Original Research

Evaluating the Effect of Dental Filling Material and Filling Depth on the Strength and Deformation of Filled Teeth

Seifollah Gholampour[1], Ghazale Zoorazma[2], Ehsan Shakouri[3]

[1]Assistant professor of Biomechanical Engineering, Department of Biomedical Engineering, Tehran North Branch, Islamic Azad University, Tehran, Iran.
[2]Student of Biomechanical Engineering. Department of Biomedical Engineering, Tehran North Branch, Islamic Azad University, Tehran, Iran.
[3]Assistant professor of Mechanical Engineering, Department of Biomedical Engineering, Tehran North Branch, Islamic Azad University, Tehran, Iran.

Received 28 June 2016 and Accepted 16 September 2016

Abstract

Background and aim: It is important to evaluate the effect of the type of filling material on deformation and strength of tooth after filling and also the effect of filling depth on quality of restoration of a decayed tooth. **Material and Methods:** The Orthopantomogram (OPG) of the first and second molars of a 28-year-old man was made and the teeth were 3D modeled. The stress-deformation analysis was then performed on the models in the three states of normal tooth, tooth filled with amalgam and tooth filled with composite using finite element method under a distributed load of 400N equivalent to chewing force. Two values (1/2 and 1/3 of the tooth height) were considered for filling depth in the analyses. **Results:** The results showed that the normal first molar was exposed to a 7.2% greater risk of dental injuries compared to the normal second molar and also a greater stress is created in it when it is filled with composite. The first molar filled with a composite material is 13.7% weaker than the normal tooth while it is almost as strong as a normal tooth when it is filled with amalgam. The effect of the type of filling material on the strength and deformation of the second molar was trivial. **Conclusion:** Amalgam is a more proper dental filling material for the first molar although a 16.7% change in drilling depth is needed for tooth preparation. Dental filling material and filling depth have a small effect on the strength and deformation of filled second molars.

Key words: Amalgam, composite, tooth strength, filling depth, tooth deformation

.

Gholampour S, Zoorazma G, Shakouri E. Evaluating the effect of dental filling material and filling depth on the strength and deformation of filled teeth. J Dent Mater Tech 2016; 5(3): 172-180.

Introduction

Tooth decay is one of the most common diseases in the oral and maxillofacial region and 29% to 59% of individuals over the age of 50 experience it at least once (1). Depending on the type of decay and it's intensity, decayed teeth are either restored or replaced with implants. Filling is the most common treatment for decayed teeth and amalgam and composite fillings are used most commonly as dental filling materials (2, 3).

Photoelastic analysis and Finite Element Method (FEM) are among the main methods of investigating and analyzing biophysical stress in restored teeth (4). FEM is the best method for numerical analysis of mechanical properties in a filled tooth (5). Chimello et al. calculated mechanical parameters of a normal tooth under a concentrated compressive loading through 3D modeling using FEM. They evaluated and compared the stress exerted in various conditions on a normal tooth as well (3). Cornacchia et al. investigated tooth strength under various loadings using 3D FEM modeling and compared the effects of concentrated and distributed loads on tooth strength (6).Ashrafi et al. in a recent study, analysed the effect of loading type on the stress exerted on periodontal ligament in premolar and incisor teeth using FEM. They investigated the effect of loading type – distributed or concentrated – on the shear stress exerted on the sides of the teeth (7). Other studies like that of Noort et al. Analyzed the shear and normal forces exerted on teeth two dimensionally (8). Considering complexities of teeth, however, it is necessary to use 3D models for analyses (9). However, none of these studies considered tooth decay and the probable effect of dental fillings in their analysis. They only examined the mechanical parameters in normal teeth under various conditions.

Barden et al. introduced modified composites in dentistry in the early 1990s and examined the effects of various dental composites used for restoring decayed teeth(10). Restorative materials like amalgam, gold and porcelain were developed as dental fillings in the mid-19th-century (11, 12). Vrijhoef et al. investigated the biomechanical properties of amalgam fillings and proposed a tensile test device with proper technical features for these measurements (13). It should be noted that the most important finding of this study was the presentation of the most suitable biomechanical model for numerical simulation of a filled tooth. The results of the study showed that a linearly elastic model is the most suitable model for tooth analysis (13). Mahler et al. evaluated the biomechanical parameters in a decayed tooth before and up to one week after filling. They compared these parameters with each other and monitored the changes during this period (14).

One of the most important parameters that help dentists to assess the quality of a filled tooth is the effect of the type of dental filling on the strength of a filled tooth. The improved cements are also considered as relatively common filling materials. The aim of the present study was to compare the mechanical properties of teeth filled with amalgam and composite, the two most commonly used filling materials in Iran. According to the study by Goel et al., the size of the cavity can be effective in the strength of a filled tooth (15).Therefore, in addition to examining the strength of teeth filled with amalgam and composite under similar loadings, the results were compared in the first and second molars with different geometry and cavity size. Moreover, the effect of filling depth on tooth strength was evaluated numerically.

Materials and Methods

The Orthopantomogram (OPG) of the decayed first and second molars of a 28-year-old man was produced in the present study (Fig. 1). The images were made in 196 slices and the imaging protocol was similar to that in the study by Goktas et al. (16). The data acquired from imaging was then transferred to Mimics software version 10.01 to produce the point clouds. The obtained point clouds were transferred to the 3-Mathic software version 9.0 and thereafter the 3D solid model of the both teeth was created (Fig. 2). It is noteworthy that according to previous studies, FEM is the most appropriate technique for analysis of the force exerted on teeth (17, 18), so the models were transferred to ABAQUS version 6.14-2 for FEM analysis.

It is important to mention that all analyses were performed in three states: normal first and second molars without decay, two teeth filled with composite fillings and two filled with amalgam. The type of decay to be studied was chosen according to a cavity form surrounded by four lateral walls. Furthermore, to analyse the effect of filling depth on the quality of restoration, the analyses were performed in two filling depths of 1/2 and 1/3 of the tooth height and the results were compared with each other.

Loading and Mechanical properties

The amount of chewing force exerted on teeth was 400N and applied as a distributed load to the upper surfaces of both teeth (19, 20).The contact area of the teeth with gingiva was constrained in three directions. Table 1 presents the biomechanical properties of teeth, composite and amalgam fillings (21).

One of the main concerns in FEM analysis of teeth is the meshing conditions of a 3D model (22). The elements used in analysis of 3D models of teeth were C3D4 which is a linear tetrahedral element. A total of 35574 elements were used for meshing the first molar and 53870 for the second molar.

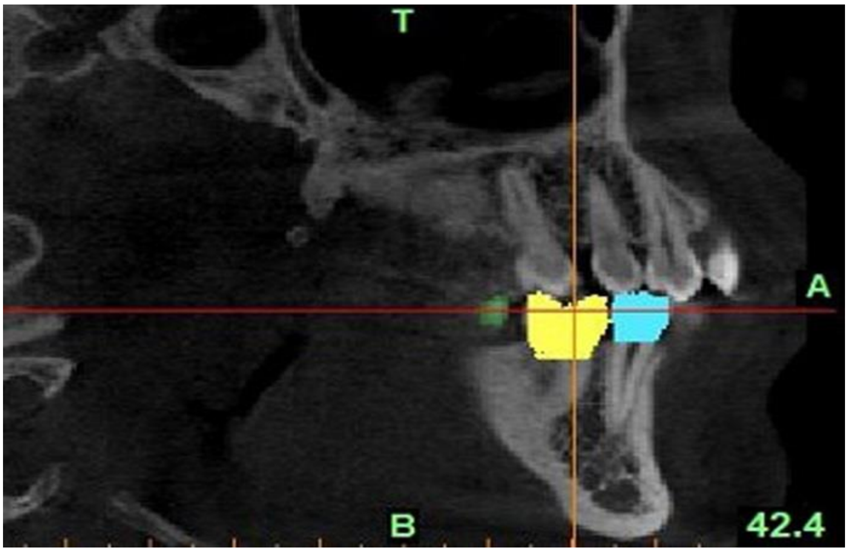


Figure 1.Radiography image of the first and second molars.

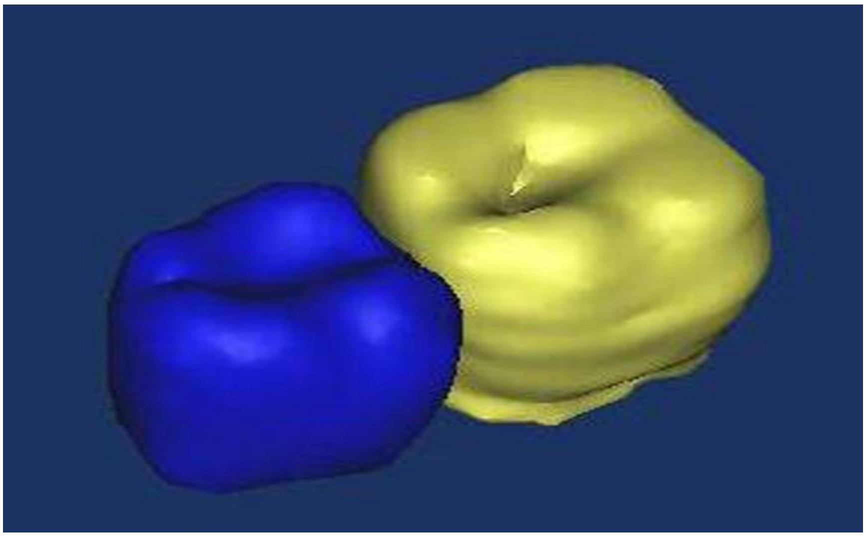


Figure 2. A view of a 3D model of the first and second molars.

Table 1. Mechanical properties of the first and second molars and filling materials.

Mechanical property	Normal teeth	Composite (Paradigm MZ100,3M-ESPE)	Amalgam
Elastic modulus (MPa)	18600	15000	22000
Poison ratio	0.31	0.30	0.37
Density (gr/mm^3)	0.0040	0.0019	0.0105

Results

Evaluation of normal stress in tooth

The criterion of Von Mises stress was used in this study for evaluating the normal stress in teeth. Figure 3 shows the stress distribution in the normal first and second molars. As seen, the maximum stress in the first and second molar was 37.1 and 34.6 Pa, respectively. The maximum normal stress in the first molar was 7.2% greater than that in the second molar.

According to table 2, when the filling depth was half the tooth height, the Von Mises stresses in the normal first molar, the first molar filled with composite and the first molar filled with amalgam were 37.1, 42.4 and 37.7 Pa, respectively. After teeth were filled, a greater stress was created in the tooth filled with composite under similar loadings such that the first molar filled with composite was 13.7% weaker than the normal tooth, while the difference of stress between the teeth filled with amalgam and the normal tooth was less than 1.7%. So it is clear that the strength of the first molar filled with amalgam is almost similar to that of the normal tooth. Repeating the same examination for the second molar resulted in Von Mises stresses of 34.6, 35.8 and 34.8 Pa in the normal tooth, the tooth filled with composite and the one filled with amalgam, respectively. The stress difference between the second molars filled with composite and amalgam is less than 2.8% while this value is 12.5% for the first molars. Contrary to the first molar, the stress difference between the second molar filled with amalgam or composite and the normal second molar is less than 3.5%.

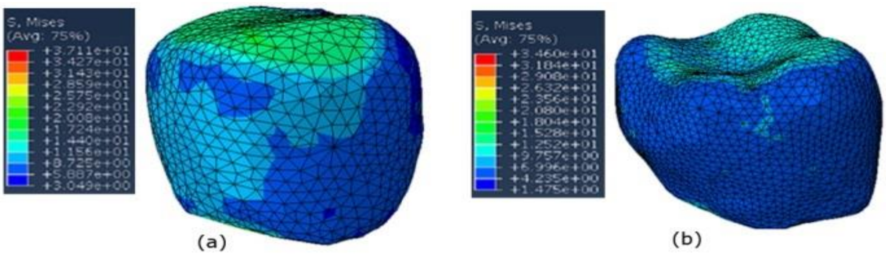


Figure 3.(a) Stress distribution in normal first molar. **(b)** Stress distribution in normal second molar.

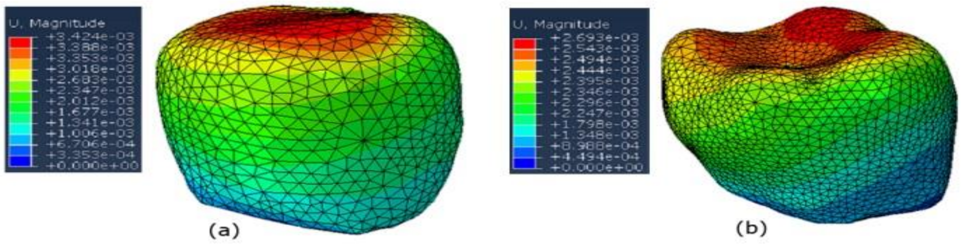
Table 2. Evaluation of the Von Mises stresses exerted on normal teeth and the teeth filled with amalgam and composite with a filling depth equaling to 1/2 of the tooth height.

Tooth	Maximum stresses in normal teeth (Pa)	Maximum stresses in teeth filled with composite (Pa)	Maximum stresses in teeth filled with amalgam (Pa)
First molar	37.1	42.4	37.7
Second molar	34.6	35.8	34.8

Evaluation of tooth deformation

Mere investigation of the stress exerted on tooth is not sufficient for evaluating the biomechanical conditions of a filled tooth and it is certainly necessary to analyse tooth deformation conditions in the filled region. Deformation (U) is the most appropriate index for evaluating the degree of deformity in the upper surface of the tooth in the filled region. Figure 4 shows the distribution of deformation created in two normal teeth under similar loadings. As seen, deformations in the first and second molars were 3.4 and 2.7µm, respectively. In the same manner, the stress in the first molar is 7.2% greater than that in the second molar, the deformation in the first molar is 26% greater than the deformation in the second molar.

According to table 3, when the filling depth equals to half of the tooth height, maximum deformations in the normal first molar, the first molar filled with composite and the first molar filled with amalgam were 3.4, 4.3 and 3.7 µm, respectively. Maximum deformations in the tooth filled with composite and the tooth filled with amalgam were, respectively, 26.5% and 8.8% greater than the deformation in the normal tooth.Therefore, after filling the first molar, maximum deformation under similar loading is created in the same manner as the maximum stress –in the tooth filled with composite. Repeating the same examination for the second molar made clear that the maximum deformations in the normal tooth, the one filled with composite and the one filled with amalgam were 2.7, 2.9 and 2.8 μm, respectively. Therefore, similar to stress difference, deformation difference between the normal second molar and the filled ones, especially when filled with amalgam, was small.



Table

Figure 4. (a) Deformation distribution in normal first molar. **(b)** Deformation distribution in normal second molar.

Table 3.. Evaluation of deformations resulted in normal first and second molars and those filled with amalgam and composite with a filling depth equaling to 1/2 of the tooth height.

Tooth	Maximum deformations of normal teeth (μm)	Maximum deformations of teeth filled with composite (μm)	Maximum deformations of teeth filled with amalgam (μm)
First molar	3.4	4.3	3.7
Second molar	2.7	2.9	2.8

Discussion

The impact of filling on teeth can generally be divided into two groups. First, the shear stress that is imposed between the filling material and cavity walls leading mainly to chipping-off of a portion of the filling material or damage to the lower and lateral sides of the filling material. It should be considered that there is not a similar mechanism of adhesion of filling material to tooth structure in amalgam and composite fillings and that is the reason why the first group of impacts, the resultant shear stress, is different in the two groups. The second group, gradual abrasion and loss of filling material and/or surface crack or fracture of the tooth surface, which appear as a result of increase in the normal stress on tooth surface and due to insufficient strength of the filling material in that region. We dealt with the second group of impacts in the present study and investigated the effect of normal stress. The form of cavity outlines (a U-shaped or V-shaped cross-section of the filling material-tooth structure), especially for amalgam filling, can be very effective. The form (U-shaped in this study) and adhesion mechanism of both filling materials are assumed to be the same for the both groups in the present study.

Stress and toughness as well as deformation are among the most important biomechanical parameters for analysis of the second group of impacts (23). Maximum deformation (U) for evaluation of deformities and maximum Von Mises stress (S) for evaluation of tooth strength were calculated by software in the present study. According to Table 2, the maximum normal stress had occurred in the first molar (37.1 Pa). The maximum stress reported in the study by Pakla et al. for the first molar under similar loading was 34.2 Pa (21). The difference of 8.5% in the results of the two studies was due to anatomical and dimensional differences of the teeth in the subjects under study.

Since the texture of normal teeth was assumed to be similar and the same distributed load, equal to chewing load, was applied to both teeth under similar conditions, the upper surface geometry, the angle and the height of the first molar, naturally played an effective roll in raising the stress exerted on the teeth. According to Hook’s law, maximum strain and deformation should also occur in the same tooth as confirmed by the results in table 3.

The results in table 2 shows that after the first molar is filled with composite, it is 12.5% weaker than when filled with amalgam under similar loadings.

Although amalgam is preferred for restoring first molars, the strength difference between a normal second molar and one filled with composite or amalgam is small. The results regarding deformation in the first molar indicated that maximum deformation occurred in the tooth filled with composite, so composite is weaker than amalgam in regard to deformation (table 3). Deformation difference between second molars filled with two different filling materials is less than 3.4%. The deformation has also its maximum value in teeth filled with composite.

With similar filling depth and cross-sectional shape and under similar loading, amalgam yielded greater strength and less deformation when used for filling the first molar. Although the differences of strength and deformation between amalgam and composite fillings in the second molar are less, amalgam is still a little better filling material than composite.

Effect of the filling depth

Amalgam,opposed to composites, shows no adhesion to tooth structure, therefore it is necessary to romove more dental tissue to prepare a strong bed for amalgam fillings (24). The reason for this excessive drilling is that the perdurability of amalgam in cavity depends on friction with cavity walls. So in cavities with a V-shaped cross section and a depth of less than 2 mm, amalgam won't endure as the perdurability of amalgam increases when the cavity has a U-shaped form and a depth of at least 2 mm (24). It is hence necessary to investigate the effect of filling depth on tooth strength and deformation in order to evaluate the positive and negative effects of additional drilling of tooth structure on mechanical properties of filled teeth;furthuremore, the need for additional drilling of tooth is greater when amalgam is used ,making these impacts more notable for amalgam restorations than composite fillings(24). . To investigate the effect of filling depth, two teeth with a same cross-sectional shape and under the aforementioned loading and a filling depth equaling to 1/3 of the tooth height (16.7% difference with the previous depth) were analyzed using FEM.

According to figure 5, maximum stress in the first molar filled with composite changed 8.9% with a16.7% increase in the filling depth while the difference in the maximum stress in the second molar was much smaller, about 1.7%, as is shown in the results in section 3.1 that the effect of filling typerestoration material on tooth strength is less in restored second molars than the first molars. Due to good agreement of tooth biomechanical properties between the tooth filled with amalgam and the normal tooth, the strength difference between the tooth filled with amalgam with a filling depth equaling to 1/3 of tooth height and the normal tooth was very small for both the first and second molars.

Figure 6 compares deformations in the first and second molars for two different filling materials and two different filling depths. For composite fillings, the amount of deformation increase in the first molar for the filling depth equaling to 1/2 and 1/3 of tooth height was 25.1% and 24.8%, respectively. These values were small for amalgam fillings in both filling depths. The amount of deformation rate in the first molar filled with amalgam and composite with a 16.7% difference of filling depth was 5.7% and 13.1%, respectively. The related figures were smaller for the second molar. Based on hook's law, with reduction of filling depth, deformation in both teeth had decreased similar to the stress (figures 5 and 6). So neither the decrease or increase in filling depth nor the type of filling material affects deformation and strength of second molars significantly; however, in the first molar, amalgam filling is a more appropriate material for both filling depths**.**

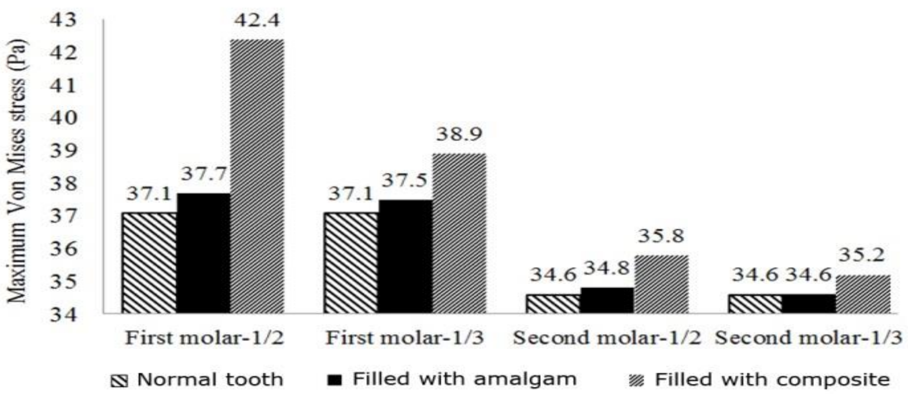


Figure 5. Comparison of maximum stress exerted on the first and second molars filled with amalgam and composite with filling depths equaling to 1/2 and 1/3 of the height of the normal tooth.

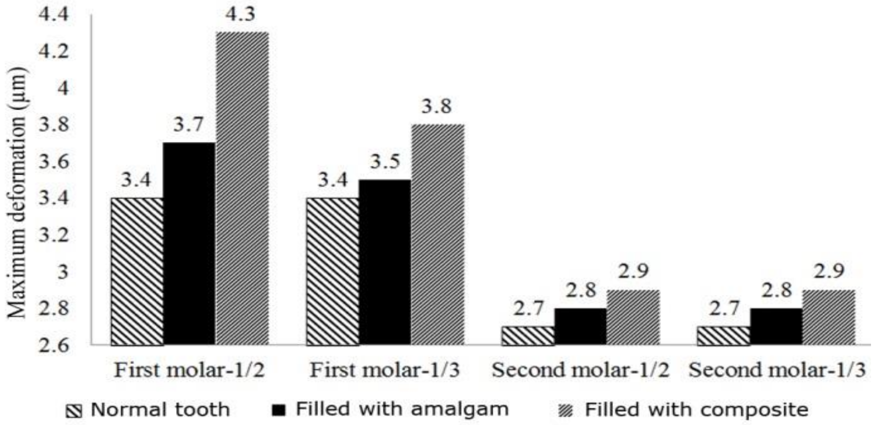


Figure 6. Comparison of maximum deformations exerted on the first and second molars filled with amalgam and composite with filling depths equaling to 1/2 and 1/3 of the height of the normal tooth.

Location of maximum stress and deformation in teeth

As seen in figures7a and b, the maximum stress in the first molar filled with amalgam or composite occurs both on the upper surface of the filling area and in the lower part of the tooth. However, the maximum stress in the lower part of the tooth filled with composite is greater than that filled with amalgam. Figures 7c and d show that the 16.7% difference in filling depth doesn't change the location of maximum stress but it does changes the amount of stress very little.

The results show that the maximum deformation in the filled teeth occurs in the same place where the maximum stress happens. The maximum stress in the normal tooth, however, occurs only on the upper surface of the tooth as seen in figure 3, so the probability of injury or fracture at the lower part of a filled tooth is greater than that in the normal tooth. This effect is greater in a tooth filled with composite according to figures 7a and b.

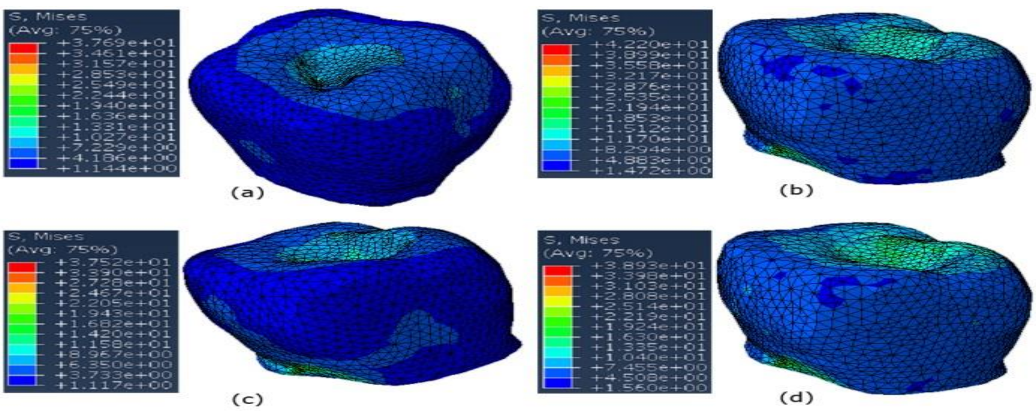


Figure 7. .Location of maximum normal stress in the first molar (a) filled with amalgam with a filling depth equaling to 1/2 of the tooth height;(b) filled with composite with a filling depth equaling to 1/2 of the tooth height;(c) filled with amalgam with a filling depth equaling to 1/3 of the tooth height;(d) filled with composite with a filling depth equaling to 1/3 of the tooth height.

Limitation and future work

The method of filling the teeth was considered to be exactly similar for both fillings and the effect of stress concentration due to lack of uniformity in filling the teeth and lack of proper surface quality in the filling area was ignored. The degree of losing strength with time is not similar in composite and amalgam fillings. In the present study, however, the effect of time on surface abrasion and decrease in the strength of the filling was not considered. Hot and cold foods also have different effects on the strength of filling materials. These effects were also ignored in the present study. Such parametres can be investigated in future studies.

Conclusion

Considering the aforementioned limitations, the results of this study show that amalgam is a better filling material for the decayed first molar under a distributed load similar to chewing, due to the cross-sectional shape of the cavity, the greater strength of amalgam and less deformation in comparison to composite fillings. The effect of amalgam fillings on properties of the second molars, however, is relatively smaller and the strength and deformation difference of amalgam and composite fillings in this tooth type are less than those in the first molar. In a majority of cases, dentists are obliged to drill out more dental tissuein decayed teeth when using amalgam fillings. Hence, the effect of a filling depth difference of 16.7% on the strength and deformation of the teeth filled with amalgam and composite fillings was investigated in the present study. Results show that the 16.7% difference in filling depth leads to a 8.9% stress difference in the first molar filled with composite; however, the effect of depth on level of stress in the tooth filled with amalgam is not considerable. It can be concluded that amalgam is a more proper filling material for the first molar to an extent that although accompanied by a 16.7% change in drilling depth for tooth preparation,it doesn’t cause any significant change in the strength and deformation in the filled tooth**.**

References

1. Pereira SM, da Silva Tagliaferro EP, Ambrosano GM, Cortellazzi KL, de Castro Meneghim M, Pereira AC. Dental Caries in 12-year-old Schoolchildren and its Relationship with Socioeconomic and Behavioural Variables. Oral health & preventive dentistry. 2007 Sep 1; 5(4)):299-306.
2. De Vree JH, Spierings TA, Plasschaert AJ. Materials science a simulation model for transient thermal analysis of restored teeth. Journal of dental research. 1983 Jun 1; 62(6):756-759.
3. Chimello DT, Dibb RG, Corona SA, Lara EH. Assessing wear and surface roughness of different composite resins after tooth brushing. Materials Research. 2001 Oct;4(4):285-289.
4. Morin DL, Douglas WH, Cross M, DeLong R. Biophysical stress analysis of restored teeth: experimental strain measurement. Dental Materials. 1988 Feb 29; 4(1):41-48.
5. Toparli M, Gökay N, Aksoy T. An investigation of temperature and stress distribution on a restored maxillary second premolar tooth using a three-dimensional finite element method. Journal of oral rehabilitation. 2000 Dec 1; 27(12):1077-1081.
6. Cornacchia TP, Las Casas EB, CiminiJr CA, Peixoto RG. 3D finite element analysis on esthetic indirect dental restorations under thermal and mechanical loading. Medical & biological engineering & computing. 2010 Nov 1; 48(11):1107-1113.
7. Ashrafi M, Ghalichi F, Mirzakouchaki B. Numerical Simulation of Stress Distribution in Periodontal Ligament of Incisor and Premolar with Different Loadings. Iranian Journal of Biomedical Engineering. 2016Apr; 9(1):49-57.
8. Braden M, Clarke RL, Nicholson J, Parker S. Polymeric dental materials. Springer Science & Business Media; 2012 Dec 6.
9. Saito S, Tosaki S, Hirota K. Characteristics of glass-ionomer cements. Advances in glassionomer cements. Chicago: Quintessence. 1999:15-50.
10. Smith DC. Development of glass-ionomer cements systems. Biomaterials. 1998 Apr 30; 19(6):467-78.
11. Vrijhoef MM, Driessens FC. On the interaction between specimen and testing machine in mechanical testing procedures. Journal of biomechanics. 1971 Jul 1; 4(4):233-238.
12. Mahler DB, ENGLE JH, Simms LE, Terkla LG. One-year clinical evaluation of bonded amalgam restorations. The Journal of the American Dental Association. 1996 Mar 31; 127(3):345-349.

13. Goel VK, Khera SC, Gurusami S, Chen RC. Effect of cavity depth on stresses in a restored tooth. The Journal of prosthetic dentistry. 1992 Feb 29; 67(2):174-183.
14. Van Noort R, Cardew GE, Howard IC. A study of the interfacial shear and tensile stresses in a restored molar tooth. Journal of dentistry. 1988 Dec 31; 16(6):286-293.
15. Fill TS, Carey JP, Toogood RW, Major PW. Experimentally determined mechanical properties of, and models for, the periodontal ligament: critical review of current literature. Journal of dental biomechanics. 2011; 2(1).
16. Goktas S, Dmytryk JJ, McFetridge PS. Biomechanical behavior of oral soft tissues. Journal of periodontology. 2011 Aug; 82(8):1178-1186.
17. Bourauel C, Freudenreich D, Vollmer D, Kobe D, Drescher D, Jäger A. Simulation of orthodontic tooth movements. Journal of Orofacial Orthopedics/Fortschritte der Kieferorthopädie. 1999 Mar 1; 60(2):136-151.
18. Qian L, Todo M, Morita Y, Matsushita Y, Koyano K. Deformation analysis of the periodontium considering the viscoelasticity of the periodontal ligament. Dental Materials. 2009 Oct 31; 25(10):1285-1292.
19. Ausiello P, Rengo S, Davidson CL, Watts DC. Stress distributions in adhesively cemented ceramic and resin-composite Class II inlay restorations: a 3D-FEA study. Dental Materials. 2004 Nov 30; 20(9):862-872.
20. Ausiello P, Apicella A, Davidson CL. Effect of adhesive layer properties on stress distribution in composite restorations—a 3D finite element analysis. Dental Materials. 2002 Jun 30; 18(4):295-303.
21. Hohmann A, Kober C, Young P, Dorow C, Geiger M, Boryor A, Sander FM, Sander C, Sander FG. Influence of different modeling strategies for the periodontal ligament on finite element simulation results. American Journal of Orthodontics and Dentofacial Orthopedics. 2011 Jun 30; 139(6):775-783.
22. Ferracane JL. Resin-based composite performance: are there some things we can’t predict?. Dental materials. 2013 Jan 31; 29(1):51-58.
23. Pałka K, Bieniaś J, Dębski H, Niewczas A. Finite element analysis of thermo-mechanical loaded teeth. Computational Materials Science. 2012 Nov 30; 64:289-294.
24. Kopperud SE, Staxrud F, Espelid I, Tveit AB. The Post-Amalgam Era: Norwegian Dentists’ Experiences with Composite Resins and Repair of Defective Amalgam Restorations. International journal of environmental research and public health. 2016 Apr 22; 13(4):441.

Corresponding Author:
Seifollah Gholampour
Assistant professor of Biomechanical Engineering
Department of Biomedical Engineering,
Tehran North Branch, Islamic Azad University, P.O.B. 1651153311, Tehran, Iran.
Tell: +982177009836-42
Email: s.gholampour@iau-tnb.ac.ir