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Analysis of the main stresses on dental crowns

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Abstract. *This paper presents an analysis of the main stresses to which dental crowns are subjected. The first part presents a series of aspects regarding the dental biomechanics (mechanical characteristics of hard tissues and periodontal ligaments, identification of masticatory movements and, the stresses to which the teeth are subjected). It is very important in the field of dental biomechanics to know how a force is transferred to a tooth root and the surrounding tissues. Because of the difficulty in measuring physical parameters in this region, stress-strain distributions have usually been estimated by finite element analysis (FEA). The most representative materials and the main stages of making dental crowns using CAD-CAM technology are presented. The paper ends with a series of results and conclusions obtained from this analysis.*

Keywords: Dental crowns, 3D printing, CAD-CAM, FEA.

Introduction

The mechanical characteristics of any object depends on the forces applied to the structure, the resulting burdens (stresses, strains) placed on the materials that comprise the structure, and the ability of the materials to withstand and sustain the burdens (material properties). As a living material, bone is uniquely capable of responding and adapting to mechanical cues that influence its size and shape. For example, with the loss of teeth, individuals experience decreased mastication and biting functionality, and the strength and stiffness of the mandible decrease accordingly.Conversely, as a result of increased exercise, long bones increase their size and shape in response to large incident forces, which increases their ability to withstand loads. When a force is applied to a structure, such as a whole bone, the structure deforms, and strains and stresses develop throughout the material. Material properties are intrinsic characteristics and independent of geometry or architecture.(Lynch, M.E., et al., 2012; Gradinaru, I., et al., 2020; Costan, V.V., et al., 2020)

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Mechanic characteristics of periodontal ligament-PDL

A tooth is secured to the alveolar bone by fibrous connective tissue that is called the periodontal ligament (PDL). The PDL not only strongly binds the tooth root to the supporting alveolar bone but also absorbs occlusal loads and distributes the resulting stress over the alveolar bone.The mechanical properties of the PDL are, therefore, essential parameters for understanding the mechanical behavior of a tooth root and that of surrounding tissues. The PDL also plays an important role in the mechanical adaptation of the dentition, based on alveolar bone remodeling induced by a change in mechanical stress or strain around a tooth root. (Nishihira, M., et al., 2012)

Human Bite Force

Maximum human bite force and the factor that affect it have been closely studied in numerous laboratory experiments. It varies with several factors including subject gender and age, food type, jaw disorders, tooth quality, muscular strength, and other factors. The factors that increase force are: tilting the bite force forward, keeping the jaw perpendicular to the occlusal plane as it is opened, placing teeth nearer the midline, raising teeth height for forwarding bite forces, and tilting the articular surface of the condyle forward. (McGarry, J., et al., 2020)The bite force is also dependent on the teeth that are in direct contact with the food. Incisors are located in the front of the jaw and have the least mechanical advantage, being at the front of the mouth. (Fernández, E., et al., 2003) Force measurement has been conducted to assess both the force required for mastication and maximum bite force. Common foods such as carrots, biscuits, and cooked meats produce forces in the range of 70-150 N on a single tooth. Forces on all contacting teeth during mastication range between 190 and 260 N. Maximum bite force is variable between experiments but generally falls within the range of 500-700 N. Maximum bite force as reported by several different articles for young, healthy subjects is shown in Table 1.(McGarry, J., et al., 2020)

Table no. 1. Maximum bite force in male and female subjects as reported by different articles.

Article Number	Male Max. Force [N][a)]	Female Max. Force [N][a)]	Measurement Device	Citation
1	847	597	Quartz force transducer	(Waltimo & Könönen, 1993)
2	909	777	N/A	(Waltimo & Könönen, 1995)
3	652	553	Strain gauge mounted on the mouthpiece	(Van Der Blit, Tekamp, Van Der Glas & Abbink, 2008)
4	587	425	Digital dynamometer	(Calderon, Kogawa, Lauris & Conti, 2006)
Average	700	533	-	-

Source: McGarry, J., Spangenberger,A., *Dynamic Evaluation of Forces During Mastication,* Worcester Polytechnic Institute, Project Number: ME-SYS-0787, available at https://web.wpi.edu/Pubs/E-project/Available/E-project-042612-121524/unrestricted/Mastication_Fixture_Final.pdf, accessed: 08, 2020.

CAD/CAM Technology and Representative materialsfor Dental Implant
Computer Assisted Design (CAD) and Computer Assisted Manufacturing (CAM) have been gaining increased use in implant dentistry over the past 10 years. Selective Laser Melting (SLM) is a layer-wise material addition technique that allows generating complex 3D parts by selectively melting successive layers of metal powder on top of each other, using the thermal energy of a focused and computer-controlled laser beam. (Vandenbroucke, B., et al., 2008) Some of the materials being used in this process can include Ni based superalloys, copper, aluminum, stainless steel, tool steel, cobalt chrome, titanium, and tungsten. The competitive advantages of SLM are geometrical freedom and material flexibility (metals). Dental parts, like crowns, bridges, and frameworks, are very suitable to be produced by SLM due to their complex geometry, low volume, strong individualization, and high aggregate price.(Vandenbroucke, B., et al., 2008)Dental implants are usually manufactured in pure commercial titanium because of their biocompatibility and suitable mechanical and corrosion properties.(Fernández, E., et al., 2003) Metals and alloys for structural applications are characterized by both their high elastic modulus and yield stress. When they come into contact with human tissue, properties such as biocompatibility, corrosion resistance, high static and fatigue strength, and fracture toughness are also required. The main degradation processes, which may lead to the eventual failure of the medical device, are due to fatigue, corrosion, wear, and any interaction among them. Though few metallic alloys can be used as biomaterials in dental use, some families of metals and alloys exhibit good properties of fatigue, corrosion, and wear. Materials that have traditionally been used, such as gold, stainless steel, or chromium-cobalt-nickel alloys have been substituted by a new generation of alloys with excellent characteristics of and strain recovery as well as suitable properties of mechanical strength, fatigue, and corrosion. (Fernández, E., et al., 2003)

Materials and Methods

The CAD model of the dental crowns
In this study, the CAD models and FEA of the lower molar and dental crown were made using the SolidWorks 2012 software (Figure 1). SolidWorks is part of the most advanced CAD-CAM systems currently used in designing and contains, compared to other similar systems, several facilities in working with 3D spatial shapes.

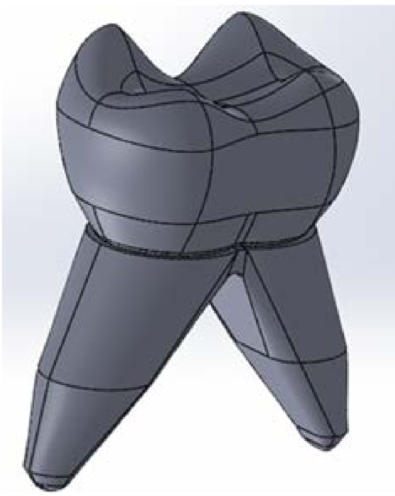


Figure no. 1. The CAD model of the lower molar

FEA of the main stresses on dental crowns

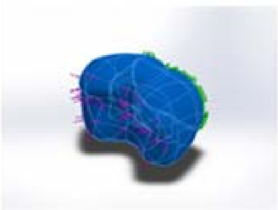
The study starts with a geometric model; this could be a native SolidWorks part, multi-body part, or an assembly. It could also be a file from another CAD system or even a neutral format such as a STEP or IGES. SolidWorks Simulation is capable of analyzing all of these file types. Next, it assigns materials to all the components, defines the loads acting on the structure and apply restraints to describe how it's anchored or held in place. (Pessoa, R.S., et al., 2012)Lastly, it approximates the geometry by splitting it into smaller and simpler entities known as elements. This process is called "meshing", and it can be automated by the software. The type, arrangement, and the total number of elements, as well as the interpolation function, are important factors affecting the accuracy of the results.(Pessoa, R.S., et al., 2012)

Mesh type	Solid Mesh
Mesher Used:	Standard mesh
Automatic Transition:	Off
Include Mesh Auto Loops:	Off
Jacobian points	4 Points
Element Size	0.826252 mm
Tolerance	0.0413126 mm
Mesh Quality	High

Mesh Information - Details

Total Nodes	15536
Total Elements	9961
Maximum Aspect Ratio	61.726
% of elements with Aspect Ratio < 3	95.7
% of elements with Aspect Ratio > 10	0.341
% of distorted elements(Jacobian)	0
Time to complete mesh(hh;mm;ss):	00:00:07
Computer name:	KIS

Figure no. 2. Mesh Information

Model Reference	Properties	Components
	Name: Ceramic Porcelain Model type: Linear Elastic Isotropic Default failure criterion: Mohr-Coulomb Stress Tensile strength: 1.7234e+008 N/m^2 Compressive strength: 5.5149e+008 N/m^2 Elastic modulus: 2.2059e+011 N/m^2 Poisson's ratio: 0.22 Mass density: 2300 kg/m^3 Shear modulus: 9.0407e+010 N/m^2 Thermal expansion coefficient: 1.08e-005 /Kelvin	SolidBody 1(Imported1)(Stress simulation)

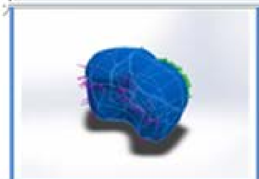
	Coroane metalo-ceramice	Mass:0.00129551 kg Volume:5.63264e-007 m^3 Density:2300 kg/m^3 Weight:0.012696 N	C:\Users\Aron\Desktop\Stress simulation 2.0.SLDPRT Jun 28 00:08:48 2019

Figure no. 3. Material Properties

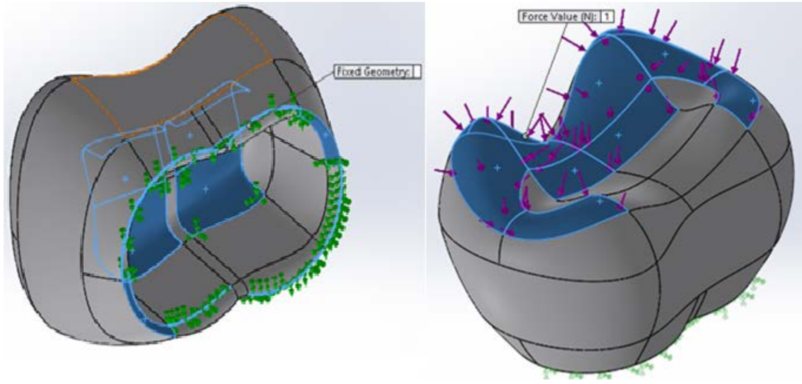


Figure no. 4. Distribution of forces on the surface of the dental crown and fixation points

More information (details) about the discretization of the CAD model of the studied dental crown is presented in Figure 2. The properties of the material chosen for the manufacture and FEA analysis of the dental crown are presented in Figure 3. A force of 490 N was used for the FEA of the dental crown- Figures 4 and 5. The finite element mesh was constructed using linear tetrahedral elements and the final models presented a specific number of nodes and elements (9,961 nodes and 15,536 elements).

Results and discussions

Following the FEA, an uneven distribution of masticatory forces was obtained on the surface of the dental crown, as shown in Figure no. 5.

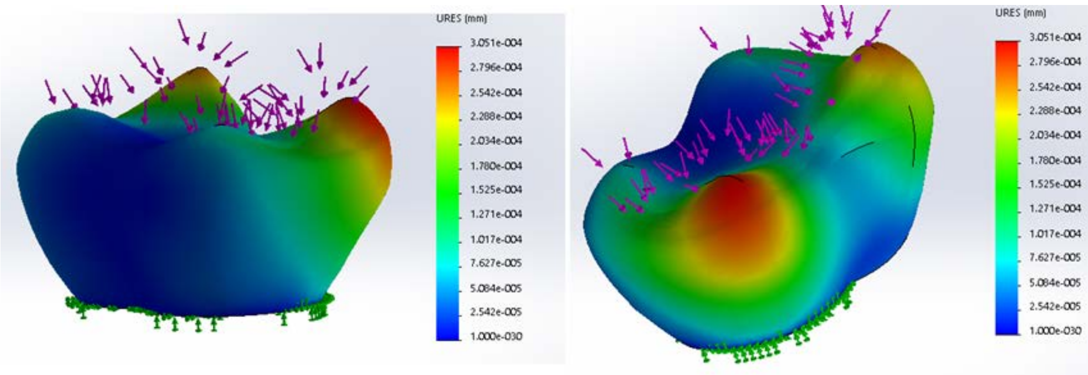


Figure no. 5. The results found after FEA of the dental crown

Conclusion

Although FEA is an indisputably valuable and efficient tool for the analysis of diverse Biomechanical problems, it is important to understand the limitations of the method. FEA uses approximated mathematical models to represent the behavior of physical systems. Also, the elaboration of a finite element model for an implant evaluation involves the acquisition of the implant system and bone geometries, the assignment of appropriate materials properties and interface conditions, and the determination of proper boundary conditions, loading magnitude, and direction. Simplifications in any of these stages will have a direct effect on the model's precision. Thus, to validate a finite element model, it is recommended to confront its previsions with data derived from other analysis types, in particular, from experimental measurements.(Pessoa, R.S., et al., 2012) The masticatory forces are not evenly distributed over the entire occlusal surface of the crown.

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