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# Deformation Studies of Endodontic Obturator Tip Using FEM Approach

**Ratnakar R.Ghorpade[1], Dr.Kalyana Sundaram[2], Dr.Vivek Hegde[3]**
*[1]Department of Mechanical Engineering, MAEER's, Maharashtra Institute of Technology, Paud Road, Kothrud, University of Pune, Pune-411 038.*
*[2]Department of Mechanical Engineering,BRACT's, Vishwakarma Institute of Technology,Bibwewadi, University of Pune, Pune-411 037.*
*[3]Department of Conservative Dentistry & Endodontics, M.A.Rangoonwala College of Dental Sciences & Research Centre, Pune – 411 001.*

***Abstract—Heated Cutter tips are used by dental surgeons extensively 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 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 gutta percha from the apical region of tooth crown with ease. The Gutta Percha Cutter Tip geometry is selected initially based on ideal root canal geometry available. The cutter tip is being heated by a suitable heating mechanism to 300˚C for 3 to 5 seconds. There is cyclic effect of heating tip temperatures on inner point in tip. Thermo-mechanical analysis of Gutta Percha Cutter tip is carried out in ANSYS10.0, which gives the combined stress pattern and deformation pattern on the tip. FEA is a proven cost saving tool and can reduce design cycle time therefore it can be used as accurate tool to investigate thermo-mechanical stress and deformation pattern on cutter tip, and it will ensure minimal effects of combined stresses in tip on the inner wall of prepared root canal cavity.***

***Keywords—Gutta Percha, ANSYS10.0, FEA.***

## I. INTRODUCTION

### 1.1 Problem Statement:-

Gutta percha 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 gutta percha 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 gutta percha from the apical region of tooth crown with ease. The objective of this paper is to evaluate critical failure safety of the cutter used for dental surgery.

### 1.2 Methodology:-

The design of Gutta percha cutter tip, challenges the creativity of the designer to use knowledge of solid geometry with liberty, based on his/her own experience to avoid tooth interference, and knowledge of optimization practices. FEA is a proven cost saving tool and can reduce design cycle time and therefore can be used as accurate tool to investigate thermo-mechanical stress and deformation pattern on cutter tip. Our work in this paper is directed towards optimizing the tip geometry for defined cutting load and given heat pattern on tip surface. We also sought to predict the range of deformation possible due to combined effect of thermal stress and stress due to cutting load.

### 1.3 Description :

The Gutta Percha Cutter Tip geometry is modeled based on an idealized root canal assumed for a typical molar tooth. The cutter tip is heated to 300 degree Celsius 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 gutta percha. Heat is continuously supplied to the gutta percha tip by a suitable mechanism. Thus temperatures on inner point in tip, the cutting force on tip surface, are the inputs for the analysis. Thermo-mechanical analysis of Gutta Percha Cutter tip is carried out in ANSYS10.0, which gives the combined stress pattern and deformation pattern on the tip. Further based on this analysis the data were used to make design decisions.

### 1.4 Analysis :-

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. FEA acts as a tool for analyzing different Tip geometries for current study. It also saves time and also simplify complexity involved in analysis of element i.e. tip in the biomedical device. FEA also helps us to analyze and better understand various critical sections and to predict the failure mode.

## II. LITERATURE SURVEY

Prior work on the Gutta Percha cutter tip reveals that a "wedging effect" created by the intracanal forces developed during obturations which 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[i] **[1].**

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.[ii] **[2]**

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. FEA used for numerical analysis of complex structures to determine the stress and strain distribution pattern in the internal structure of tooth. Assessment of stress levels by measuring deformation patterns (using photoelastic method, strain gauges, Instron Universal machine) inside the root canal is extremely difficult , therefore FEA have been utilized to address these difficulties and gain insight into internal stress distributions. Assumptions and input data for FEA: i) A straight root was chosen for this study in order to eliminate effects due to canal curvature. ii) Guttapercha were compacted by vertical condensation technique in three separate vertical increments (apical 1/3, middle 1/3, cervical 1/3). iii) Vertical compaction forces of 10N and 15 N are used for each increment, applied by simulated plugger. iv) Periodontal ligament layer is assumed to be 200µm thick v) A surrounding bone volume to support the root were created. vi) Simulated standard access opening made in the crown. vii) 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. viii) 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). ix) 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). x) Coefficient of friction between GP and root canal wall were selected as 0.1 to 0.25. xi) 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. xii) 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. Conclusion: 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, noncutting 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. **[3]**

The ultimate goal of endodontic treatment is to preserve the tooth in normal function as long as possible. Stress distributions were investigated 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; The original tooth model was adapted to construct the other tooth models with varying degrees of curvature (15, 30, and 45 degrees. 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 µm 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 degrees of freedom 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. The results in this study are presented in a qualitative rather than a quantitative manner. **[4]**

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. Authors carried out extensive research based on their previous findings by comparing the mechanical performance of three different Ni-Ti alloys, when used to produce rotary endodontic instruments.Modeling and Analysis: Rhinoceros 2.0 Evaluation (Used to create geometrical model), ABAQUES 6.5-1/ standard (Used for computational Analysis). Considerations: The handle part of the file does not serve any specific function in the shaping procedure, and therefore it was neglected in the numerical analyses.Model meshing: 10-nodes tetrahedral elements. And canals were meshed using 4-node bilinear elements. Element & node optimization: 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. FEA are recognized to have an important role in optimizing the behavior of biomedical devices. **[5]**

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. Factors influencing the fracture: 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 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. **[6]**

To calculate the stress in the tooth, surrounding periodontal ligament, and in the alveolar bone when a lower first premolar is subjected to intrusion or torque movement using a constant moment. Model was subjected to an intrusive force on the premolar of 0.5 N and a lingual root torque of 3 Nmm. The extent of changes in tissue structures was proportional to the amount and duration of applied forces and moments. The main resorption occurred at the root apex.The tooth is constructed as a hollow body with a consistent thickness of 0.2 mm. Young’s modulus of the tooth is much greater than that of the periodontal ligament. Young’s modulus of the bone is clearly greater (1.000– 10.000-times) than that of the periodontal ligament. The exact geometry of the periodontal ligament space could not be quantified because of its slight width.Parameters for the linear, elastic mechanical properties of the tooth (consisting of enamel and dentin), periodontal ligament (the Young’s modulus varies) and alveolar bone. Capillary blood pressure in PDL ranges between 15 & 35 mm Hg ( i.e.0.002 – 0.0047 MPa), Meshing: 8 noded hexagonal elements ( as stability much better than tetrahedrons). PDL undergoes greatest deformation (as being softest tissue, thus high element density is used for it.). Force: Fz = -0.25 N (on lingual and labial sides of tooth crown), Fz = -0.5 N ( as intrusive force). Maximums and minimums of the hydrostatic stress portion at the apex and alveolar crest. Further research need: It is as yet impossible to measure the stress inside the periodontal ligament *in-vivo*. Stress and strain in this area can only be calculated using the finite element method. 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 represents only one cofactor affecting root resorption. **[7]**

A marked decrease of instantaneous shear modulus was observed at the melting point, and the range of the first-order transition temperature at heating was from $42^0$C to $60^0$C. Also A marked specific volume change was observed at the first-order transition temperature. During the setting process, the crystallization of gutta percha 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 gutta percha alone may not be favourable compared with conventional lateral condensation because melted gutta percha undergoes a large amount of shrinkage during setting. **[8]**

The findings of 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.**[9]**

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 β-phase begins the α-phase change when heat reaches the temperature range of 48.6°C to 55.7°C, and that the α-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. **[10]**

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. **[11]**

## III. MATHEMATICAL MODELING OF CUTTER TIP

### 3.1 Mathematical model

The device under study can be handheld portable apparatus used to heat, soften & cut gutta percha as filler material with ease and also fill it in root cavity without disturbing patient. The cutter tip is modeled as tapered bar loaded at smaller end (i.e. free end) with a force 'P' and fixed at the bigger end, in order to determine its deformation behavior.

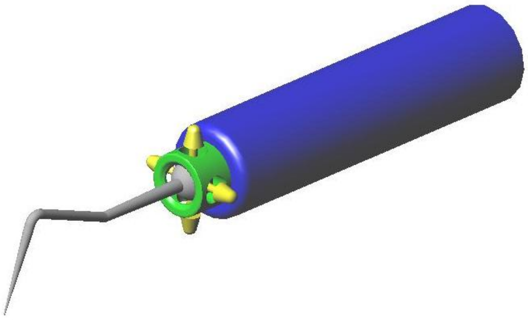


*Fig. 1 Solid Model of Dental device with cutter tip*

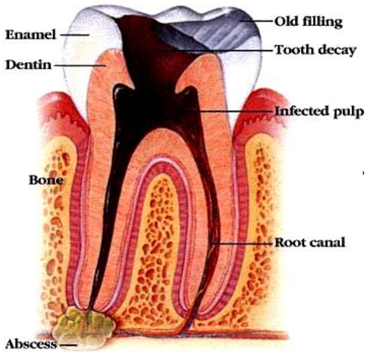


*Fig. 2 The basic structure of the tooth, with the infected part, that needs to be cleaned. Also, the root canal of the tooth can be seen.*

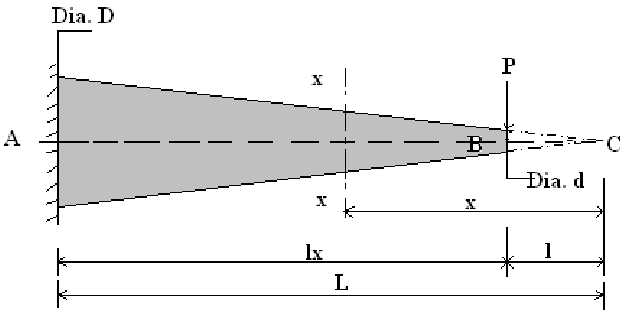


*Fig. 3 Gutta Percha cutter tip geometry under study*

D: Diameter at larger end (i.e.at fixed end 'A'), (mm)
d: Diameter at smaller end (i.e.at free end 'B'), (mm)
P: Load at the free end of tapered bar, (N)
*l*x: Length of tapered bar, (mm)
*l*: Length of smaller diameter from point 'C', (mm)
L: Length of fixed end/larger diameter from point 'C', (mm)
x-x: Any cross section along the bar at distance 'x' from point 'C',
dx: Diameter at section x-x, (mm)
$M_{x-x}$: Bending moment at section x-x, (N-mm)
$I_x$: Moment of inertia at section x-x,
E: Young's Modulus. ($N/mm^2$)
Taper lines are extended to meet at point 'C'

Diameter at section x-x:

$$d_x = \frac{x.d}{l}$$

$$I_X = \frac{\pi}{64}\,(d_x)^4$$

$$= \frac{\pi}{64}\,(\frac{x.d}{l})^4$$

$$M_{x-x} = P\,(x-l)$$

For uniformly varying cross-sectional area,

$$E.I\,\frac{d^2y}{dx^2} = M \qquad \text{-------------------(1)}$$

can be rearranged as

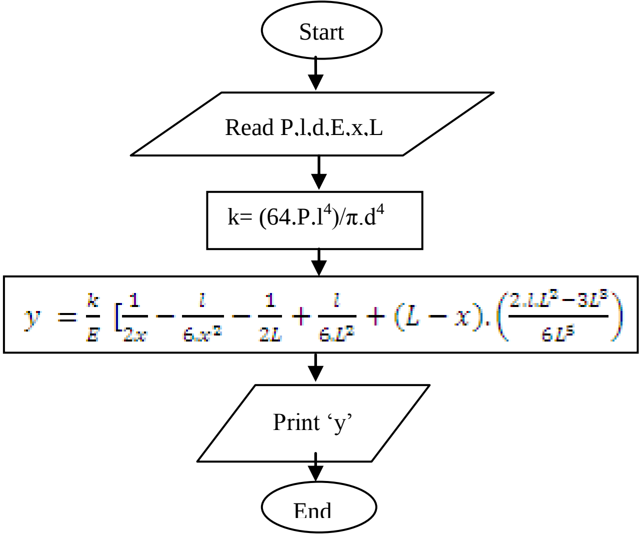
$$E.I\,\frac{d^2y}{dx^2} = \frac{M_{x-x}}{I_x} \qquad \text{-------------------(2)}$$

Solution of above equation for deflection is,

$$y = \frac{k}{E}\left[\frac{1}{2x} - \frac{l}{6.x^2} - \frac{1}{2L} + \frac{l}{6.L^2} + (L-x).\left(\frac{2.l.L^2 - 3L^3}{6L^5}\right)\right. \qquad \text{------------------(3)}$$

Where, k= $(64.P.l^4)/\pi.d^4$ ----------------- (4)

**3.2 Flowchart to find the deflection at any point on the tapered bar loaded at it's end (smaller end) and fixed at the bigger end:**



**3.3 Analytical Solution:**

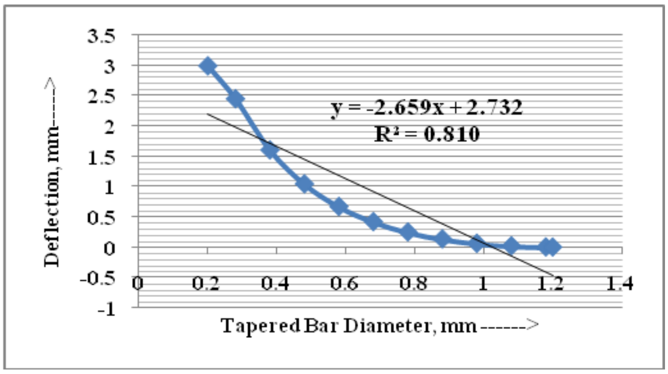


*Fig. 4 Deflection plot (Analytical Solution)*

## IV. FINITE ELEMENT ANALYSIS OF CUTTER TIP

### 4.1 FEA Basis:

The plugger is introduced for 3-4 mm into the gutta-percha cone (this also must not touch the dentinal walls), where it remains for a fraction of a second and is then removed. In actual practice, the probe of the Touch'n Heat unit is introduced into the orifice, started and allowed to plunge 3-4 mm into the coronal most extent of the gutta-percha. The heat-activating element is then released and after hesitating momentarily, the cooling instrument is removed, along with an adhered bite of gutta-percha. In this manner, the gutta-percha is heated around the heat-carrier and about 3-4 mm apically (no more, because gutta-percha is not a conductor of heat. When the instrument is withdrawn from the root canal, simultaneously a bite of gutta-percha has remained attached to it and is then removed.

A new introduction of the heat-carrier will then remove another bite of gutta-percha, moving more apically the level of compaction. Now the assistant will hand the smallest plugger, to compact the softened material in the most apical portion of the root canal.

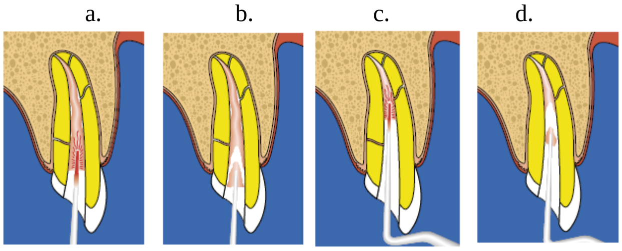


*Fig. 5 Heat Softening & Compaction of Gutta Percha by Cutter Tip in steps*

a. The heatcarrier is returned, which is introduced into the center of the gutta-percha cone in the root canal.
b. The heat-carrier is heating the gutta-percha apically to its tip and removes the surrounding material from the canal.
c. A new introduction of the heatcarrier is softening the gutta-percha in the apical one third.
d. Another piece of gutta-percha has been removed. Now it is time to use the smallest plugger,

**4.2 Assumptions and input data for FEA:**

i) A straight root was chosen for this study in order to eliminate effects due to canal curvature.
ii) Guttapercha were compacted by vertical condensation technique in three separate vertical increments (apical 1/3, middle 1/3, cervical 1/3).
iii) Vertical compaction force of 10N is used for each increment, applied by simulated plugger.
iv) 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.
v) Plugger surface was assumed to have flat and a tip diameter of 0.2 mm ( smaller than the canal diameter) at each compaction increment.
vi) The handle part of the cutter does not serve any specific function in the shaping procedure, and therefore it was neglected in the numerical analyses.

**4.3 Finite Element Analysis:**

**Analysis tool:** ANSYS 10.0

**Material Properties used for NiTi Tips in FEA:** Young's Modulus: 83GPa, Poisson's ratio: 0.33

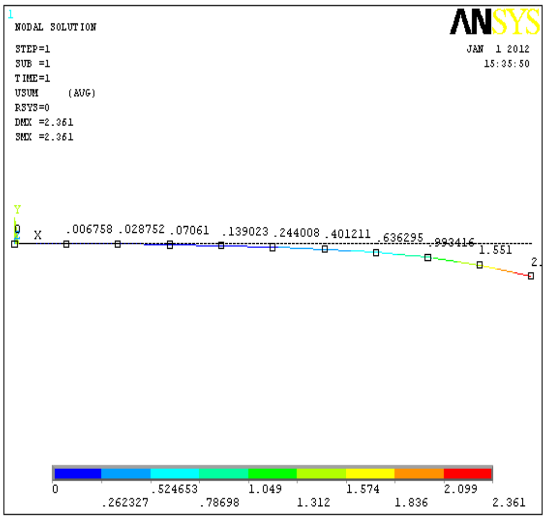
**Model Meshing:**

BEAM element of class **BEAM 44**, (3D Tapered element for structural analysis).

**Loads & constraints:**

Structural loading: Tip is loaded at it's end in transverse direction by a compaction force of 10 N. As the tip is joined to NiTi pipe at it's bigger end, it is constrained for the displacement in the three directions at this end.

**4.4 FEA Results:**


```
1
NODAL SOLUTION

STEP=1
SUB =1
TIME=1
USUM      (AVG)
RSYS=0
DMX =2.361
SMX =2.361
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*Fig. 6 FEA Solution for deflection of tapered bar for 10 N*

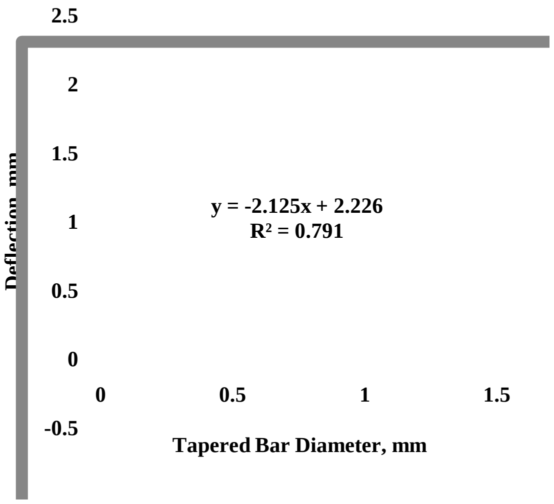

*Fig. 7 Deflection plot (FEA Solution)*

**Table 1: Analytical & FEA solution for deflection of 10 mm long tapered bar at various diameters along it's length when loaded at smaller free end by 10 N**

| Distance from free end (mm) | Diameter (mm) | Deflection (mm) Analytical Solution | Deflection (mm) FEA Solution |
|---|---|---|---|
| x= 0 | 0.2 | 2.993315 | |
| 0.5 | 0.28 | 2.449849 | 2.3609 |
| 1.5 | 0.38 | 1.603915 | 1.5507 |
| 2.5 | 0.48 | 1.043858 | 0.99342 |
| 3.5 | 0.58 | 0.670952 | 0.63630 |
| 4.5 | 0.68 | 0.419134 | 0.40121 |
| 5.5 | 0.78 | 0.248644 | 0.24401 |
| 6.5 | 0.88 | 0.134983 | 0.13902 |
| 7.5 | 0.98 | 0.062444 | 0.07061 |
| 8.5 | 1.08 | 0.020558 | 0.028752 |
| 9.5 | 1.18 | 0.002104 | 0.0067579 |
| 10 | 1.2 | 0 | 0 |

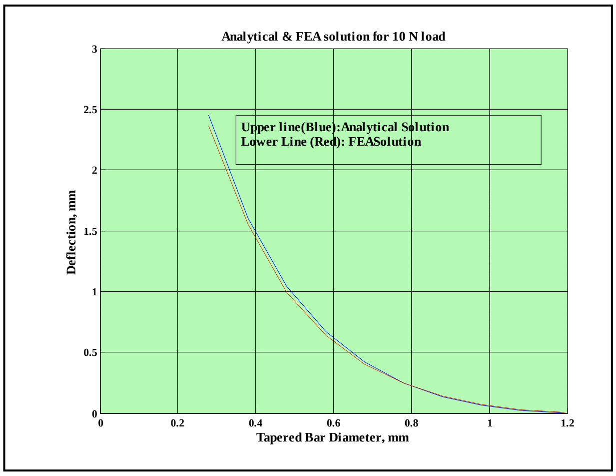

*Fig. 8 Analytical and FEA Solution for 10 N load*

### 4.5 Thermal Expansion in the material:

For the cutter tip of length 10 mm, 15 mm and 20 mm the thermal expansion is 0.016917 mm, 0.0253755 mm and 0.033834 mm respectively. It is based on

$$dl = L_0 \, \alpha \, (t_1 - t_0) \qquad \text{---------------------------------------} \quad (5)$$

where, $dl$ = change in length (mm)
$L_0$ = initial length (mm)
$\alpha$ = linear expansion coefficient ( $7.9X10^{-6}$)
$t_0$ = initial temperature ($^{o}C$)
$t_1$ = final temperature ($^{o}C$)

## V. CONCLUSION

Structural deformation behavior of the Endodontic cutter tip is analyzed based on analytical approach & FEA approach. The results obtained (Maximum deflection at the cutter tip end observed to be 2.449849 mm analytically, and 2.3609 mm by FEA), which are closely matching, and could be further utilized in analyzing the effect of stressing the tip on the root canal cavity. Thus the optimum balance between cutting force on tip and friction force on Gutta percha surface in contact with the root canal wall is required, while compacting gutta percha in the cavity. It will ensure minimal effects of combined stresses in tip on the inner wall of prepared root canal cavity. Thus FEA of tip of the Gutta Percha Cutter helps us to standardize to certain extent the design procedure for the Tip which will have minimum stress effects on inner wall of the root canal cavity.

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