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Doi: 10.7126/cumudj.440789 *RESEARCH ARTICLES*

THE EFFECT OF DIFFERENT FACTORS ON STRESS DISTRIBUTION IN A MOLAR TOOTH

Bir Molar Dişin Stres Dağılımı Üzerinde Farklı Faktörlerin Etkisi

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ABSTRACT

Objectives: The aim of present study was to evaluate the effect of different factors on the stress distribution of a molar tooth by finite element analysis.

Materials and Methods: A 3D tooth model of a maxillary molar tooth was created for present study. The cavities (Class I and Class II) were created in the computer model. The cavities were restored with three different restorative materials (resin composite, amalgam and glass ionomer cement) in the computer model. Two thermal load (5 ºC and 55 ºC) and two mechanical load (mechanical singular load-perpendicular and mechanical distributed load-perpendicular) used in this study. Twelve study groups were created. The von Mises stress distribution was evaluated.

Results: Von Mises stress values were not statistically significant different among the groups for restorative material and mechanical load factors ($p>0.05$) while there were statistically significant differences among the groups for cavity geometry and thermal load factors ($p<0.05$).

Conclusions: Within the limitations of our study, the higher Von Mises stress values were found in Class I cavity for cavity geometry and 5°C for thermal load.

Keywords: Cavity geometry, restorative material, thermal load, mechanical load, finite element analysis.

ÖZ

Amaç: Bu çalışmanın amacı bir molar dişin stres dağılımı üzerinde farklı faktörlerin etkisini sonlu elemanlar analizi ile değerlendirmektir.

Gereç ve Yöntem: Çalışma için bir maksiller molar dişin 3 boyutlu diş modeli oluşturuldu. Kaviteler (Sınıf I ve Sınıf II) bilgisayar ortamında oluşturuldu. Kaviteler bilgisayar ortamında üç farklı restoratif material ile (kompozit rezin, amalgam ve cam iyonomer siman) restore edildi. Bu çalışma için iki termal yük (5 ºC ve 55 ºC) ve iki mekanik yük (mekanik tekil yük-dik ve mekanik yayılı yük-dik) kullanıldı. On iki çalışma grubu oluşturuldu. Von Mises stres dağılımı değerlendirildi.

Bulgular: Restoratif materyal ve mekanik yük faktörleri için gruplar arasında Von Mises stres değerleri istatistiksel olarak anlamlı bir farklılık göstermezken ($p>0,05$), kavite geometrisi ve termal yük faktörleri için gruplar arasında istatistiksel olarak anlamlı bir farklılık vardı ($p<0,05$).

Sonuçlar: Çalışmamızın sınırları dahilinde, en yüksek Von Mises stres değeri kavite geometrisi için Sınıf I kavitede ve termal yük için 5 °C'de bulundu.

Anahtar Kelimeler: Kavite geometrisi, restoratif material, termal yük, mekanik yük, sonlu elemanlar analizi.

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INTRODUCTION

The aim of restorative dentistry is to provide a natural teeth appearance, accurate diagnose and treatment. Different restorative materials may be used for the dental treatment.[1] However, the restorative materials present certain drawbacks such as thermal and mechanical stress. Restored teeth are exposed to mechanical stress at different levels since occlusal forces, and the durability of the restorations mostly depends upon these stresses.

In addition, many factors such as the type of the restorative material, cavity geometry, and thermal fluctuations, affect the stress that occurs on restored teeth.[2] The oral cavity can be exposed to thermal fluctuations. These rapid fluctuations create thermal stress.[3,4]

The Finite Element Analysis (FEA) method, which uses advanced computing and modeling techniques, provides a reliable means of determining the biomechanics of restorative materials. Computer-aided quantitative studies have also become a very important tool in dentistry, particularly in the identification of the source of failure, offering satisfying and reliable results when combined with FEA. In addition, experiments that could not be performed on patients can be done in the computer environment using FEA. Moreover, analyzing the durability of the restorative materials when exposed to occlusal forces by this method could be quick and cost-effective.[5,6]

There are different studies related to the effect of variable cavity geometry, occlusal forces and thermal changes on stress distribution.[6-11] However, study related to thermal stress distribution at tooth-restorative material interface bonding has been very limited.[6] The aim of present study was to evaluate the effect of different factors such as cavity geometry, restorative material, thermal and mechanical load factors on the stress distribution of a molar tooth.

MATERIAL AND METHOD

Modeling of Tooth

An extracted maxillary left first molar tooth was used for the 3D tooth model. The 3D tooth model procedures were made according to Toparli *et al.*[4] and Hashemipour *et al.*[7] recommendations (Fig. 1).

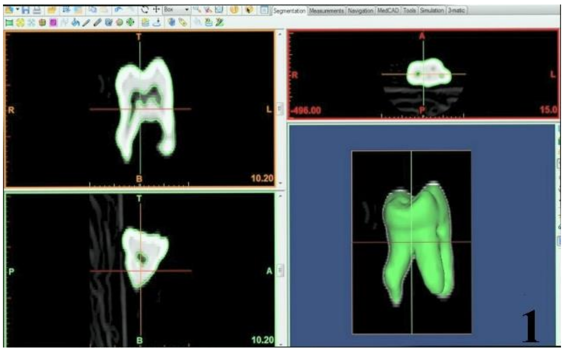

Figure 1: Preparing a three-dimensional model using the Mimics program before Solidworks program.

Meshing

Mesh (72.621 elements and 104.665 nodes) was obtained automatically using the ANSYS 13 Workbench (Swanson Ansys Inc., Houston, USA). Figure 2 is shown the meshed model.

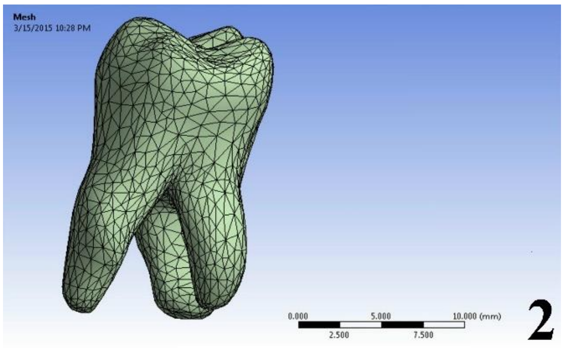

Figure 2: The meshed model.

Cavity Preparation

The cavities were prepared in the computer model.

Class I cavity (5x3x2 mm^3) was prepared on the occlusal surface of the tooth (Fig. 3).

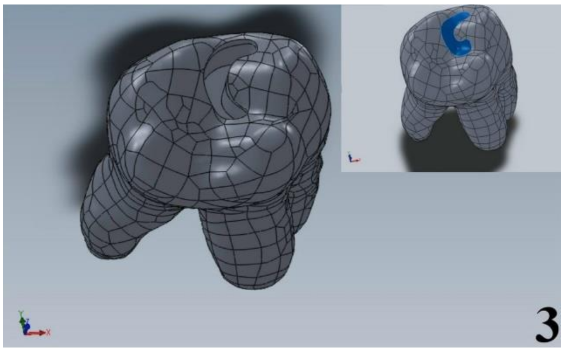

Figure 3: The preparation of Class I cavity.

Class II cavity (5x3x2 mm^3) was prepared with the cervical margin 1 mm below the cementum-enamel junction (Fig. 4).

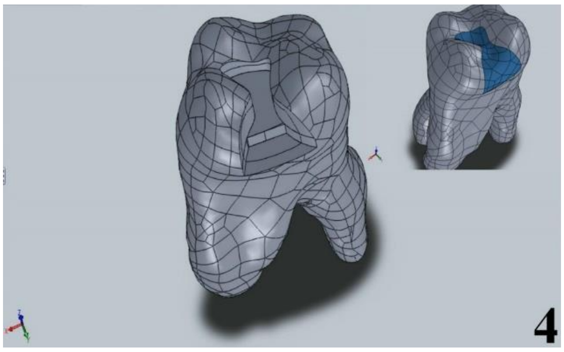

Figure 4: The preparation of Class II cavity.

The cavity was restored with three different restorative materials (resin composite, amalgam and glass ionomer cement) in the computer model. The restorative materials commonly used for restoration in dentistry are preferred for this study. Table 1 presents the mechanical properties of restorative materials used in present study.[4,7]

Table 1. The mechanical and thermal properties of the tooth and the restorative materials used in this study.

Materials	Modulus of Elasticity (GPa)	Poisson's Ratio	Specific Heat (J/kg °C)	Thermal Expansion Coefficient (1/°C)	Thermal Conductivity (W/m °C)	Densi (kg/m
Enamel	80	0.33	750	11 x 10^{-6}	0.84	280
Dentine	20	0.31	1302	11.4 x 10^{-6}	0.63	200
Pulp	0.003	0.45	4200	180.1 x10^{-6}	0.0418	100
Resin Composite	15	0.24	820	34 x 10^{-6}	1.26	200
Glass Ionomer	10.8	0.30	1177	35 x 10^{-6}	0.615	210
Amalgam	35	0.35	240	25 x 10^{-6}	23.1	105

Thermal and Mechanical Load

To simulate the sudden intake of hot and cold food and drink, two thermal load (5 ºC and 55 ºC) used in this study.[12] The tooth was assumed to initially have a uniform temperature of 36.5ºC, the temperature was assumed to change from 36.5 to 5 or 55ºC, respectively.

Mechanical loads were within the ranged 10-431 N in the intraoral.[13] Two mechanical load (mechanical singular load-perpendicular and mechanical distributed load-perpendicular) used in this study. Mechanical singular or distributed loads of 270 N at an angle of 90^{o} were then applied on the restorative material in the longitudinal axis of the tooth at temperatures of 5 or 55 °C.

The von Mises stress distribution was calculation using ANSYS 13 Workbench software.

Study Groups

Table 2 presents the twelve experimental groups created in present study.

Table 2: The distribution of study groups

Study Groups		Cavity Geometry	Restorative Material	Thermal Load	Mechanical Load
Group 1	**Group 1.1**	Class I	Composite Resin	5 °C	Mechanical Singular Load-Perpendicular
	Group 1.2	Class I	Composite Resin	5 °C	Mechanical Distributed Load-Perpendicular
Group 2	**Group 2.1**	Class I	Composite Resin	55 °C	Mechanical Singular Load-Perpendicular
	Group 2.2	Class I	Composite Resin	55 °C	Mechanical Distributed Load-Perpendicular
Group 3	**Group 3.1**	Class II	Composite Resin	5 °C	Mechanical Singular Load-Perpendicular
	Group 3.2	Class II	Composite Resin	5 °C	Mechanical Distributed Load-Perpendicular
Group 4	**Group 4.1**	Class II	Composite Resin	55 °C	Mechanical Singular Load-Perpendicular
	Group 4.2	Class II	Composite Resin	55 °C	Mechanical Distributed Load-Perpendicular
Group 5	**Group 5.1**	Class I	Amalgam	5 °C	Mechanical Singular Load-Perpendicular
	Group 5.2	Class I	Amalgam	5 °C	Mechanical Distributed Load-Perpendicular
Group 6	**Group 6.1**	Class I	Amalgam	55 °C	Mechanical Singular Load-Perpendicular
	Group 6.2	Class I	Amalgam	55 °C	Mechanical Distributed Load-Perpendicular
Group 7	**Group 7.1**	Class II	Amalgam	5 °C	Mechanical Singular Load-Perpendicular
	Group 7.2	Class II	Amalgam	5 °C	Mechanical Distributed Load-Perpendicular
Group 8	**Group 8.1**	Class II	Amalgam	55 °C	Mechanical Singular Load-Perpendicular
	Group 8.2	Class II	Amalgam	55 °C	Mechanical Distributed Load-Perpendicular
Group 9	**Group 9.1**	Class I	Glass Ionomer Cement	5 °C	Mechanical Singular Load-Perpendicular
	Group 9.2	Class I	Glass Ionomer Cement	5 °C	Mechanical Distributed Load-Perpendicular
Group 10	**Group 10.1**	Class I	Glass Ionomer Cement	55 °C	Mechanical Singular Load-Perpendicular
	Group 10.2	Class I	Glass Ionomer Cement	55 °C	Mechanical Distributed Load-Perpendicular
Group 11	**Group 11.1**	Class II	Glass Ionomer Cement	5 °C	Mechanical Singular Load-Perpendicular
	Group 11.2	Class II	Glass Ionomer Cement	5 °C	Mechanical Distributed Load-Perpendicular
Group 12	**Group 12.1**	Class II	Glass Ionomer Cement	55 °C	Mechanical Singular Load-Perpendicular
	Group 12.2	Class II	Glass Ionomer Cement	55 °C	Mechanical Distributed Load-Perpendicular

Statistical Analysis

The effect of different factors on stress distribution were analyzed with Kruskal-Wallis and Mann-Whitney U tests using SPSS 13.0 for Windows (SPSS Inc, Chicago, IL, USA).

RESULTS

Von Mises stress values were not statistically significant different among the groups for restorative material and mechanical load factors ($p>0.05$) while there were statistically significant differences among the groups for cavity geometry and thermal load factors ($p<0.05$).

Von Mises stress distribution of according to cavity geometry and thermal load factors are shown in Table 3 and Table 4, respectively.

Table 3: Distribution of descriptive statistical data according to cavity geometry factor (MPa).

Cavity Geometry	Von Mises Stress Distribution (σM)					
	Mean	Median	Standard Deviation	Standard Error	Minimum	Maximum
Class I Cavity	73.73	72.60	26.17	7.55	38.1	106.9
Class II Cavity	49.60	45.90	17.18	4.96	30.2	75.2
p	**0.024**					

Table 4: Distribution of descriptive statistical data according to thermal load factor (MPa).

Thermal Load	Von Mises Stress Distribution (σM)					
	Mean	Median	Standard Deviation	Standard Error	Minimum	Maximum
5 °C	80.20	77.90	20.19	5.83	48.9	106.9
55 °C	43.13	41.35	11.84	3.42	30.2	64.6
p	**0.001**					

The higher Von Mises stress values were found in Class I cavity for cavity geometry and 5°C for thermal load (Figure 5 and 6). Von Mises stress distribution according to study groups are shown in Figure 7.

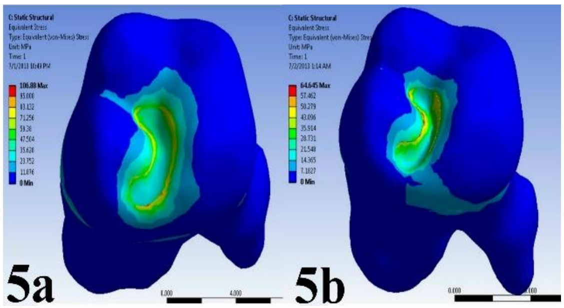

Figure 5:
a- Von Mises stress distribution of Class I cavity in Group 1.1.
b- Von Mises stress distribution of Class I cavity in Group 2.1.

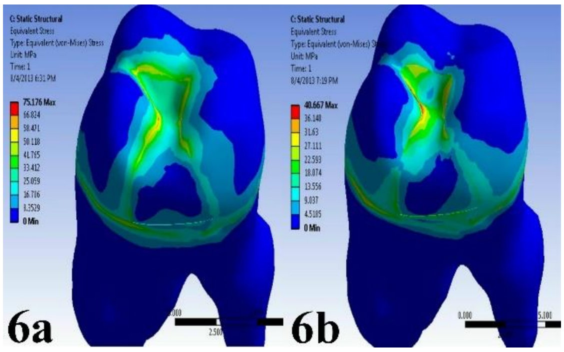

Figure 6: a- Von Mises stress distribution of Class II cavity in Group 3.1.
b- Von Mises stress distribution of Class II cavity in Group 4.1.

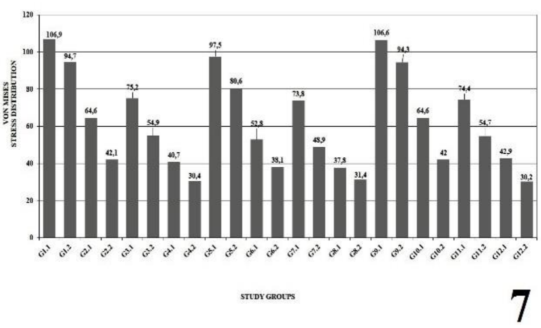

Figure 7: Von Mises stress distribution according to groups.

DISCUSSION

Restorative materials and tooth structures in the oral cavity expand when exposed to cold or hot food and drink.[14] Temperature changes create thermal stress on restored teeth. Differences in the thermal and mechanical properties between the tooth structures and restorative materials promote the development of stress.[15-17] The induced stress may cause cracking within the tooth or failure in the tooth-restorative material interface bonding.[18-20] The type, elastic modulus, and rigidity of restorative material are very important to the tooth-restorative material interface bonding. Our study mainly focused on stress and thermal analysis of a restored molar tooth, using FEA and calculate the stresses and thermal fields present.

The thermal expansion coefficients of restorative materials and tooth are used in the thermal stress analysis. When there is a mismatch between the restorative materials and the thermal expansion coefficients of the tooth, there will be expansion or contraction in the restorative material during thermal changes.[21] The present study demonstrated that stress distribution created by cold exposure was greater than with hot exposure. This result was comparable to the other studies.[9,22]

Evidence shows that the depth and width of cavity play important roles in fracture resistance of restorations.[23,24] Valian *et al.*[25] reported that by occlusal extension of the Class II cavities, the amount of stress at the interface increased. However, Chang *et al.*[26] found that by increasing the cavity dimensions, the stress at the interface did not increase. We found that the higher Von Mises stress values were found in Class I cavity for cavity geometry.

In vivo studies have reported different findings on occlusal forces at the posterior region. In addition, practical occlusal force in clinic is sometimes larger than the normal occlusal force. Fu *et al.*[27] reported that the biggest occlusal force can achieve 480 N for the maxillary first molar. Two mechanical load (mechanical singular load-perpendicular and mechanical distributed load-perpendicular) used in the present study. Using of different mechanical load may cause different von Mises stress distribution.

Tooth decay can be treated with various restorative materials and different restorative application techniques. Today, the use of aesthetically pleasing materials has increased in response to patient demand. However, clinicians should consider not only the aesthetics of the restorative material but also its biomechanics and durability when selecting a material.[28] The cavity was restored with three different restorative materials (resin composite, amalgam and glass ionomer cement) in this study. However, we found that the stress distribution of this restorative materials were similar. Using of restorative materials with different mechanical and thermal properties may cause different von Mises stress distribution. However, our study results should be supported by clinical studies.

CONCLUSION

- The higher Von Mises stress values were found in Class I cavity for cavity geometry factor.
- The higher Von Mises stress values were found in 5°C for thermal load factor.

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CONFLICTS OF INTEREST

The authors declare no potential conflicts of interest with respect to the authorship and/or publication of this article.

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