and thermal properties of different materials used to set up the FEA models

Material/ structure	**Modulus of elasticity (MPa)**	**Poisson's Ratio (ц)**	**Thermal expansion coefficient (10^{-6} / ºC)**
Enamel (11)	84100	0.33 (99-102)	11.4
Dentin (12)	18600	0.31 (104-106)	8.3
Gutta-percha (13)	292	0.45 (108)	494

Mathematical analysis of the stress distribution patterns and maximum von Mises (VM) stresses after load application "both thermal expansion and force" to all models was assessed at one, five millimeters from the root apices, at the apex and at the orifice by FEA using the Cosmos software package.

RESULTS

During the simulation of the different obturation techniques, by modelling different force magnitudes and at a temperature of 55ºC, the maximum von Mises stresses in each model was recorded.

Stage one of continuous wave compaction technique:

Colour schemes representing areas of stress distribution for stage one of the continuous wave compaction technique, are displayed in figure 4. At 1 mm from the root apex, the areas of maximum Von Mises stresses were roughly 0.3 MPa (fig. 4a), however at a 5 mm distance from the root apex the greatest stresses were nearly 3 MPa (fig. 4b). No stresses were observed at the canal orifice level during stage one (Fig. 4c). Nevertheless, the magnitude of the maximum Von Mises stresses in the longitudinal section of the root, was expressed at the apex and was around 6.3 MPa (Fig.4d).

Stage two of continuous wave compaction technique:

In stage two of the continuous wave compaction; the area of maximum stresses at 1 mm from the root apex, was 0.3 MPa (Fig. 4e); and at 5 mm form the root apex maximum stress concentration was nearly 1Mpa (Fig. 4f). The magnitude of the Von Mises stresses observed was highest at the canal orifice level, which was around 29.3 MPa (Fig. 4h).

Single cone technique:

The colour schemes representing areas of stress distribution during the simulation of the single cone technique, are displayed in figure 5. The point of greatest stress at 1 mm from the root apex was around 0.2 MPa (Fig.5a). While, at 5 mm from the root apex, the highest stress reached was approximately 1 MPa (Fig. 5b). At the orifice level, the maximum von Mises stress was approximately 27.2 MPa (Fig. 5c, d), stresses in the longitudinal section of the root at the exact apex was around 0.5 MPa.

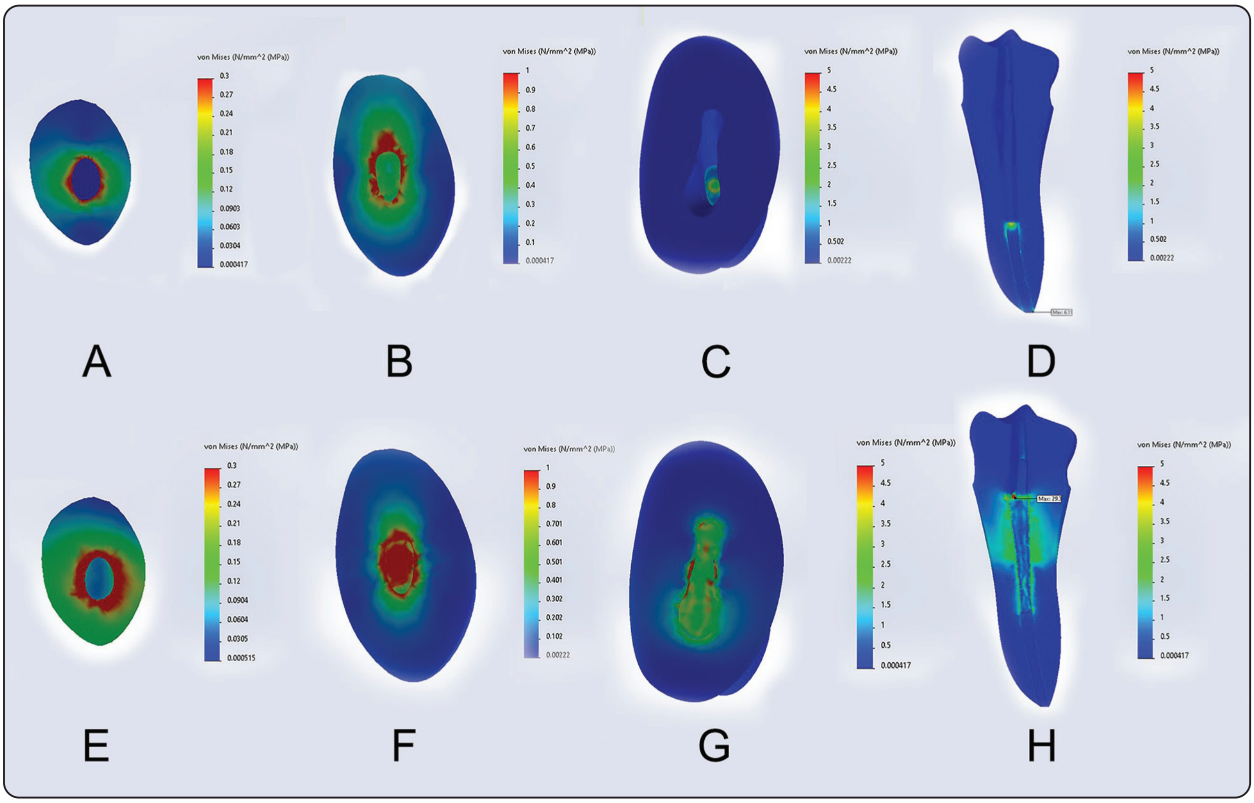

Fig. (4) Von Mises stress distribution in stage one of the continuous wave compaction model in root sections at (a) 1mm, (b) 5mm, and (c) at the canal orifice; (d) longitudinal section displaying areas of maximum stress. Stress distribution in stage two of the continuous wave compaction model in root sections at (e) 1mm; (f) 5mm; (g) at the canal orifice; and & (h) longitudinal section displaying areas of maximum stress.

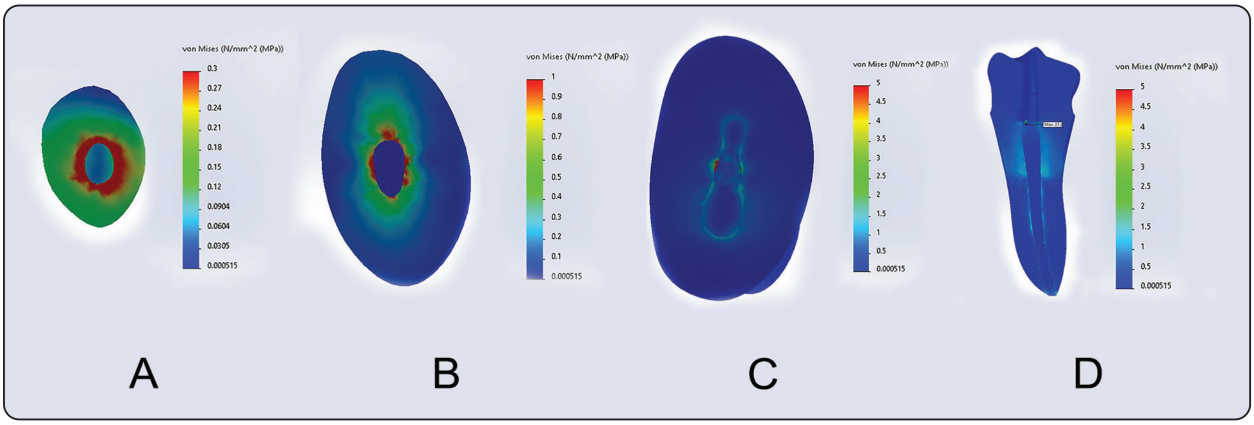

Fig. (5) Von Mises stress distribution in the single cone model in root sections at (a) 1mm; (b) 5mm; (c) at the canal orifice; and (d) a longitudinal section showing areas of maximum stress concentration

DISCUSSION

Root fractures and microcracks of endodontically treated teeth arising from transferred stresses during mastication can result from various reasons including over enlargement of the root canal preparation, excessive force application during obturation, and failure to protect the tooth with satisfactory cuspal coverage restorations(14). Assessment of stress distribution in teeth is more accurate when using the finite element analysis (FEA) as compared to in vitro studies. This is due to the more standardized, qualitative and uniform data, which can be presented then deduced from the FEA (15). Thus FEA was used in the current study to assess the stress distribution during obturation rather than applying an in vitro test. A maxillary second premolar tooth was chosen to fabricate the model because maxillary premolars show a high incidence of fractures(16). Obturation with the continuous wave compaction (CWC) technique results in stresses within the root canal(17). In a recent study micro cracks were found to occur in the root dentine when using the CWC technique, however no cracks were found when the single cone (SC) technique was used (18). Thus the aim of the present study was to evaluate the amount of transferred stresses in root dentine when using the CWC and SC obturation techniques by simulation with the FEA in a maxillary second premolar tooth model. The plugger compaction force in other studies was simulated at 15N (19) based on a study done by Wilcox etal (20). However in the previous study the compaction force measurement was done on the lateral compaction technique and not the CWC. Thus in the current study the plugger compaction force (12N) measurement was done using a pinche gauge so that the compaction force would be as close as possible to that performed in the patient's mouth. The highest stresses generated in the root model were measured at 1mm, 5mm from the apex and at the orifice.. In stage one of the CWC the highest stress was found at the apex (6.3MPa) which was greater than the 5mm level (3MPa). This means that greater stresses are concentrated at the root apex during compaction of the gutta percha as compared to the 5mm root level where the actual compaction is being done in stage one of the obturation. Silver etal and Rundquist etal also found that stresses are greater at the apex in the first stage of CWC (21, 22). In stage two of the CWC the highest stress was at the orifice (29.3 MPa). Thus in the CWC the highest stresses during obturation can be found coronally at the orifice level rather than apically, which was also found in another study evaluating the root stresses during obturation(23). In the SC model the highest stresses were also found at the orifice level (27.2MPa), however the stresses at the exact apex were higher in the CWC as compared to the SC technique. These recorded maximum stresses in both obturation techniques are less from the amount of stresses required to fracture root dentine (24).

CONCLUSIONS

1. Gentle forces should be employed with the plugger during compaction of the gutta percha in the first stage of the CWC technique, due to the greater force concentration at the apex.
2. The greatest stresses generated during obturation in both the CWC and SC techniques are less than the stresses required to fracture root dentine.

Conflict of Interest:

The authors deny any conflict of interest.

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