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ScienceDirect

Procedia Engineering 69 (2014) 1251 – 1257

Procedia Engineering

www.elsevier.com/locate/procedia

24th DAAAM International Symposium on Intelligent Manufacturing and Automation, 2013

Comparative Study of the Biomechanical Behavior of the Deciduous Molar-Restorative Material-Bone Assembly

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Abstract

A medical problem of great importance is the treatment of dental caries at children. If this treatment is efficient, the teeth vitality is preserved and a normal function of the dental maxillary assembly is carried out. Therefore, the purpose of this study, performed with the finite element method, was to determine the stress and strain distributions in bone structure – primary molar – restorative material assembly, and also to evaluate the contact pressure at the interfaces bone – molar and molar – restorative material when a load of 120 N has been applied over all the upper surface area of model. Finally, the results for two dental fillings often used by practitioners were compared. The method used for obtaining the 3D models consisted in processing with special software (Mimics) the tomography images acquired with the aid of a CT scanner.

Selection and peer-review under responsibility of DAAAM International Vienna

Keywords: primary molar; restoration material; FEM; stress; displacement; pressure contact

1. Introduction

The treatment of dental caries at children is not only a medical problem but also a social one. The efficient and pertinent treatment of tooth decay fully ensures the mastication function and prevents the development of the odontogenic inflammatory processes.

Caries in deciduous teeth represent a common form of illness with direct implications and possible consequences on permanent teeth. Therefore, a more efficient treatment of caries in primary teeth in terms of restoration leads to

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1877-7058
Selection and peer-review under responsibility of DAAAM International Vienna
doi:10.1016/j.proeng.2014.03.116

the preservation of teeth vitality. Thus the deciduous tooth is maintained on the arch until the age of exfoliation and a normal function of the dental-maxillary assembly is carried out with a high degree of comfort for the patient.

This requires that the dental restorative material should provide an active and perfectly sealed interface between the filling material and the hard dental biological structures and also should have a high degree of durability in time. The number of studies regarding the evaluation of the characteristics of dental products is increasing due to the rapid development of the dental materials [1]. Therefore, in order to expect a long-term performance, before using the restorative material in practice, it is important for the practitioners to be aware of the previous laboratory and clinical trials.

In restorative dentistry a very important factor taken into consideration is the occlusion. The occlusal surfaces of the teeth to be restored represent functional units of the stomatognathic system of the patient. Crown morphology should provide mandibular support both in functional positions, max intercuspid, and in eccentric movements of the mandible.

Restored teeth should not interfere with functional activities like mastication, phonation, deglutition and also must not transmit excessive forces to the periodontium and to the temporomandibular joint in mandibular intercuspid or eccentric positions, nor during the movements.

The restorations are subjected to stresses from the activity of mastication. The durability in time of the teeth and material may be compromised due to their different reactions to these forces, which can lead to deformation. It is useful to know the performance of such materials under specific test conditions in order to study the behavior of the restorative dental materials when clinically in service.

The study of dental structures was performed using experimental methods such as photoelasticity [2, 3] and strain-gauge technique, computer simulation methods and finite element analysis (FEM) to conduct stress analyses.

Because of its ability to accurately assess the complex biomechanical behavior of irregular structures and heterogeneous materials, FEM has been widely applied in dentistry for stress analysis of dental structures such as internal stresses in teeth and different dental materials, for the optimization of the shape of restorations etc. [4]. Unlike mechanical testing involving biomaterials which usually require a large number of samples, FEM eliminates the need of a large number of experimental teeth because it uses a mathematical model.

The investigation of the biomechanical behavior of complex structures can be performed with 2D or 3D models, the decision depending of many factors: complexity of geometry, material, properties, etc. Though 2D models are easier to build and less time consuming, they do not represent the complexity of the real problem. More reliable and accurate results may be obtained with 3D models [5].

Two methods are used in order to reconstruct the 3D geometry of the tooth. The traditional one consists of embedding the tooth in resin mould and sectioning it perpendicularly to the long axis using a precise electric saw. Thus thinner sections of the occlusal area are obtained. Then, each section is digitally photographed and by assembling these slices and using a specialized computer program, the 3D model of the tooth is constructed. The latest method of reconstructing the 3D tooth is achieved using the computer tomograph (CT). The advantages of using a CT model consist in obtaining a more accurate model, in the possibility of including the surrounding soft structures, of scanning larger areas (while the structures remain in the patient's mouth) and of scanning the same structure before and after reconstruction.

This paper presents a comparative study of the mechanical behavior of the deciduous molar - restorative material - bone assembly subjected to the loads occurring during the activity of mastication. A finite element analysis was performed using 3D models of the above assembly for two dental restorations: composite resin and Gic Fuji IX material.

2. Finite Element Analysis

2.1. Finite element model

The method used for obtaining the 3D models of the primary molar decay and of the primary molar filling was applied with the aid of a CT scanner. The tomography images acquired were processed with special software (Mimics). This made possible the reconstruction of the three-dimensional image of the tooth in both cases by converting the CT images in geometric volumes. This technology opened up the possibility for a complex 3D modeling.

Fig. 1 presents three of the images retrieved from the CT scan and the 3D image of the deciduous molar. The latter has been reconstructed using geometry processing of the images with the Mimics program.

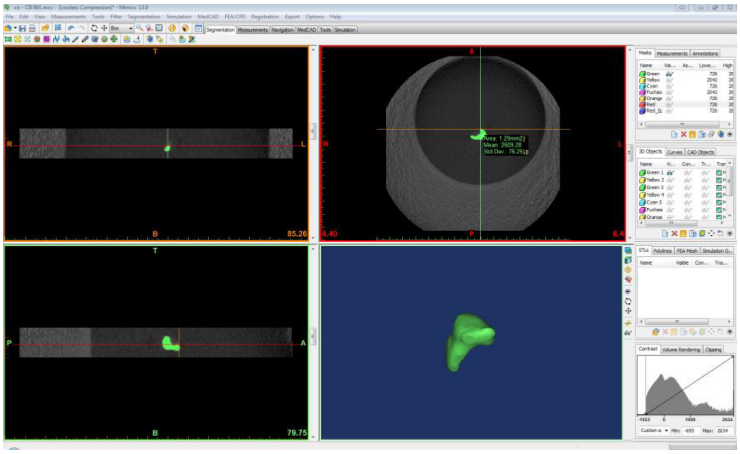

Fig. 1. Three images from the CT scan and the 3D image of the deciduous molar.

The 3D model of the primary molar decay obtained after the reconstruction with Mimics software of the tomographic images is shown in Fig. 2a. The calculation was carried out assuming the tooth is fixed in a bone structure, embedded at the bottom. The 3D image of the assembly bone structure - primary molar - restorative material is presented in Fig.2b.

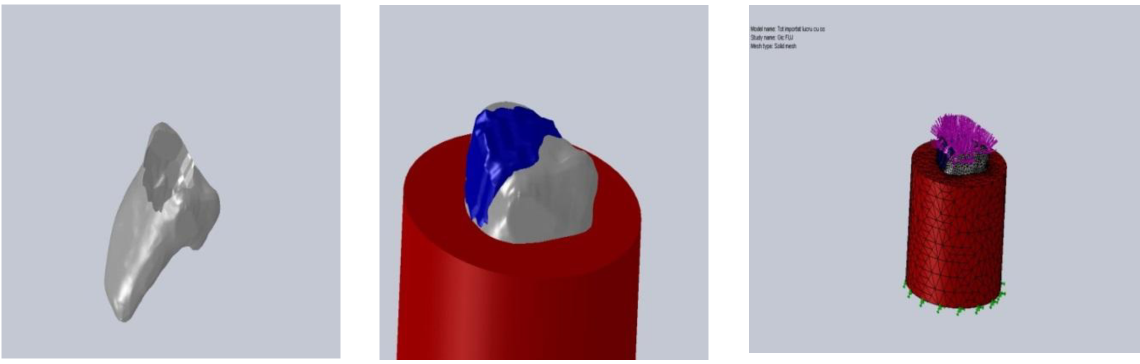

Fig. 2. (a) 3D model of the primary molar decay; (b) 3D model of the assembly bone structure-molar-restorative material; (c) finite element mesh.

The computerized image was imported into ANSYS program for mesh generation using tetrahedral elements and for the processing with FEM. A load of 120 N has been uniformly distributed over all the upper surface area of the model of the assembly (Fig. 2c). It can be noticed that the nodes at the bottom of the bone structures in which the molar has been embedded have zero-displacements in two directions. The analysis was performed for two different restorative materials often used by practitioners: composite resin and Gic Fuji IX. Young's modulus and Poisson's ratio, which describe the physical characteristics of each structure, were loaded into the software to identify the materials from which existing structures were made (Table 1). Solid features were accepted in the program as linearly resilient, homogenous and isotropic [6, 7].

Table 1.

Material	E [MPa]	υ
Bone	1.2×10^4	0.33
Molar	2.686×10^4	0.33
Composite resin	1.83×10^4	0.35
Gic Fuji IX	0.4×10^4	0.3

2.2. Stress and displacement distributions and special computation element

Data were analyzed in two forms: von Mises stress distributions [8] and displacement distributions for the assembly bone structure - primary molar– restorative material, for both dental fillings: composite resin (Fig.3a and Fig.3b) and Gic Fuji IX (Fig.4a and Fig.4b).

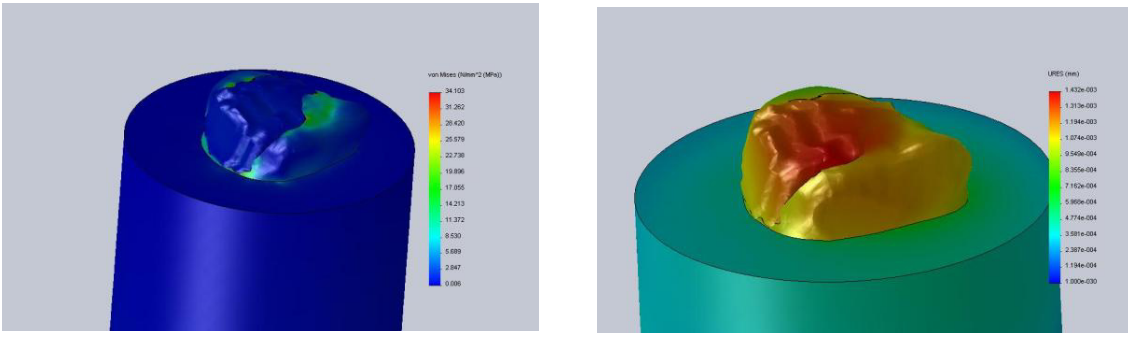

Fig. 3. (a) Von Mises stress distributions for bone structure- molar -composite resin; (b) Displacement distributions for bone structure- molar - composite resin.

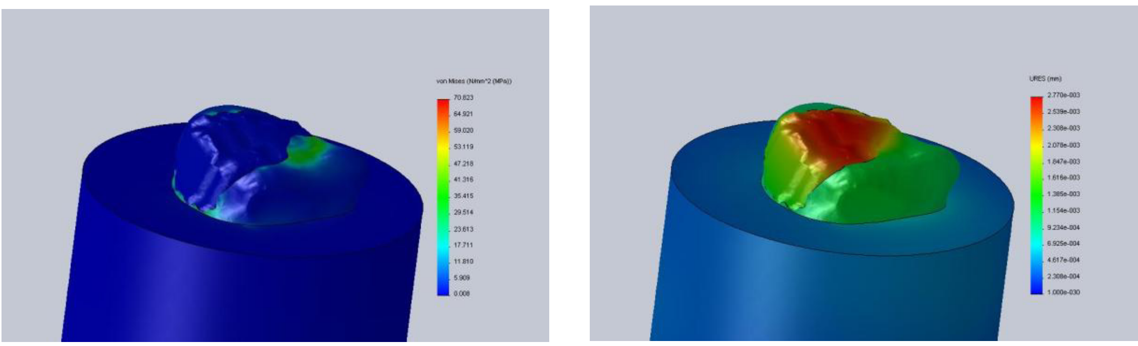

Fig. 4. (a) Von Mises stress distributions for bone structure- molar - Gic Fuji IX; (b) Displacement distributions for bone structure -molar - Gic Fuji IX.

The values of von Mises equivalent stresses in the dangerous section in the case when the restorative material is composite resin (Fig. 5a) are compared with those having the dental restoration Gic Fuji IX (Fig. 5b).

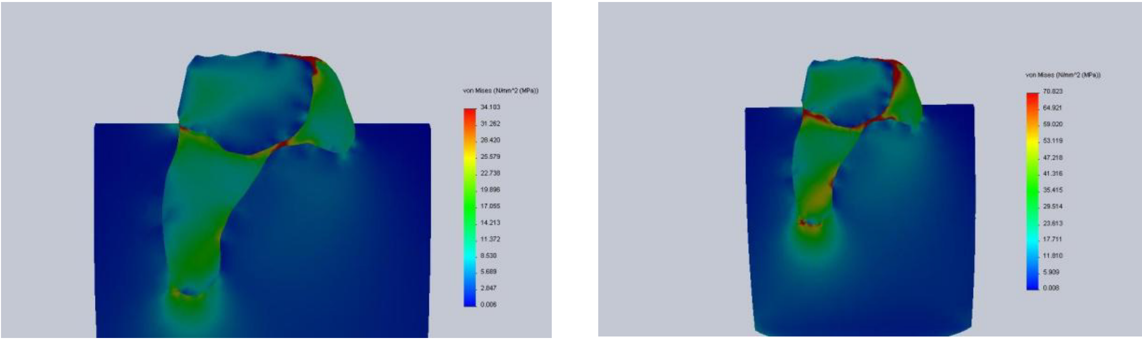

Fig. 5. (a) Von Mises stresses in dangerous section for dental filling composite raisin; (b) Von Mises stresses in dangerous section for dental filling Gic Fuji IX.

The values of the contact pressure for the whole assembly (primary molar - restorative material – bone structure) and also at the interface bone-molar and molar – restorative material respectively were determined for both dental fillings: Fig. 6a and Fig. 6b respectively for composite raisin and Fig. 7a and Fig. 7b respectively for Gic Fuji IX.

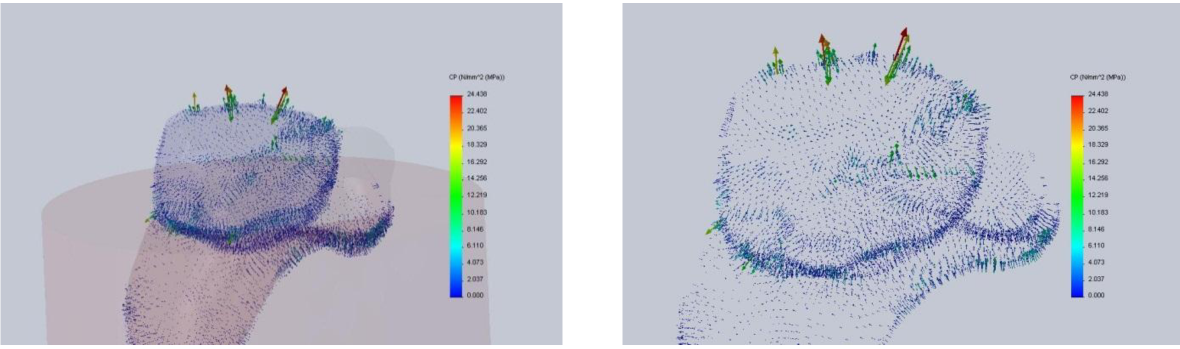

Fig. 6. (a) Contact pressure for bone- molar - composite raisin assembly; (b) Contact pressure at the interface bone- molar and molar-composite resin.

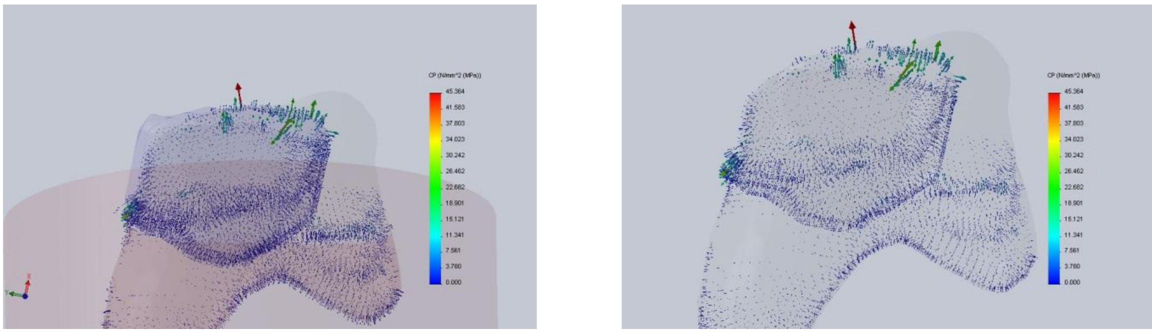

Fig. 7. (a) Contact pressure for bone- molar - Gic Fuji IX assembly; (b) Contact pressure at the interface bone- molar and molar- Gic Fuji IX.

3. Conclusion

The finite element study of the 3D models led to the determination of the stress and displacement distributions in any point on the surface and in the sections of the structural assembly primary molar – restoration material, emphasizing the most stressed areas which occur during the activity of mastication. In the same time it was possible to quantitatively assess the pressure contact at the interface dental filling-tooth and tooth-bone.

The results obtained led to the following conclusions regarding the biomechanical behavior of the structural components (restorative material - molar – bone):

- von Mises equivalent stresses have generally small values on the surface of the assembly dental filling-tooth, with the exception of some points on the contact area. These zones are referred as *dangerous sections*. The values of these stresses correspond to the data presented in Fig. 8a. The maximum values of the stresses in the case of the composite resin used as dental filling are 50% smaller than the stresses in the case of Gic Fuji IX material.
- Due to the close values of Young's modules for the tooth and for the bone structures, the contact pressure on the interface molar-bone has low values. Instead, on the interface restorative material-molar, due to larger differences between the elasticity modules of the teeth and filling materials, the values of the contact pressure are higher. Thus the contact pressure on the interface molar-composite resin is 53.8% smaller in comparison with the case of dental filling consisting of Gic Fuji IX material (Fig. 8b).This difference is caused due to the fact that Young's modulus of this material is 33.33% less than that of the molar. Therefore it is normal that the contact pressure on this surface has higher values.
- The displacement distributions on the surface restorative material-molar assembly are shown in Fig. 8c. It can be noticed from the histogram that the maximum values of the displacements are small.

As further research work, with the information offered by this study, it will be possible to compare these results with the stress and strain distributions for the assembly bone structure- canine - restorative material, or bone structure - incisor - restorative material and provide a better treatment for dental caries.

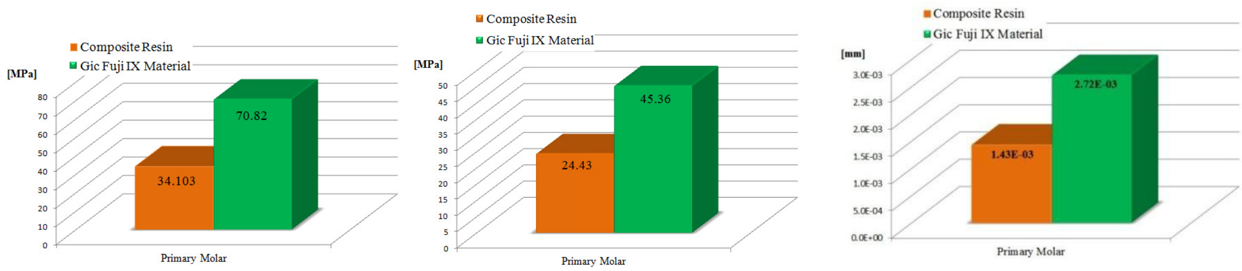

Fig. 8. (a) Maximum values of von Mises stresses on the surface of the restorative material - molar assembly; (b) Maximum contact pressure on the interface molar-restorative material; (c) Maximum values of the displacements.

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