Original Article

Assessment of heat transfer to periodontal tissues and stress distribution in a tooth with simulated internal resorption cavities at different root levels using two thermoplasticized obturation systems - A finite element analysis study

Vibha Rahul Hegde, Pritisha Bharat Jain, Pooja Sunil Bhagat
Department of Conservative Dentistry and Endodontics, Y.M.T Dental College and Hospital, Navi Mumbai, Maharashtra, India

ABSTRACT

Aim: This study aimed to evaluate the heat transfer to periodontal tissues and stress distribution within simulated roots with internal root resorption cavities at three different levels using two thermoplasticized obturation systems using finite element analysis.

Methods: Maxillary central incisors with single canals were chosen for the construction of the simulation and geometric models. Cone beam computed tomography scan of a skull was used to model the periodontal ligament and alveolar bone. Construction of the simulating model and geometric model and conversion to finite element model was conducted with three-dimensional tetrahedral elements at three different levels. These three models were duplicated for stress distribution and heat transfer analysis during the down packing and backfilling procedure to periodontal tissues. A simulation of root canal preparation and obturation procedures was conducted using ANSYS 19.2 software, and static structural, steady-state thermal, and transient analysis were carried out.

Results: The total average stress was the highest when the resorption cavity was in the middle third (1.72 Mpa) for the calamus dual obturation system. The total average temperature observed was the highest when the resorption cavity was in the middle third (37.4 C) for the elements free obturation system and in the apical third (53.73 C) for the calamus dual obturation system.

Conclusion: It was observed that between the two systems, elements free obturation system led to lower heat transfer and heat flux during the down packing procedure in comparison to the calamus dual obturation system, and the remaining dentin thickness was directly proportional to the amount of heat transferred to the surrounding tissues.

Keywords: Cone beam computed tomography, endodontics, finite element analysis, gutta-percha, heat, heat transfer, root canal, temperature rise, thermal injury, thermoplasticized obturation system

INTRODUCTION

The natural root canal anatomy may be altered in various pathological processes making this task very difficult and, at times, impossible to achieve complete sealing of the root canal system by normal methods of obturation. Internal root resorption is one such pathological process that results in the progressive destruction of dentine from the root canal walls.[1]

Thermoplastic filling techniques such as injectable gutta-percha and continuous wave of condensation have

Submitted: 02-Jun-2022 **Revised:** 06-Jul-2022
Accepted: 13-Jul-2022 **Available Online:** 28-Dec-2022

Access this article online	
	Quick Response Code
Website: www.endodontologyonweb.org	
DOI: 10.4103/endo.endo_144_22	

Address for correspondence: Dr. Pritisha Bharat Jain, Shankeshwar Darshan, B-Wing, Room No-410, Byculla, Lovelane, Mumbai - 400 010, Maharashtra, India.
E-mail: jainpriti337@gmail.com

How to cite this article: Hegde VR, Jain PB, Bhagat PS. Assessment of heat transfer to periodontal tissues and stress distribution in a tooth with simulated internal resorption cavities at different root levels using two thermoplasticized obturation systems – A finite element analysis study. Endodontology 2022;34:275-81.

been shown to fill the canal irregularities better than cold lateral condensation.[2] However, the use of this technique may lead to an unconscious transmission of excessive heat to the surrounding tissues, which may cause irreversible injury to tissues. According to some *in vivo* studies, although an exact temperature was not specified, when thermal irritation was introduced to the endodontic wall, local necrosis, bone resorption, and ankylosis were found on the periodontal ligament.[3,4]

Roots with internal resorption defects have areas of thin dentinal walls, compared with the roots without resorption. Therefore, temperature rise on the external root surface should be considered during canal filling with thermoplasticized gutta-percha techniques.[2]

The finite element method is considered a fast, accurate, and reliable alternative to studies *in vivo* and *in vitro*.[5] One of its advantages is that longitudinal temperature changes of the entire model can be monitored as a dynamic process under the simulated working condition.

Given the abovementioned advantages, finite element analysis (FEA) can be used to predict fracture patterns and fracture susceptibility. Variations of root shape and loads can be easily incorporated into the calculation to make the results more accurate and authentic.

Combined with fracture strength tests, FEA can provide comprehensive and convincing information about vertical root fracture for practitioners to take better preventive measurements. Although the use of the finite element method can provide very accurate results; the results are still only estimates for the specific condition. Therefore, one should not expect a finite element model (FEM) to yield precise answers to actual conditions but rather provide reliable estimates.

Therefore, the aim of the present study was to evaluate the heat transfer to periodontal tissues and stress distribution within simulated roots with internal root resorption cavities at three different levels using two thermoplasticized obturation systems using FEA.

METHODOLOGY

The study was designed to evaluate the heat transfer to periodontal tissues and stress distribution within simulated roots with internal root resorption cavities when using calamus dual and elements free thermoplasticized obturation systems.

Maxillary central incisors with single canals were chosen for the construction and simulation of the geometric model. A cone beam computed tomography (CBCT) scan (FOV 24 × 19 full volume) of a skull was used to model the periodontal ligament and alveolar bone. This image DICOM data were further studied by MIMICS 8.11, a medical modeling software used for visualizing and segmentation of computerized tomographic images to obtain a three-dimensional (3D) image.

Construction of the simulating model and geometric model and conversion to finite element model

These 3D profiles were imported on Computer-Aided Designing SOLIDWORKS 2020 software (Dassault Systemes, U.S) to obtain a complete profile of the tooth in a geometric model format along with the supporting structures. In all FEA models, the dentine tissue thickness surrounding the resorption cavity was 1 mm. Similarly, the down pack and the backfill tips of both the devices were simulated for both the thermoplasticized obturation systems [Figure 1]. Three-dimensional tetrahedral elements were used for the construction of the FEMs simulating internal resorption cavities at three different levels (coronal, middle, and apical).

Duplication and defining boundaries of model

These three models were duplicated for stress distribution analysis during the down packing procedure and the thermal (heat transfer to periodontal tissues) analysis during both down packing and backfilling procedures for both thermoplasticized obturation systems resulting in a total of 18 FEMs.

Individual parts of the tooth such as the enamel, dentin, the bone supporting the tooth, and periodontal ligament were discretized and assembled. The model was held constant at a place away from the application of the load and temperature settings.

Loading configuration

A simulation of root canal preparation and obturation procedures was conducted using ANSYS 19.2 software (Canonsburg, Pennsylvania, U.S). Root canal dimension simulation was performed to a final apical size of 30 with 0.06 taper, followed by root canal obturation, where the apical thirds of the root canals were obturated by GP using the continuous wave condensation technique using calamus dual and elements free system down pack heat source at 200°C. A #30 0.06 taper master GP cone was assumed to be placed 0.5 mm short of WL in the root canal.

The temperature of the GP was originally 22°C; 200°C heat was applied to the GP at a distance of 5 mm short of the WL. Times of 4 s and 0.5 s were allowed for calamus dual and elements free obturation systems, respectively, for heat activation at this stage (down-pack phase). The remainder of the canal was backfilled in two segments using the backfilling tips at a temperature setting of 180°C and 200°C for calamus dual and elements free obturation systems, respectively.

Outcome assessment

Static structural analysis

The resorption cavity was in the coronal, middle, and apical parts of the root. The stress distribution was evaluated during down pack procedure when using the down pack thermopluggers of the Calamus dual obturation system and Elements Free obturation system [Figure 2].

Steady-state thermal analysis

The down pack thermoplugger was set at a temperature setting of 200°C and activated at 4 s and 0.5 s at a distance of 5 mm from the WL for calamus dual and elements free obturation systems, respectively. Temperature changes were recorded along the periodontal ligament and apical GP during the down pack using ANSYS 19.2 software [Figure 2].

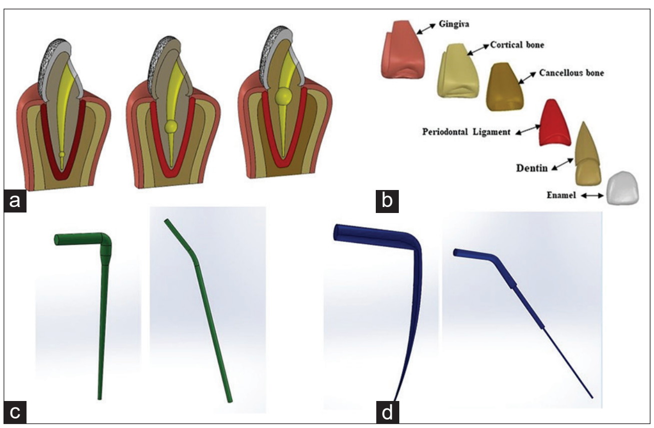

Figure 1: Construction of the three-dimensional simulating models (a) maxillary central incisor with internal resorption cavities at coronal, middle apical levels (b) surrounding tissues (c) down pack thermoplugger and backfill tip of calamus dual thermoplasticized obturation system and (d) down pack thermoplugger and backfill tip of elements Free thermoplasticized obturation system, respectively

Transient thermal analysis

The remainder of the canal was backfilled in two segments using the backfilling tips at a temperature setting of 180°C and 200°C for calamus dual and elements free obturation systems, respectively. Temperature changes were recorded along the periodontal ligament and apical GP during the backfilling phase of obturation using ANSYS 19.2 and its dedicated software package [Figure 2].

Statistical analysis

The descriptive statistics were performed with various software and interpreted according to the results with model-based values and graphs for both the obturation system based on three primary outcomes of stress distribution, heat transfer during down packing, and backfilling.

RESULTS

Static structural analysis

When comparing the two systems for stress distribution during the down packing, it was observed that the elements free obturation system exerted lesser stresses than the calamus dual obturation system. The total average stress was highest when the resorption cavity was in the middle third (1.72 Mpa), followed by when the resorption cavity was in the apical third (7.80×10^1 Mpa) and the least when the cavity was in the coronal third (7.50×10^1 Mpa) for calamus dual obturation system. The total average stress was highest when the resorption cavity was in the apical and middle third (0.23 Mpa) and the least was when the resorption cavity was in the coronal third (0.2 Mpa) for elements free obturation system [Table 1].

Steady-state thermal analysis

The heat transfers during down packing showed that the total average temperature observed was highest when the resorption cavity was in the middle third (37.4°C), followed by that when the cavity was in the apical third (34.95°C), and the least temperature was noted when the resorption cavity was in the coronal third (31.36°C) for elements free obturation system.

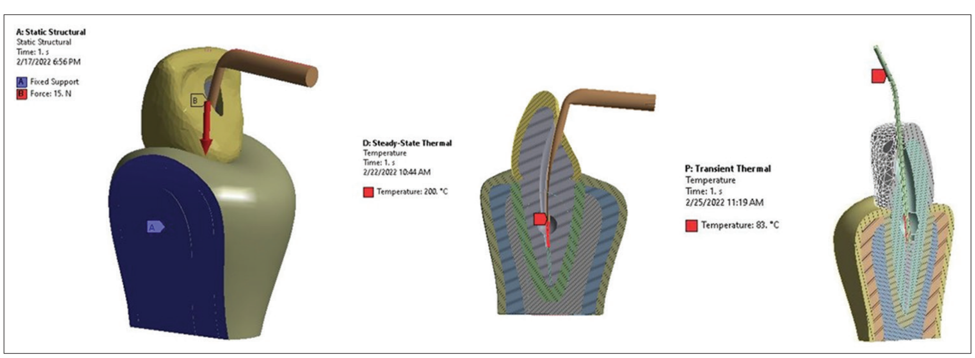

Figure 2: Loading conditions for static structural, steady-state thermal, and transient thermal analysis, respectively

Table 1: Von Mises equivalent stress during static structural analysis and temperature contours and heat flux results for steady-state thermal analysis during the down packing procedure for the elements free and calamus dual thermoplasticized obturation system

	Elements free obturation system			Calamus dual obturation system		
	Cavity level					
	Coronal	Middle	Apical	Coronal	Middle	Apical
Von Mises equivalent stress (Mpa)						
Enamel	0.17	0.22	0.24	0.84	3.93	0.79
Dentin	0.32	0.35	0.33	1.03	0.36	1.27
PDL	6.13×10^{2}	6.39×10^{2}	6.27×10^{2}	8.24×10^{2}	0.33	8.35×10^{2}
Cortical bone	0.22	9.02×10^{2}	2.20×10^{1}	7.01×10^{12}	1.09	0.36
Cancellous bone	6.24×10^{2}	8.36×10^{2}	6.33×10^{2}	7.14×10^{2}	8.40×10^{2}	7.16×10^{2}
Mucosa	1.37×10^{11}	5.29×10^{12}	4.34×10^{12}	7.01×10^{12}	1.27×10^{10}	7.23×10^{12}
Total	0.2	0.23	0.23	7.50×10^{1}	1.72	7.80×10^{1}
Temperature plots (°C)						
Enamel	28.84	34.66	32.42	47.53	43.85	48.6
Dentin	30.06	36.67	34.712	53.95	49.44	56.72
PDL	32.97	38.92	38.153	58.01	53.43	58.11
Cortical bone	31.19	37.15	35.97	54.66	50.34	58.72
Cancellous bone	33.9	38.94	39.19	59.61	55.34	55.54
Mucosa	30.16	36.97	34.62	52.51	48.09	54.16
Total	31.36	37.4	34.95	51.96	47.64	53.73
Total heat flux (W/mm²)	7.78×10^{4}	9.95×10^{4}	1.23×10^{3}	1.82×10^{3}	1.75×10^{3}	1.95×10^{3}

PDL: Periodontal ligament

Similarly, the total average temperature observed was highest when the resorption cavity was in the apical third (53.73°C), followed by when the cavity was in the coronal third (51.96°C), and the least temperature readings were observed when the resorption cavity was in the middle third (47.64°C) for calamus dual obturation system [Table 1].

Transient thermal analysis

For the calamus dual system, when the remaining canal was backfilled up to 50%, the highest average temperature was recorded in the dentin when the resorption cavity was in the apical third (22.12°C) and in the cancellous bone (29.52°C) when the resorption cavity was in the coronal third. The total average temperature recorded during 50% of backfill was 23.04°C, 22.42°C, and 27.96°C for the position of the resorption cavity in the apical, middle, and coronal third, respectively. The total average temperature recorded during 100% of backfill was 24.46°C, 23.25°C, and 23.89°C for the resorption cavity in the apical, middle, and coronal third, respectively [Table 2].

During the transient thermal analysis of the backfill procedure using the elements free obturation system, it was observed that when the remainder of the canal was backfilled up to 100%, the highest average temperature was noted in the dentin when the resorption cavity was in the apical third (26.47°C) and coronal third (22.95°C) and in the enamel (22.19°C) when the resorption cavity was in the middle third. The total average temperature observed for 50% of backfill was 26.49°C, 22.93°C, and 22.38°C when the resorption cavity was in the apical, middle, and coronal third, respectively. The total average temperature observed for 100% of backfill was 24.3°C, 22.22°C, and 24.48°C for the resorption cavity in the apical, middle, and coronal third, respectively [Table 2].

It was observed that between the two systems, the elements free obturation system led to lower heat transfer and heat flux during the down packing procedure in comparison to the calamus dual obturation system in the steady-state thermal analysis.

DISCUSSION

Cold canal filling techniques using gutta-percha are thought to be inadequate to completely seal the internal resorption defects due to the difficulty associated with its adaptation and condensation as put forth by Agarwal *et al*.,[6] Collins *et al*.[7] New systems have been developed which utilize thermoplasticized gutta-percha in the obturation of root canals. The relationship of root fracture to obturation with thermally plasticized gutta-percha is not known. Hence, this study has been undertaken with the aim to evaluate the amount of stress and temperature changes caused by elements free and calamus dual thermoplasticized obturation systems during the continuous wave obturation technique using FEA.

Table 2: Temperature contours and heat flux results for transient thermal analysis during the backfilling procedure at 50% and 100% of the remainder of the canal for the elements free and calamus dual thermoplasticized obturation systems

	Elements free obturation system			Calamus dual obturation system		
	Cavity level					
	Coronal	Middle	Apical	Coronal	Middle	Apical
Temperature plots (°C) at 50%						
Enamel	22	22.19	26.09	27.33	22	22
Dentin	22.95	22.04	26.47	28.045	22	22.12
PDL	22.02	22	25.56	27.75	22	22
Cortical bone	22	22	25.51	27.515	22	22
Cancellous bone	22.01	22	24.67	29.52	22	22
Mucosa	22	22.05	26.43	28	22	22
Total	22.38	22.93	26.49	27.96	22.41	23.04
Total heat flux (W/mm²)	1.05×10^4	9.51×10^5	9.89×10^5	1.67×10^4	1.56×10^4	1.54×10^4
Temperature plots (°C) at 100%						
Enamel	24.09	22	24.02	23.45	22	24.06
Dentin	24.32	22.02	24.22	23.67	22.03	24.34
PDL	23.82	22	23.74	24.13	22.17	24.71
Cortical bone	23.79	22	23.69	24.05	22	24.59
Cancellous bone	23.36	22	23.27	24.2	22.01	24.62
Mucosa	24.27	22	24.19	23.84	22	24.52
Total	24.48	22.22	24.3	23.89	73.25	24.46
Total heat flux (W/mm²)	1.56×10^4	1.32×10^4	1.24×10^4	1.58×10^4	1.69×10^4	1.66×10^4

PDL: Periodontal ligament

It is commonly perceived that remaining dentin thickness (RDT) determines the temperature changes on the external root surface during obturation. Calişkan and Türkün[8] reported that in cases of thin walls, the heat can be rapidly transmitted to the external root surfaces, such as internal root resorption, and since internal root resorption is more common in maxillary central incisors as they are more prone to trauma, the clinical condition of internal root resorption in maxillary central incisors was considered in the present study.

FEA, which has been extensively used in analyzing the distribution of stress and temperature *in vitro*, is considered a fast and reliable alternative. Combined with a fracture strength test, FEA can provide comprehensive and convincing information about Vertical root fracture for practitioners to take better preventive measures. Hence, FEA method was used in the present study. This is in accordance with studies reported by Er *et al.*,[9] Dorow and Sander[10] who claimed that FEA as a methodology could prove to be advantageous as the longitudinal temperature changes of the entire model can be monitored as a dynamic process under the simulated working condition.[11-14]

In the present study, the anatomic dimensions of the supporting tissues were generated with the aid of a full volume CBCT of a skull with FOV 24 × 19 with emphasis on mimicking the periodontal ligament according to the data present in the literature, which is advantageous for the stress and heat transfer analysis. The FEA method requires mechanical properties of the components involved like Elastic Modulus, Poisson's ratio, Yield Strength of each enamel, dentine, pulp, and composite. Thus, helping standardize the nature and uniformity of the sample throughout the study. FEA helps to replicate a model multiple times, maintaining the uniformity of the model accurately, hence not requiring multiple samples. Similarly, in the current study, the models were replicated with high accuracy and standardization, which is in accordance with FEA studies carried out by Er *et al.*,[9] Chatvanitkul and Lertchirakarn,[15] Aslan *et al.*[16] and Cen *et al.*[17]

In the present study, the Von Misses equivalent stress for stress distribution was evaluated during the down packing procedure for the two thermoplasticized obturation systems. Wheeler's ratio was used to form the geometric model, this method provided comparable and uniform FEA models. Thus, in the present study, the anatomic dimensions of the supporting tissues were generated with the aid of a full volume CBCT of a skull with FOV 24 × 19 with emphasis on mimicking the periodontal ligament according to the data present in the literature, which is advantageous for the stress and heat transfer analysis and maintaining the uniformity of the model accurately, hence not requiring multiple samples.

When comparing the two systems, it was observed that elements free obturation system exerted lesser stresses than the calamus dual obturation system. Between the two systems, the elements free obturation system led to lower heat transfer during the backfill procedure in comparison to the calamus dual obturation system. These differences in the temperature changes can be attributed to differences in the backfill tip geometries as the backfill tip of elements free system has a variable stepped taper as compared to the calamus dual obturation systems backfill tip, which has a continuous hollow cylindrical tip contacting the canal walls more as compared to the elements backfill tip due to stepped tapered tip design and is in accordance with the findings of Ghorpade *et al*.[18] who reported in their study that 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 peak temperature at the alveolar bone adjoining the tooth root being obturated with thermoplasticized GP is reduced in the presence of a layer of the periodontium. This peak temperature is further reduced when blood flow is present within the PDL. Therefore, the cooling capacity of periodontal blood flow must be examined in the investigation of heat transfer during thermoplasticized root canal obturation.

In the current study, it has been observed that there was greater heat and stress transfer during the down packing procedure with a round cross-section thermoplugger of the calamus dual obturation system than the tapered flat-ended thermoplugger of the elements free obturation system. However, there is a paucity of literature findings on the difference in the cross-section of the thermoplugger tips and their effect on stress and heat transfer to the surrounding tissues during the continuous-wave condensation obturation technique.

CONCLUSION

1. When comparing the two thermoplasticized obturation systems, it was observed that the elements free obturation system exerted lesser stresses than calamus dual obturation system
2. It was observed that between the two systems, the elements free obturation system led to lower heat transfer and heat flux during both down packing and backfilling procedure in comparison to the calamus dual obturation system in the steady-state thermal analysis
3. There were higher temperature changes observed when the resorption cavity was in the apical third for both the systems; therefore, care should be exercised while obturating apical resorptive defects
4. It can be concluded that in the present study RDT was directly proportional to the amount of heat transferred to the surrounding tissues.

Acknowledgment

I wish to extend my sincere gratitude to, Dr. Vibha Hegde, who provided insight and expertise that greatly assisted the research. I would also like to thank my friends and family, who supported me and offered deep insight into the study.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

REFERENCES

1. Patel S, Ricucci D, Durak C, Tay F. Internal root resorption: A review. J Endod 2010;36:1107-21.
2. Ulusoy ÖI, Yılmazoğlu MZ, Görgül G. Effect of several thermoplastic canal filling techniques on surface temperature rise on roots with simulated internal resorption cavities: An infrared thermographic analysis. Int Endod J 2015;48:171-6.
3. Atrizadeh F, Kennedy J, Zander H. Ankylosis of teeth following thermal injury. J Periodontal Res 1971;6:159-67.
4. Line SE, Polson AM, Zander HA. Relationship between periodontal injury, selective cell repopulation and ankylosis. J Periodontol 1974;45:725-30.
5. Blum JY, Machtou P, Micallef JP. Analysis of forces developed during obturations. Wedging effect: Part I. J Endod 1998;24:217-22.
6. Agarwal M, Rajkumar K, Lakshminarayanan L. Obturation of internal resorption cavities with four different techniques: An *in-vitro* comparative study. Endod 2002;14:3-8.
7. Collins J, Walker MP, Kulild J, Lee C. A comparison of three gutta-percha obturation techniques to replicate canal irregularities. J Endod 2006;32:762-5.
8. Calişkan MK, Türkün M. Prognosis of permanent teeth with internal resorption: A clinical review. Endod Dent Traumatol 1997;13:75-81.
9. Er O, Yaman SD, Hasan M. Finite element analysis of the effects of thermal obturation in maxillary canine teeth. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2007;104:277-86.
10. Dorow C, Sander FG. Development of a model for the simulation of orthodontic load on lower first premolars using the finite element method. J Orofac Orthop 2005;66:208-18.
11. Cheng R, Zhou XD, Liu Z, Hu T. Development of a finite element analysis model with curved canal and stress analysis. J Endod 2007;33:727-31.
12. Cheng R, Zhou XD, Liu Z, Yang H, Gao QH, Hu T. Finite element analysis of the effects of three preparation techniques on stresses within roots having curved canals. Int Endod J 2009;42:220-6.
13. Ana PA, Velloso WF Jr, Zezell DM. Three-dimensional finite element thermal analysis of dental tissues irradiated with Er, Cr: YSGG laser. Rev Sci Instrum 2008;79:093910. doi:10.1063/1.2953526.
14. Santos AF, Tanaka CB, Lima RG, Espósito CO, Ballester RY, Braga RR, *et al*. Vertical root fracture in upper premolars with endodontic posts: Finite element analysis. J Endod 2009;35:117-20.
15. Chatvanitkul C, Lertchirakarn V. Stress distribution with different restorations in teeth with curved roots: A finite element analysis study.

J Endod 2010;36:115-8.
16. Aslan T, Üstün Y, Esim E. Stress distributions in internal resorption cavities restored with different materials at different root levels: A finite element analysis study. Aust Endod J 2019;45:64-71.
17. Cen R, Wang R, Cheung GS. Periodontal blood flow protects the alveolar bone from thermal injury during thermoplasticized obturation: A finite element analysis study. J Endod 2018;44:139-44.
18. Ghorpade R, Sundaram K, Hegde V. Thermal and stress analysis of Gutta Percha in simulated root canal using finite element analysis. Int J Mech Prod Eng Res Dev 2012;2:19-30.