Comparative study on stress analysis in human molar tooth between metallic and nonmetallic dental filling material

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Abstract. Dental filling is regarded as proven dental restoration method in dealing with partial missing of tooth crown due to caries or trauma. This study analyses the reliability and durability of materials for dental filling using finite element analysis. Specifically, it determines the stress induced at a dental filling due to occlusal load. Two filling depths were simulated: (a) filling depth in enamel and (b) filling depth in enamel/dentine on top of molar tooth. Dental filling made of glass ionomer cement (GIC), composite, and amalgam (as a reference material) which represented metallic and non-metallic filling materials were chosen as the materials for this study. A 100 MPa pressure was applied on the dental filling to represent an occlusal load. The results obtained were the stress (magnitude and distribution) for enamel/amalgam, enamel/GIC, enamel/composite, enamel/dentine/amalgam, enamel/dentine/GIC, and enamel/dentine/composite. It was found that the maximum induced stress was higher for enamel/dentine depth while there is no significant difference in stress magnitude for all dental filling materials.

1. Introduction

Dental filling basically replaces the partially lost tooth structure due to external causes such as trauma or dental caries and is subjected to similar variety of load as intact tooth. These loads may be due to mastication, swallowing, biting, chewing, speech, clinching, bruxism and also by the action of tongue, perioral and circumoral musculature [1]. This required biologically compatible replacement of tooth crown. It is interesting to note that to date there is still no filling material that has properties similar to dental crown (enamel and dentine).

In the past years, studies have been done using finite element analysis on dental filling. Some looked at the biomechanics which is also related to compatibility, mechanical and clinical behavior of filling materials. Others discussed about the development of modelling techniques in outlining the risk of failure in filling materials. In a previous study, the authors [1] stated that improvement in computer modelling render the finite element method a very reliable and accurate approach in biomechanical applications. The advantage of finite element analysis to alter structures and material properties under controlled conditions is described in previous literature [2].
Amalgam is the commonly used dental filling material, considering its relatively low cost, mechanical strength sufficient to apply in posterior teeth, ease of preparation, and ease of applying. However, considering amalgam contains mercury and its aesthetic is low, alternative filling materials are made available. A previous study to investigate the stress analysis in amalgam and porcelain dental fillings found that amalgam outperforms porcelain in terms of stress [3]. This study intends to make comparison between amalgam and other nonmetallic filling materials which are commercially available. Composite and glass ionomer cements are the materials of interest in this study. Both are dental fillings that have visually similar look as tooth and bond well to dental tissue, suitable for posterior teeth restoration [4]. Clinically, use of composite filling for class II restoration recorded 100% retention rate after over 3.5 years, showing no recurring caries, sensitivity, or fractures [5].

Dental filling functions when the material can withstand the loads (mechanical or thermal) it is subjected to and there is proper bonding between the dental filling and the tooth it attaches on. Both can be analysed with revealing the stress induced in the dental filling. This study intends to determine the stress induced on a dental filling on a tooth, loaded with mastication load, using finite element analysis. Scenarios where dental filling material only restores the enamel and when it is restoring both enamel and dentin were simulated.

2. Materials and methods
The developed three-dimensional model represents an approximate physical model of human third molar. Two software, a computer-aided design SolidWorks (Dassault Systemes S.A.) and a finite element analysis Abaqus FEA v. 6.13 (Dassault Systemes S.A.) were used in this study.

A solid model was created [3] from the mean dimensions of a large population of sound teeth based on Asian people which represented an “average” lower third molar (posterior) using the SolidWorks. The restored molar tooth was divided into parts (enamel, dentine, adhesive and filling) which were then exported into an ACIS SAT 3D file. The three-dimensional model was filled with tetrahedral (C3D10M) elements and the meshing was created with 0.3 mm long elements using Abaqus. A convergence test was done [6]. It was indicated that convergence was achieved when using elements smaller than 0.5 mm in length. The generated model consisted of 161316 elements. All other nodes were given three degrees of freedom (X, Y and Z). The classification for dental filling shape [7] is Class I, i.e. caries affecting on occlusal surface of molar tooth.

The occlusal load during chewing and biting for molar tooth was presumed to be a pressure (P) of 100 MPa on top of the enamel/filling surface as shown in figure 1. This pressure is equivalent to a force of 380 N as reported by previous work [8, 9]. The root was made to be fully constrained in all direction.

![Figure 1](image-url)  
**Figure 1.** Geometry model used in this study: (a) Restored molar tooth with constrains fixed to the root and vertical occlusal load (P) applied to enamel/filling surface area. (b) Sectional view of restored molar tooth with adhesive layer, (c) composite filling [3].
Following assumptions were made into the model:

i. Complete bonding between enamel and dentine,

ii. Pulp was not included in the model,

iii. Root of the tooth was not included in stress analysis,

iv. There was no time-dependent behavior of the elastic modulus of the materials,

v. Only static loading was applied, and

vi. The dental filling has uniform cylindrical shape as the basis comparison.

The material types and properties of the tooth as described by [6, 10, 11] are listed in table 1. All materials, tooth structures (enamel and dentine) were modeled as isotropic, homogeneous materials. For composite filling case study which required bonding agent, the adhesive layer between the filling material, enamel and dentine has been included in the model shown in figure 1. For that purpose, a thickness for the adhesive layer is defined in accordance to [12, 13]. GIC type II is used in this study which serve as filling materials as classified by [14].

| Material            | Young’s Modulus, $E$ [GPa] | Poisson’s ratio, $v$ | References |
|---------------------|---------------------------|---------------------|------------|
| Amalgam             | 50                        | 0.29                | [6]        |
| GIC (Fuji IX GP)    | 10.8                      | 0.30                | [11]       |
| Composite           | 15                        | 0.30                | [10]       |
| Adhesive            | 4.5                       | 0.30                | [10]       |
| Enamel              | 80                        | 0.30                | [6]        |
| Dentine             | 20                        | 0.31                | [6]        |

3. Results and discussion

All the finite element analysis of restored molar tooth with amalgam, composite and GIC are performed under static loading with magnitude of 100 MPa occlusal load with two different filling depths. The results indicate that maximum value of stress (Von Mises) for enamel/amalgam, enamel/GIC, enamel/composite, enamel/dentine/amalgam, enamel/dentine/GIC and enamel/dentine/composite fillings are 257 MPa, 259 MPa, 258 MPa, 292 MPa, 292 MPa and 293 MPa, respectively. The highest magnitude of stress is found in enamel/dentine/GIC filling and lowest magnitude of stress is observed in enamel/amalgam filling.

The overview of stress distribution and magnitude within the dental filling and restored molar are presented in figures 2 and 3. Each of the model shows different stress distribution as well as stress magnitude.

![Figure 2](image_url)

Figure 2. Von Mises stress distribution in dental filling using: (a) enamel/amalgam, (b) enamel/composite, (c) enamel/GIC, (d) enamel/dentine/amalgam, (e) enamel/dentine/composite and (f) enamel/dentine/GIC as the filling materials.
From figure 2, generally the stress is lower in enamel depth fillings compared to enamel/dentin depth fillings. This shows a good agreement with past study [15] where smaller restorations showed better survival compared with larger restorations and the more surfaces a restoration covered the greater the chance of failure. Stress distribution and magnitude in enamel/GIC filling was the lowest of all fillings. Enamel has higher stiffness compared to dentin. Hence, more stress was borne by the enamel, leaving less to be borne by the dental filling. Dentin has lower stiffness than enamel. Hence, less stress is induced at the dentin compared to at the enamel. GIC has the lowest Young’s modulus of the dental filling materials. Consequently, this makes the most stress was borne by the tooth region when GIC was used. Although, it should be noted that the difference in maximum stress magnitude is not significant compared to the other two filling materials.

![Figure 3. Von Mises stress (MPa) distribution for the Class I restored molar tooth using: (a) enamel/amalgam, (b) enamel/composite, (c) enamel/GIC, (d) enamel/dentine/amalgam, (e) enamel/dentine/composite and (f) enamel/dentine/GIC as the filling materials. For the clarity, dental fillings are not shown.](image)

Seen through the tooth’s cross section in buccal-lingual direction (figure 3), the location of the maximum stress resulting from occlusal loading of the restored tooth can be seen more clearly. For enamel depth fillings, high stress occurs predominantly at the bottom surface of enamel/filling interface, as evident in figures 3(b) and 3(c). While for enamel/dentin depth fillings, high stress is concentrated in dentine wall and occlusal surface. The former can be attributed to the lower mechanical properties of the dentin compared to enamel. It should be noted that the filling materials gave no significant effect on the maximum stress magnitude for the same depth of filling.

To have clear results on the stress magnitude on occlusal surface, the magnitude of stress can be plotted against its location. In figure 4, the path outlines are indicated with the red-coloured line. Both paths are plotted on the occlusal surface between the dental tissue (enamel) and filling material which covered the loading area. Von Mises stress was assessed along these paths (figure 5). Two paths are defined in these models, i.e. (a) following the mesial and distal wall profiles of the tooth and (b) following buccal and lingual wall profiles of the tooth.

Overall, the stress induced on occlusal surface is lower than the stress in filling-tooth interface, both for enamel depth and enamel/dentin depth. From figure 5, the enamel/dentine/GIC filling has the highest magnitude of stress which exceeds 180 MPa, while the lowest magnitude of stress is found in enamel/amalgam filling, which is close to 80 MPa. In figure 5(a), points 0.2 and 0.8 and in figure 5(b),...
points 0.1 and 0.9 are points of enamel/filling interface respectively. This means the highest stress occurs at the filling/tooth interface. This interface is where the expected failure to occur when a static load is applied. This finding supports previous report [6] that found the highest stress is along the filling/tooth interface.

**Figure 4.** Paths defined in restored molar tooth considering the area of loaded enamel/filling surface. (a) Path A-B mesial-distally directed and (b) Path A’-B’ buccal-lingual directed.

Another point to note is that a material can be a failure when the magnitude of stress exceeds their strength. The strength of amalgam is 380 – 414 MPa, GIC (Fuji IX GP) is 88 MPa [11, 16] and composite 300 MPa [17]. Considering the stress induced and the strength of filling material, it is likely that GIC will fail due to the occlusal loading of 100 MPa. This is because the maximum stress induced at occlusal surface is 180MPa, and it is even higher at internal interface of filling/enamel beneath the occlusal surface, while its strength is only 88MPa. Composite and amalgam dental fillings are likely to survive the simulated masticatory load.

**Figure 5.** Von Mises stress along previously defined (a) path A-B and (b) path A’-B’ for Class I dental filling. (Note: EA: Enamel/Amalgam, EG: Enamel/GIC, EC: Enamel/Composite, DA: Enamel/Dentine/Amalgam, DG: Enamel/Dentine/GIC, and DC: Enamel/Dentine/Composite filling.)
4. Conclusion
Finite element analysis was performed to investigate the stress (distribution and magnitude) in a Class I restored molar tooth loaded by masticatory load. The variation parameters were filling depth (enamel depth and enamel/dentin depth) and filling materials (composite, GIC, and amalgam). Under the load, it can be concluded that

1. Stress at enamel/dentin depth filling is higher than at enamel depth filling, regardless of the filling material.
2. There is no significant difference in stress for all dental filling materials.
3. The highest stress occurs at interface between filling and tooth for all dental fillings.
4. Maximum stress can be used to determine whether dental filling fails under the load. In this case, GIC is likely to fail.

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