

# Evaluation Of Stress Distributions In Mandibular Molar Tooth With Different Iatrogenic Perforations Repaired With Biodentine, Mta & Endocem-Zr: A Finite Element Analysis Study

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## Abstract

**Background :** Apart from the connections between anatomical structures, any communication between the root canal space and the external tooth surface is considered as perforation . **Aim :** In this study, finite element analysis (FEA) was used to evaluate the stress distributions in simulated mandibular molar teeth with various iatrogenic root perforation (IRP) types after reparation with Biodentine, mineral trioxide aggregate (MTA) and Endocem Zr. **Material Method :** An extracted human mandibular molar tooth was scanned using micro-CT device, and solid model was created. Then, four different IRPs (furcation perforation, strip perforation, coronal perforation and lateral root perforation) and three different repair materials (MTA and Biodentine, Endocem Zr) were simulated on the model. Consequently, a total of seventeen experimental models were designed. An oblique force of 300 N angled at 45° to the occlusal plane was simulated. Evaluations of von Mises stress were carried out in the perforated regions. **Results :** The overall maximum stress in the sound tooth model was observed to be 109.83 MPa followed by (CP/UR) model which was 108.4 MPa, which was 106.92 MPa, (LRP/E) which was 91.63 MPa and the least was observed in the (FP/UR) which was 82.085 MPa. **Conclusion :** The use of MTA and Biodentine may reduce the risk of potentially harmful stresses in root perforation regions.

**KEYWORDS :** Biodentin, MTA, EndocemZr, von mises stress, perforation.

## INTRODUCTION :

Maintaining the integrity of the natural dentition is essential for fully functional and esthetic conditions. Perforations are artificial openings in root walls created by boring, piercing, cutting, or resorption that result in a communication between the pulp space and periodontal tissues. Perforation may be created as a result of inadequate removal of the pulp chamber roof that results in misdirection of a bur during access preparation. In a malaligned tooth, perforation may result if a bur is not properly angulated in relationship to the long axis of the

tooth<sup>[1]</sup> Perforations that are apical to crestal bone and epithelial attachment are observed to have good prognosis however prognosis depends upon cleaning, shaping and obturation procedures. <sup>[2]</sup>

MTA is a fine powder primarily composed of tricalcium silicate, tricalcium aluminate, tricalcium oxide, and silicate oxide that upon hydration, forms a colloidal gel that solidifies in approximately 3 h. Therefore, when used as a root repair material, although the periradicular tissues provide some moisture from the external surface of the material, to assure proper setting, moisture must also be provided from the internal aspect of the root using a moist cotton pellet.<sup>[3]</sup>

Recently, a new type of MTA derived from pozzolan cement, ENDOCEM Zr(Maruchi, Wonju, Korea), has been introduced. According to the manufacturer, ENDOCEM Zr is advantageous because of its rapid setting (4 minutes) and manipulation properties, maintaining a chemical composition similar to that of commercially available MTA (calcium oxide [46.7%]; silicon dioxide [12.8%]; aluminum oxide [5.4%]; bismuth oxide [11%], with zirconium oxide acting as the radiopacifying agent.8 Zirconium oxide has been employed as a radiopacifier of calcium silicate-based endodontic materials as a substitute of bismuth oxide, because bismuth oxide retards the setting reaction of MTA.<sup>[4]</sup>

Finite element analysis (FEA) is a numerical method of analysing stress and deformation in the structures of any given geometry; thus, it a powerful technique in dental biomechanics. Iatrogenic root perforations (IRPs) can cause several biological damages. Therefore, we evaluated the maximum von Mises stresses (the value used to determine if a given material will yield or fracture) using FEA in the simulated tooth with different IRPs, after repairing with Biodentine, MTA and Endocem - Zr. <sup>[2]</sup>

## MATERIAL & METHODS

Single extracted permanent mandibular molar tooth with completely formed apex was selected for study.

### 1st MICRO CT SCAN :

An extracted sound human mandibular molar tooth with a regular crown and root morphology was scanned at 21 µm voxel size, 80 kV X-ray tube voltages and 125 µA anode current using a micro-CT device (Phoenix Vtomx s by GE, Germany).

The access cavity was prepared on the same tooth with a high-speed handpiece under water cooling using round bur and endo access bur. Confirmation of apical patency was performed with #10K files and biomechanical preparation was done with the ProTaper Gold system (Dentsply Maillefer) Ballaigues, Switzerland).

### 2 nd MICRO CT SCAN

Afterwards, the prepared tooth was 80 subjected to a second micro-CT scan using the device settings in the first scan.

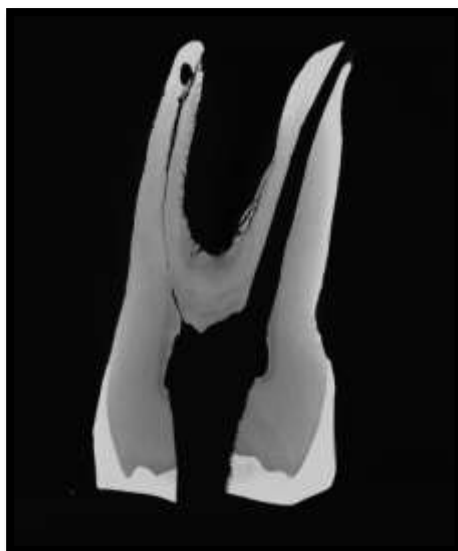


Figure 1 : Micro Ct image of tooth

### CREATION OF 3D MODELS :

The files were configured using dedicated software and then converted into one stereolithography (STL) file with CTAn software. The three-dimensional (3D) surface model with STL format was converted into a 3D solid model by Geomagic Design X software (Geomagic, Inc., Morrisville, NC, USA).



Figure 2 : Meshing Models

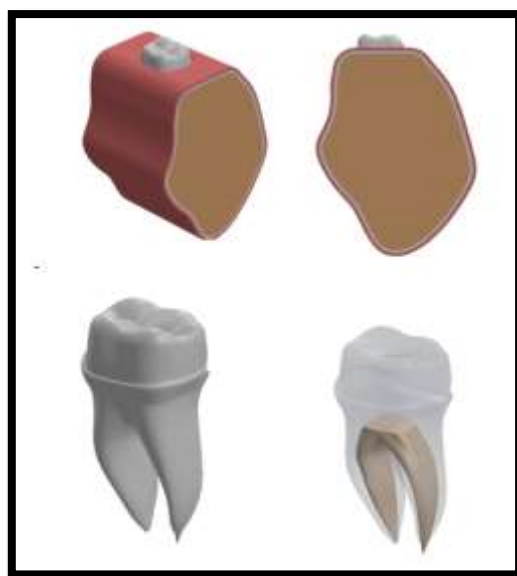


Figure 3 : Geometrical models of sound tooth

### CREATION OF PERFORATION ON TOOTH MODEL :

Four different types of Iatrogenic Root Perforations were then designed on the 3D solid model obtained by second micro-CT scan, using SolidWorks software (SolidWorks Corp., Waltham, MA, USA). These perforations were repaired using Biodentine, MTA and Endocem Zr.

Then, root canals were filled with gutta percha after the perforation regions repaired, and access cavities were filled with composite resin. To evaluate the von Mises stress for each iatrogenic root perforation (Furcation perforation, strip perforation, lateral root perforation and coronal perforation), the repair material (Biodentine, Endocem Zr and MTA) were used.

To compare the sound tooth with other perforation models, 4 different regions of the sound tooth corresponding to the perforation regions were taken into consideration : Sixteen models were created and one control group were as follows:

**(Sound Tooth) Control group** : Simulated sound tooth model without any type of perforation.

### FURCATION PERFORATION MODELS

**FP/M** : Simulated FP repaired with MTA

**FP/BD** : Simulated FP repaired with Biodentine

**FP/E** : Simulated FP repaired with Endocem Zr

**FP/UR** : Simulated FP left unrepaired

### STRIP PERFORATION MODELS

**SP/M** : Simulated SP repaired with MTA

**SP/BD** : Simulated SP repaired with Biodentine

**SP/E** : Simulated SP repaired with Endocem Zr

**SP/UR** : Simulated SP left unrepaired

### LATERAL ROOT PERFORATION MODELS

**LRP/M** : Simulated LRP repaired with MTA

**LRP/BD** : Simulated LRP repaired with Biodentine

**LRP/E** : Simulated LRP repaired with Endocem Zr

**LRP/UR** : Simulated LRP left unrepaired

### **CORONAL PERFORATION MODELS**

**CP/M** : Simulated CP repaired with MTA

**CP/BD** : Simulated CP repaired with Biodentine

**CP/E** : Simulated CP repaired with Endocem Zr

**CP/UR** : Simulated CP left unrepaired

### **CREATION OF FURCATION PERFORATION MODEL :**

In the furcation perforation (FP) model, a perforation with an average diameter of 1.0– 1.2 mm (the diameter of an average fissure bur) and a length of 2 mm extending from the pulp chamber of the mandibular molar tooth model to the bifurcation region was created.



**Figure 4: Furcation Perforation Model**

### **CREATION OF STRIP PERFORATION MODEL:**

In the strip perforation (SP) model, on the inside of the mandibular molar tooth's mesial root curvature, a 1.2-mm-wide and 7-mm-long perforation was created in the region between the middle and cervical thirds of the root, simulating the misuse of a Gates Glidden bur.



**Figure 5 : Strip Perforation Model**

**CREATION OF LATERAL ROOT PERFORATION MODEL:**

In the lateral root perforation (LRP) model, perforation was created at the middle third of the distal root of the mandibular molar, extending from the root canal system to the periodontal ligament.



**Figure 6 : Lateral Root Perforation Model**

**CREATION OF CORONAL PERFORATION MODEL:**

In the coronal perforation (CP) model, a 10-mm-long perforation opening with diameter of 2 mm was created in the coronal segment of the mandibular molar, extending from the cusp to cemento enamel junction. <sup>[5]</sup>

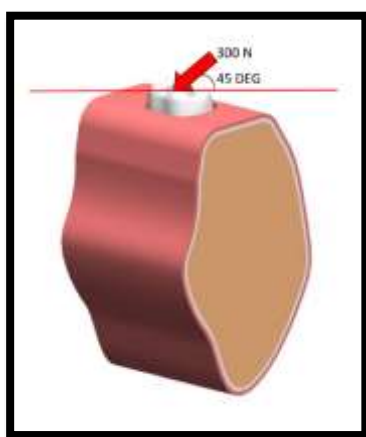


**Figure 7 : Coronal Perforation Model**

These models were repaired with 3 different repair materials which were simulated and filled at the perforation site. These were repaired with MTA, Biodentin and Endocem – Zr.

### LOADING CONDITION AND STRESS ANALYSIS

An oblique force of 300 N angled at 45° to the occlusal plane was simulated and oriented toward the buccal side. In all loading situations, it is assumed that the simulated alveolar bone is fixed to prevent rigid trunk movement of the mesial and distal surfaces. von Mises stress evaluations were carried out in the dentine tissue at the tooth regions adjacent to the perforation areas using ANSYS software. The highest equivalent stresses (MPa) in the entire tooth structure and perforation areas were selected hand-picked taking into account the colour scale, and they were recorded.



**Figure 8 : Force of 300N angulated at 45 degrees**

### RESULTS :

VON MISES STRESS TABLE				
S.NO.	MODEL NAME	MATERIAL MODEL	MAXIMUM VON MISES STRESS VALUES IN (MPa)	MAXIMUM STRESS VALUE AT PERFORATION IN (MPa)
1	FURCATION PERFORATION (FP)	FP/E	82.062	7.77
		FP/MTA	82.07	6.4
		FP/BD	82.067	7.33
		Unrepaired	82.085	6.05
2	STRIP PERFORATION	SP/E	106.85	12.8
		SP/MTA	106.92	11.53

	(SP)	SP/BD	106.91	8.7
		Unrepaired	106.91	14.6
3	LATERAL ROOT PERFORATION (LRP)	LRP/E	91.63	12.44
		LRP/MTA	77.346	12.331
		LRP/BD	77.324	11.549
		Unrepaired	77.384	10.95
4	CORONAL PERFORATION (CP)	CP/E	104.37	18.7
		CP/MTA	91.013	16.8
		CP/BD	92.143	17.56
		Unrepaired	108.4	20.2
5	SOUND TOOTH		109.83	10.361

- **COMPARISON OF THE MAXIMUM STRESSES AMONG UNREPAIRED PERFORATION MODELS:**

When the stresses were compared among the unrepaired group of all the perforation types that is furcation perforation, strip perforation, lateral root perforation and coronal perforation the maximum von mises stress was observed in coronal perforation group (CP/UR) that was 20.2 MPa followed by lateral perforation group (SP/UR) that was 14.6MPa , furcation perforation group (LRP/UR) that was 10.957 MPa and least von mises stress was observed in lateral root perforation group (FP/UR) that was 6.05 MPa.

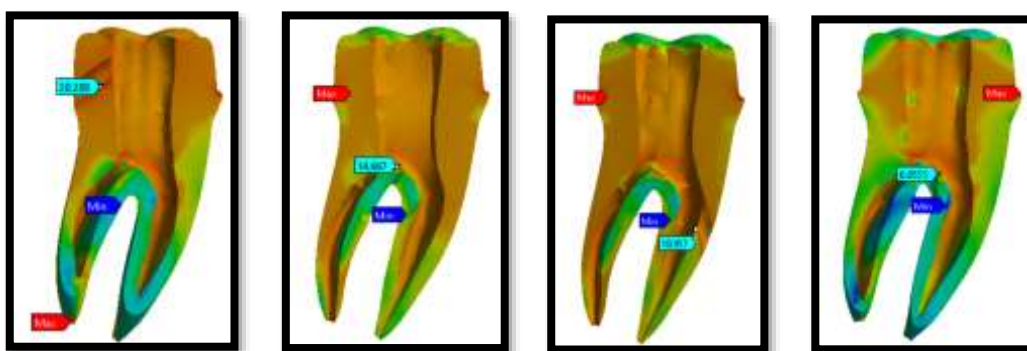


Figure 33 : **CP/UR** Figure 34: **SP/UR** Figure 35 : **LRP/UR** Figure 36 : **FP/UR**

- **STRESS DISTRIBUTIONS IN THE OVERALL ASPECT OF TOOTH DENTINE STRUCTURE:**

The maximum von mises stress value observed in the sound tooth model (control group) was higher than the other tested models. The overall maximum stress in the sound tooth model was observed to be 109.83 MPa followed by (CP/UR) model which was 108.4 MPa, (SP/MTA) which was 106.92 MPa, (LRP/E) which was 91.63 MPa and the least was observed in the (FP/UR) which was 82.085 MPa.

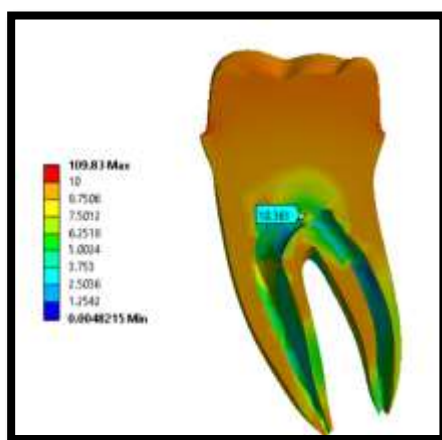


Figure 37 : Sound tooth model

## DISCUSSION

Procedural accidents are eventualities that may occur during endodontic treatment because of lack of attention to detail or even unforeseeable situation. Perforations which are located coronal to this zone have a good prognosis.<sup>[6]</sup> Perforations in the furcation area of multirooted teeth are regarded usually as crestal root perforations because of the proximity to the epithelial attachment and the gingival sulcus. Seltzer et al. have stated that perforations of in furcation region of molars are especially troublesome because they cause considerable damage and frequently lead to periodontal involvement of the furcation. Beavers et al. however, showed a 100% success rate in treatment of furcation perforations.<sup>[7]</sup>

Mesiobuccal roots of maxillary and mandibular molars are highly susceptible to strip perforation because of thin dentinal walls.<sup>[8]</sup> Strip perforation differs from other perforations because of its large affected area, irregular edge of the perforation site and difficulty in sealing ability.<sup>[9]</sup>

Many materials used for managing perforations such as: glass ionomer and resin modified glass ionomer, zinc oxide–eugenol, amalgam, calcium hydroxide and composite resin. But none of them fulfill the criteria of an ideal repair material that include sealing ability, biocompatibility and ability to induce osteogenesis and cementogenesis.<sup>[8]</sup> Thus in my study, the material of choice for perforation repair were MTA, Biodentine and Endocem-Zr due their above mentioned properties.

Mineral trioxide aggregate has several advantages over other materials while being used for perforation repair. It is very biocompatible, rarely provoking any response from the periradicular tissues. After placement of MTA, a cementum-like material has been consistently shown to grow directly on this material.<sup>[10]</sup>

Biodentine is recommended for use as a dentin substitute and an endodontic repair material because of its good sealing ability, high compressive strength, short setting time, biocompatibility, bioactivity and biomineralization properties.<sup>[11]</sup>

To overcome the limitation of MTA which includes long setting time, low washout resistance and tooth discoloration potential the third material of choice was ; ENDOCEM<sup>®</sup>Zr (Maruchi, Wonju, Korea), a pozzolan cement derived from MTA was developed. However, the radiopacifier in MTA, i.e., bismuth oxide, has been substituted with zirconium oxide in ENDOCEM-Zr.

FEA is a numerical technique used for evaluating and analyzing stress distribution patterns. The samples in laboratory fracture resistance tests are not standardized due to the variation in the anatomy of extracted teeth.

Conversely, Finite Element Analysis devises comparable standardized 3D models allowing visual assessment of stress distribution. Therefore, it can serve as an optimal tool to estimate the biomechanics of a tooth under simulated occlusal stresses.<sup>[12]</sup> According to the results obtained, perforated models with repair exhibited higher stress values than their equivalent sites in the control group (Table 2). It has been reported that the amount of the residual dental tissue influences the level of residual stress concentration, possibly explaining the occurrence of high-stress concentration in the repaired perforation sites.<sup>[13]</sup>

One reason for the very good sealing ability of MTA, when used in the furcation perforation repair is the excellent adaptation of the material to the external margins of perforation cavities.<sup>[13]</sup> White et al. reported that MTA and sodium hypochlorite reduce the fracture susceptibility of bovine dentin by 33% and 59%, respectively.<sup>[14]</sup> A finite element analysis showed that the materials with similar modulus of elasticity to dentin could reinforce the weak roots. The results of this study is in agreement with those of Bortoluzzi et al, Hatibovic-Kofman et al. and Milani et al. who found a significant increase in fracture strength of dentin when the teeth were filled with MTA.<sup>[15]</sup> Compressive strength is important when MTA is used as a base material, in the repair of furcal perforations (Islam et al. 2006a).

On the contrary, Biodentine showed the least stress concentration at the perforation site in the SP/BD group that was 8.7 MPa and LRP /BD group that was 11.549 MPa amongst the repaired strip perforation models and lateral root perforation models respectively. Biodentine has a specific feature of its capacity to continue improving in terms of compressive strength with time until reaching a similar range with natural dentine.<sup>[16]</sup>

Amongst all groups Endocem Zr showed the maximum stress concentration. Addition of zirconium oxide powder as radiopacifying material did not seem to affect the compressive strength of the resultant material. This is in accordance with previous studies investigating the effect of varying additions of bismuth oxide to cement in an MTA system but contrary to other researchers claiming that the addition of bismuth oxide adversely affected the compressive strength of MTA in a dose related manner.<sup>[17]</sup>

The average maximum von mises stress in the overall tooth structure was observed in coronal perforation models (104.37 MPa) followed by strip perforation (106.91MPa) then furcation perforation models (82.07 MPa) and least was observed on the lateral root perforation model (77.38 MPa). The loss of free water from the inner dentine after endodontic therapy can lead to alterations in the stress distribution.

Among the unrepaired models the maximum von mises stress was observed in coronal perforation group (CP/UR) that was 20.2 MPa followed by lateral perforation group (SP/UR) that was 14.6MPa , furcation perforation group (LRP/UR) that was 10.957 MPa and least von mises stress was observed in lateral root perforation group (FP/UR) that was 6.05 MPa. An explanation for these findings is that the perforation zone was empty in the unrepaired models, and thereby stresses were concentrated in these regions. In addition, it can be suggested that MTA and Biodentine have a very similar modulus of elasticity with dentin (Table 1) and function as a dentine structure, thereby retaining stress within their structure and sharing stress with dentine.

The findings of this study conferred that the presence of perforation at different sites after repair affected the stress accumulation and distribution in mandibular molar. A direct correlation between the FEA results and clinical outcome may be debatable as the treatment outcome is also affected by various other patient-related and operator-related factors. The present results only provide qualitative theoretical data and hence are to be evaluated with caution for clinical decision-making in teeth with perforations and their subsequent repair.

## **CONCLUSION :**

Acknowledging the limitations of the study, it can be concluded that:

1. The site of perforation affected the stress distribution and accumulation within the models.
2. The use of MTA and Biodentine reduced the risk of stress concentration in all iatrogenic root perforations types.
3. The maximum von mises stress values was observed to be comparatively higher in the all the groups repaired with Endocem Zr.

However, more prospective clinical studies are necessary to draw definitive conclusions.

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Nil

### Conflicts of interests :

There are no conflicts of interest.

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