THERMAL & STRESS ANALYSIS OF GUTTA PERCHA IN SIMULATED ROOT CANAL USING FINITE ELEMENT ANALYSIS

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ABSTRACT

Endodontic Obturator tips are used by dental surgeons extensively as Heated Cutter tips for treating root canal and other obturation procedures. Biocompatible Cutter design involves challenges of both structural and thermal loads in the vicinity of the root canal area. Natural Gutta Percha (GP) is very similar to natural rubber, which is mainly used as filler material to seal off the prepared root canal cavity against bacterial infections. The cutter is being used to heat, soften, condense and cut off the excess GP from the apical region of tooth crown with ease. The GP Cutter Tip geometry is selected initially based on ideal root canal geometry available. In the present paper thermal model for the heat conduction behavior in GP is formed. The depth in GP Cutter tip upto which the thermal effects are observed is outlined using a FEA tool as ANSYS10.0, which gives the temperature profile, thermal flux & thermal gradient. FEA is a proven cost saving tool and can reduce design cycle time therefore it can be used as accurate tool to investigate thermal profile in GP and the effects of heat at the interface of GP & dentine.

KEYWORDS: Endodontic; Obturation; Biocompatible; Gutta Percha; FEA

INTRODUCTION

Obturation is complete filling & sealing off root canal cavity against bacterial infection, thus to save tooth like natural one. So there are chances of re-treatments even after obturation is carried out. Gutta Percha (GP) is a natural isoprene polymer extracted from the resin and sap of the trees of the Palaquium family, which grow mainly in south-east Asia. Natural GP is very similar to natural rubber, it is mainly used as filler material to seal off the prepared root canal cavity against bacterial infections. The cutter is being used to heat, soften, condense and cut off the excess GP from the apical region of tooth crown with ease.

The objective of this paper is to perform the thermal analysis GP which is used as filler material in root canal cavity for different configurations of the obturator tip so as to increase the effectiveness of the root canal obturation. Also to ensure safety against excessive heating of GP during root canal obturation phase. Mathematical model for temperature pattern of GP in a simulated tapered root canal, during heat cycle application in obturation is formed. Also the thermal analysis is carried out using FEA and results are verified using ANSYS10.0. Stress & deflection analysis of root canal idealized cavity filled with GP was carried out for given compaction load of 15 N using ANSYS 10.0.

FEA is a proven cost saving tool and can reduce design cycle time therefore it can be used as accurate tool to investigate thermal profile in GP and the effects of heat at the interface of GP & dentine.
The GP Cutter Tip geometry is modeled based on an idealized root canal assumed for a typical molar tooth. The cutter tip is heated to 200°C for 3 to 5 seconds and is left to natural cooling during usage on the cavity. Here it cools down after transferring the heat to the GP. Heat is continuously supplied to the GP tip by a suitable mechanism. Further based on this analysis the data were used to make design decisions. The results obtained from FEA helps designers to take decisions on the design safety and also to optimize it by analyzing the design for available different materials. It saves time and also simplify complexity involved in analysis of element i.e. simulated root canal with GP filled in & biomedical device is used to soften this GP with application of heat to it’s tip. FEA also helps us to analyze and better understand various critical sections along the length of GP.

LITERATURE SURVEY

GP encyclopedia[^1], where GP is meant to be essentially a dried, coagulated sap of a peculiar species of tropical plants. This sap was first obtained from sapotaceae family of trees, which are abundant in the Malay peninsula (south east asia). The name “gutta percha” comes from the plant’s name in Malay- getah perca, meaning “percha sap”. Most of the plants yielding gutta percha belong to the natural order of sapotaceae, the most important being Dichopsis Gutta or Isonandra Gutta, also known as Palaquium Gutta. Endodontists in the past were constantly in search for an inert, biocompatible material with optimal sealing properties to be used as filling during root canal therapy. Gutta Percha was extensively researched upon for usage in endodontics, after which it has been used successfully as root canal obturating material.

American Association of Endodontic[^2],[^3] (2009), have shown that the endodontic treatment success is dependent both on the quality of the obturation and the final restoration. The quality of the endodontic obturation is usually evaluated using radiographic images upon completion. Additionally, during the root canal preparation and obturation phases of treatment, clinical criteria can be identified that are essential for achieving an adequate root canal obturation. Proper canal preparation before its obturation, provides an apical resistance form for the adequate adaptation of filling materials and the prevention of excessive apical extrusion of these materials.

Cláudio Maniglia-Ferreira, Eduardo Gurgel-Filho & Monteiro de Paul[^4], (2006) have studied transformations of GP. Two distinct interchangeable crystalline phases exist in chemically pure gutta percha, namely “alpha” and “beta”. Natural gutta percha is in alpha form, whereas commercially available gutta percha is generally in beta form. Dental gutta percha usually exists in beta semi crystalline phase. Gutta percha exhibits two crystalline transformations when heated from room temperature to 100°C. These transformations Beta to alpha: occurs between 42°C to 49°C (this phase transformation is reversible) & Alpha to amorphous occurs between 53°C to 59°C

Mário Tanomaru-Filho, et al[^5] (2006), in their preliminary studies showed that the force required to provide a significant increase in the diameter of heated gutta-percha specimens should be greater than 3 kg. Further research is required to increase the accuracy and standardisation of the analysis of the thermoplastic properties of guttapercha and similar root canal filling materials. Few studies have focused on the differences between commercially available brands of guttapercha, no specific methodology for testing the thermoplasticity of gutta-percha has been described.

Maniglia-Ferreira C, et.al[^6] (2007), have observed that in endodontic therapy, dental gutta-percha is plasticized by a heat carrier or by thermomechanical compaction, which if used improperly may cause partial decomposition if the heat generated exceeds 100°C, according to the Merck index. Root canal filling techniques must use temperature control (between 53°C and 59°C) permitting the β-phase gutta-percha to change into the α-phase, avoiding the gutta-percha
amorphous phase. gutta-percha in the $\beta$-phase begins the $\alpha$-phase change when heat reaches the temperature range of 48.6°C to 55.7°C, and that the $\alpha$-phase material changes to the amorphous phase when heated between 60°C and 62°C. The heat source must be carefully used and the condenser should be heated only for a few seconds before condensing and cutting the obturation material; if overheated, periodontal damages might occur. Heating dental gutta-percha to 130°C causes physical changes or degradation.

Maurizio Ferrante, Paolo Trentini, Fausto Croce, Morena Petrini, Giuseppe Spoto\textsuperscript{[7]} (2010), studied the thermal behavior of GP that heating up to 130°C causes chemical-physical changes of the gutta-percha; this is due to the presence of additives (70–80%), which alter the behaviour of the material. For this reason, the dimensional stability of the filling materials is not guaranteed. The mass loss in gutta-percha polymer could make the cone material more porous and could reduce its root-canal sealing property.

Zhou X, Chen Y, et.al\textsuperscript{[8]} ( 2010), have demonstrated that the apical thirds of canals were obturated by continuous-wave condensation technique, with 3 seconds and 4 seconds of activation time. The remainder was backfilled with injected gutta-percha in 2 segments (Obtura II)

The highest temperatures on the periodontal ligament reached 46.914°C and 48.887°C, in the “dangerous zone” between the root canals, when activation times were 3 seconds and 4 seconds, respectively.

The greatest temperature rise within the apical gutta-percha was only 0.859°C. The apical gutta-percha temperature was always below the desired level to achieve proper thermoplasticity.

Er O, Yaman SD, Hasan M\textsuperscript{[9]} (2007), have shown that the temperature distribution can be determined by using a three-dimensional finite element analysis. Heat applications of 200°C and 100°C were considered.

J. J. Camps, W. J. Pertot , J. Y. Escavy , M. Pravaz\textsuperscript{[10]} (2006), laid down properties of Dental Gutta Percha out of which the Melting point: approximate value is around 150°C & softening temperature is 60°C. The force required to provide a significant increase in the diameter of heated gutta-percha specimens should be greater than 3 kg. Young’s Modulus (E) of Gutta Percha is 78.7 ± 23.4 MPa, Specific Heat is 0.69 ± 0.11 J/g °C; & Tensile strength is 6.0 ± 1.2 MPa.

Michael Hü Lsmann, Ove A. Peters & Paul M.H. Dummer\textsuperscript{[11]}(2005) and Matthew Duff & Joseph Towey\textsuperscript{[12]} (2010), in their studies have discussed the reasons for Endodontic Failure as Some secondary canals may be missed during the root canal obturation process as there are many secondary canals in the main root canal of a tooth. Proper obturation or filling of these canals along with the obturation of the main root canal is required for successful tooth treatment. There may be ledge formation inside the root canal. The occurrence of ledges was related to the degree of curvature and design of instruments. Some perforations may remain even after the obturation process.

The perforation may be in the gutta percha material. Inadequately filled canals can remain. Coronal leakage or error in post placement may take place. Biologic necessity requires the elimination of the protein degradation products, bacteria, and bacterial toxins which emanate from necrotic and gangrenous root canals. Over and underextension refer solely to the vertical dimension of the root canal filling, beyond or short of the root apex. Underfilling refers to a tooth whose root canal system has been inadequately obturated in any dimension, leaving large reservoirs for recontamination and infection.

An overfilled tooth is one whose root canal system has been filled in three dimensions, and where a surplus of material extrudes beyond the foramina. The case of endodontic failure due to overfilling, where one means by “overfilling” that the root canal has been obturated in its entirety and surplus material has been intruded into the apical periodontium. On the other hand, as have other endodontists, I have encountered numerous cases of failure of vertical overextensions of underfilled root canals. In the latter cases, gutta percha or silver cones which never did seal the circumference of the
apical foramen were carelessly forced into the apical periodontium, where their presence added additional insult to the primary problem, namely the underfilled root canal.

Herbert Schilder\textsuperscript{13} (2006), had a study that the thermoplasticized gutta-percha techniques have been developed in an effort to improve the obturation of root canal irregularities, to improve density of the fill, and to reduce voids. It has been shown that warm vertical compaction of gutta-percha has the capacity to fill twice as many lateral canals than cold lateral condensation.

Jean-Yves Blum, Pierre Machtou, Jean Paul Micallef\textsuperscript{14}(1998), outlined that a “wedging effect” created by the intracanal forces developed during obturations can be measured using a force analyzer device i.e. Endogramme (measures Force vs Time that permits the comparison of different obturation techniques. Thus it provides a new approach to the analysis of intracanal forces). The wedging effect is the forces resulting from the hydrostatic pressure which is developed by a plugger while it is pushing gutta-percha into a canal. Assumption: hydrostatic pressure assumed equal in all direction.

Jean-Yves Blum, Pierre Machtou, Jean Paul Micallef\textsuperscript{15}(1998), have evolved with a the modified Endographe, with a new cupule, a force analyzer device is used to compare the forces and wedging effects developed in the root canal using four obturation techniques: warm vertical compaction, lateral condensation, thermomechanical compaction, and Thermafil condensation. The mean values for the wedging effect for warm vertical compaction, lateral condensation, thermomechanical compaction, and Thermafil condensation were, respectively, 0.65 ± 0.07 kg, 0.8 ± 0.1 kg, 0.6 ± 0.08 kg, and 0.03 ± 0.01 kg.

Dhanya Kumar n. M., Abhishek Singhania, Vasundhara Shivanna\textsuperscript{16} (2008), studied FEA that was used for numerical analysis of complex structures to determine the stress and strain distribution pattern in the internal structure of tooth. Stress distribution patterns i.e. Radicular stresses during obturation and root stresses during occlusion loading, were investigated in simulated biomechanically prepared mandibular first premolars with four different tapers at two different compaction forces and an occlusal load with finite element analysis. A straight root was chosen for this study in order to eliminate effects due to canal curvature, Gutta Percha were compacted by vertical condensation technique in three separate vertical increments (apical 1/3, middle 1/3, cervical 1/3). Vertical compaction forces of 10N and 15 N are used for each increment, applied by simulated plugger. Periodontal ligament layer is assumed to be 200µm thick.

A surrounding bone volume to support the root was created. Simulated standard access opening made in the crown. Root canals with 2%, 4%, 6%, & 12% taper created out of which 4% & 6% were chosen for clinical relevancy. 12% tapered canal chosen arbitrarily to simulate the effects of excessive canal preparation. Model with apical preparation of 0.35 mm at the point of constriction, 0.5 mm (from what would be clinically perceived as the radiographic apex). Isotropic properties applied for Dentine (D), Periodontal ligament (PDL), Supporting bone volume (B), Gutta percha (GP). PDL modeled as a soft incompressible connective layer (to approximate fluid behavior). Coefficient of friction between GP and root canal wall were selected as 0.1 to 0.25. Warm GP compacted in three vertical increments until the canal was filled, at the start of compaction a temperature of 60˚C, reduced to 37˚C during filling procedure.

Plugger surface was assumed to have rounded edges and a tip diameter of 0.5 mm (smaller than the canal diameter) at each compaction increment. During simulated obturation, root stresses decreased as the root canal taper increases and stresses were greatest at the apical third and along the canal wall. The fracture resistance of the restored endodontically treated tooth is a function of the strength of the root (taper of prepared canal) and remaining coronal tooth structure. The clinician must make a decision to use instruments which have an inherently larger or smaller taper based on
the architecture present in a given canal. The development of new design features such as varying tapers, non-cutting safety tips and varying length of cutting blades in combination with the metallurgic properties of alloy nickel-titanium have resulted in a new generation of instruments and concepts. Additional in-vivo and in-vitro tests and clinical trial are desirable in order to elucidate the accuracy of finite element analysis.

Chayanee Chatvanitkul, and Veera Lertchirakarn\cite{17} (2010), were investigated Stress distributions in a mandibular second premolar by using a commercially available 3-dimensional finite element analysis software program (MSC Patran 2007 r1a and MSC Marc 2007r1; They presented the results in this study in a qualitative rather than a quantitative manner. The ultimate goal of endodontic treatment is to preserve the tooth in normal function as long as possible. The original tooth model was adapted to construct the other tooth models with varying degrees of curvature (15°, 30°, and 45°. A standard access opening was made in the crown, and a round root canal preparation was created with 0.04 taper and a final apical preparation of size 35. The models also simulated a cylindrical section of normal bone 2 mm from the cementoenamel junction and a periodontal ligament space 200 \(\mu\)m thick. All bonds at the interface between dentin and post materials were assumed to be perfect bonds.

All posts were assumed to leave 4–5 mm of gutta-percha root filling apically. Each model was meshed by structurally solid elements defined by nodes having 6 DOF in tetrahedral bodies (MSC Patran 2007 r1a). Isotropic properties were applied for all materials. Displacement of all nodes on the lateral surface and base of the supporting bone was constrained. A cementum layer was not incorporated into the models because it was too thin to be simulated accurately, and its modulus of elasticity is close to that of dentin. All conditions can be kept identical (such as tooth morphology, mechanical properties, load, and periodontal support). The numeric method ensures that the root canal preparation has the same size and taper in each model, which would have been impossible to achieve in an experimental study in human teeth. Stress distribution in clinical situation is no longer uniform, Root canal shape and root morphology also affect the stress distribution, resulting in an increased tensile stress on the internal root canal wall.

Lorenza Petrini, Silvia Necchi, Silvio Taschieri, and Francesco Migliavacca\cite{18} (2009), have shown that FEA are recognized to have an important role in optimizing the behavior of biomedical devices. From the computational point of view, only three studies (E. Berutti, G. Chiandussi, I. Gaviglio, and A. Ibba, X. Xu and Y. Zheng, S. Necchi, S. Taschieri, L. Petrini, and F. Migliavacca) based on finite element analyses (FEA) were conducted, aiming to evaluate some aspects of the mechanical behavior of the instruments (e.g., the stress distribution) related to their critical condition during root canal instrumentation and not assessable through laboratory or in vivo tests.

Rhinoceros 2.0 Evaluation (Used to create geometrical model), ABAQUES 6.5-1/ standard (Used for computational Analysis). Model is meshed with 10-noded tetrahedral elements, and canals were meshed using 4-node bilinear elements. Element & node optimization using a grid sensitivity study was performed to choose the most convenient number of elements (in terms of computational time and results accuracy). The canals were modeled as simple rigid surfaces shaped as pipes, based on radius, angle, and position of curvature. In this work, four types of canal geometries were considered, characterized by a radius r of 2 or 5 mm, an angle a of 45° or 30°, and an apical or middle position (p) of the curvature.

The modeled instruments were forced into the root canals until the apex was reached (insertion step) and immediately retrieved (removal step), as a first approach to the problem, neither friction nor machining action was considered between the instrument blade and the canal wall. A “soft” contact with an exponential pressure-overclosure
model was imposed to simulate their interaction. Hence, the torsional stresses induced in the file during the procedure were neglected. The primary curvature parameter influencing the mechanical behavior of the instrument (higher variations of strain) is the radius of curvature. Differently, the second dominant parameter is judged the position of curvature for the Ni-Ti alloys and the angle of curvature for the stainless steel. The stainless steel instruments showed a lower ability to conform to the canal shape during an entire insertion-removal cycle. In particular, the tip of the stainless steel file plasticized just after the first contact with the canal wall. The Ni-Ti file bends uniformly along the blade, following the original curvature of the canal.

Mithra N. Hegde, Shishir Shetty, Navneet Godara\textsuperscript{[19]} (2008), were studied that the factors influencing the fracture are i) Root canal shape with reduced radius of curvature is the single most important factor influencing the location and the direction of fracture lines. ii) External root morphology. iii) Dentine thickness iv) Oval root canal. After obturation, a vertical load was applied by means of spreader inserted into the canal until fracture occurred. Forces encountered during lateral condensation alone should not be a direct cause of vertical root fracture. Load generated during lateral condensation is less than the load required to fracture the root.GP compaction in root canal achieved by attaching hand spreader tip (Hu-friedy) to Instron Testing machine (Model 4206, Instron Corp. Canton MA).

Fracture loads varies from 5 kg to 24.3 kg. Mean Fracture load obtained by Lertchirakarn et al for mandibular premolar was 9.7 kg. Fracture occurs when the tensile stress in the canal wall exceeds the ultimate tensile strength of dentin. When an apical pressure is applied with a round instrument (D11 Hand spreader) inserted into an elliptical canal, it will bind at its narrowest width, which is typically from mesial to distal. The initial forces will be directed towards the mesio-distal direction leading to a strain on the bucco-lingual surface. Hence the resulting fracture lines will orient in the bucco-lingual direction.

Christina Dorow, Franz-Günter Sander\textsuperscript{[20]} (2005), in their study focused on the stress and strain in this area which can only be calculated using the finite element method. It is as yet impossible to measure the stress inside the periodontal ligament \textit{in-vivo}. There has not been sufficient quantitative investigation so far concerning the connection between forces and movement. It is still impossible to evaluate all the factors influencing resorption. Orthodontic forces represent only one cofactor affecting root on resorption.

Tsukada G, Tanaka T, Torii M, Inoue K.\textsuperscript{[21]} (2004), in their study, have seen a marked decrease of instantaneous shear modulus that was observed at the melting point, and the range of the first-order transition temperature at heating was from 42°C to 60°C. Also A marked specific volume change was observed at the first-order transition temperature. During the setting process, the crystallization of GP is thus thought to adversely affect the sealing ability in the root canal space. The main cause of endodontic treatment failure is generally said to be incomplete sealing of the root canal, and accordingly it is important to obturate the root canal closely.

Fluidity and melting point can be altered by arranging the content, the average molecular weight and molecular weight distribution, but a large amount of volumetric shrinkage with crystal growth cannot be avoided when using gutta percha. The technique using melted GP alone may not be favourable compared with conventional lateral condensation because melted GP undergoes a large amount of shrinkage during setting.

**SIMULATED ROOT CANAL CAVITY FOR FINITE ELEMENT ANALYSIS**

The simulated root canal cavity is modeled in AutoCAD 12, as shown in the Figure 1 below. The amount of taper is
fixed & is

**Figure 1: Simulated Root Canal with Solid Gutta Percha**

**Table 1: Details of the Simulated Root Canal Cavity as Convergent Nozzle**

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Elements of Simulated canal</th>
<th>Idealized dimensions in mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Diameter of the simulated root canal on the big end</td>
<td>1.5</td>
</tr>
<tr>
<td>2</td>
<td>Diameter of the simulated root canal on the small end</td>
<td>0.15</td>
</tr>
<tr>
<td>3</td>
<td>Thickness of the wall just touching the tapered cavity</td>
<td>1.5</td>
</tr>
<tr>
<td>4</td>
<td>Thickness of the wall above the wall of 1.5 mm thickness</td>
<td>0.2</td>
</tr>
<tr>
<td>5</td>
<td>Length of the simulated root canal</td>
<td>20</td>
</tr>
<tr>
<td>6</td>
<td>Diameter of the plunger on the big end</td>
<td>1.2</td>
</tr>
<tr>
<td>7</td>
<td>Diameter of the plunger on the small end</td>
<td>0.2</td>
</tr>
</tbody>
</table>

**BASIC TOOTH STRUCTURE**

Following Figure 2 shows basic structure of tooth anatomy and the infected pulp in black representation

**Figure 2: The Basic Structure of the Tooth**

**Assumptions in Finite Element Analysis**

1. Curved path of root canal is considered as straight wall for neglecting the curvature effect.
2. The thermal conductivity ‘K’ of GP is treated as temperature independent.
3. Only 2-D analysis is considered.
4. Vertical Compaction technique is used.
5. Compactor end face is flat, with a compaction force of 15 N.
6. Steady state heat transfer analysis is considered for the present case.
7. Temperature on root surface is assumed to be 37 °C.
8. Maximum temperature at tip end is assumed to be 200 °C.

<table>
<thead>
<tr>
<th>Properties</th>
<th>NiTi</th>
<th>Tooth Elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>E (MPa)</td>
<td>75000</td>
<td>0.69, 18600</td>
</tr>
<tr>
<td></td>
<td></td>
<td>68.9</td>
</tr>
<tr>
<td>ν</td>
<td>0.33</td>
<td>0.45, 0.31</td>
</tr>
<tr>
<td>K (W/m°C)</td>
<td>18</td>
<td>0.16, 0.958</td>
</tr>
</tbody>
</table>

Figure 3: Meshed Tapered Geometry Model Along with the Plunger

Figure 4: Temperature Plot

Figure 5: Thermal Flux
DISCUSSIONS BASED ON TEMPERATURE PLOT
1. It can be observed that as GP is a very strong insulator as explained in the literature, the heat conduction takes place up to a smaller length in the GP.
2. GP gets softened till a longitudinal distance of about 2mm.
3. Temperature at the interface of GP and the wall of the tapered cavity at an axial distance of about 2.5 mm is 46.706°C which is within the allowable range of 37°C to 47°C. This temperature will further reduce as one moves farther in the axial direction.
4. Thus, the root canal obturation using a heating tip of 200 °C will not harm the inner wall (i.e. dentine) of the root canal and thus the person undergoing the obturation process.
5. The temperature inside the dentine layer near the interface at an axial distance of about 2 mm is around 46 °C.
6. The temperature at the middle of the total thickness of the dentine reduces to body temperature (37 °C).

DISCUSSIONS BASED ON THERMAL FLUX PLOT
1. It can be observed that the value of thermal flux in the vicinity of the heating tip is very high (i.e. in the order of $10^{-10}$) but as one moves farther the thermal flux increases rapidly up to certain length and then it again reduces as one moves further. For example at about 1.5mm, the thermal flux is 15.809 W/m$^2$ and then the thermal flux reduces to 0.385677 W/m$^2$ at about 6mm.
2. The thermal flux inside the dentine layer near the interface at an axial distance of about 1.5 mm is around 11.164 W/m$^2$.
3. The thermal flux at the middle of the total thickness of the dentine at an axial distance of about 4 mm is reduces to a very small value (i.e. 1.098 W/ m$^2$).

DISCUSSIONS BASED ON THERMAL GRADIENT PLOT
It can be observed that the value of thermal gradient inside the heating equipment is very small (i.e. in the order of $10^{-12}$) but it is very high in the vicinity of the interface between the heating tip and the gutta percha placed inside the root canal cavity. For example it is 157.678 W/m at about 2mm length. But as one moves further inside the root canal, the thermal flux decreases.

STRESS & DEFLECTION ANALYSIS FOR CAVITY FILLED WITH GP
Softened GP is compacted by simulated tip with a constant force of 15 N in axial direction, and the deformation analysis was carried out using ANSYS 10.0.
Discussions Based on Displacement Plot

1. It can be observed that as GP is a polymeric material but it is crystalline in nature so there is displacement (small) on the application of a load of 15 N.
2. The maximum displacement can be observed at the point of application of load. It is 0.033673 mm.
3. The displacement of the GP material occurs till a depth of about 2-3 mm.
4. The displacement of GP inside the approximated root canal as tapered cavity reduces drastically as one moves further inside the cavity.

Discussions Based on Stress Plot

1. It is seen that the dentine part of the cavity gets stressed along with the GP on which a load of 15 N is applied by a plunger of the mentioned dimensions.
2. The maximum value of stress occurs at the interface of the GP & the dentine wall on the face of the application of the load & is 22 MPa which is low.
3. Some parts of the dentine layer also gets stressed but the value is even smaller (i.e. about 2.922 MPa).
4. After the length of about 4-5 mm, no stress zone inside the cavity is seen on the application of the load.

CONCLUSIONS

GP is a very strong insulator, it gets softened till a longitudinal distance of about 2mm, with a heating tip of 200°C, the temperature inside the dentine layer near the interface at an axial distance of about 2 mm is around 46°C which is within permissible limit and hence safe for the person. The value of thermal flux in the vicinity of the heating tip is very high (i.e. in the order of $10^{10}$) but as one moves farther the thermal flux increases rapidly up to certain length and then it
again reduces as one moves further. The maximum displacement can be observed at the point of application of load (15 N). It is 0.033673 mm. The displacement of the GP material occurs till a depth of about 2-3 mm which reduces drastically in further depth of the cavity. The maximum value of stress occurs at the interface of the GP & the dentine wall on the face of the application of the load. This value is 22 MPa which is not so high value. Some parts of the dentine layer also gets stressed but the value is even smaller (i.e. about 2.922 MPa). After the length of about 4-5 mm, almost negligible stresses were observed inside the cavity on the application of the load.

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