Study on Fatigue Strength of A Dental Crown : A Review

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Abstract:

Biomedical Engineering covers a wide range of capacities e.g. to design instruments, devices, and software, for bringing together knowledge from many technical sources to develop new procedures, and to conduct research needed to solve clinical problems. The selection of an appropriate material to place in the human body may be one of the most difficult tasks. Certain metal alloys, ceramics, polymers, and composites have been used as implantable materials. Biomaterials must be nontoxic, non-carcinogenic, chemically inert, stable, and mechanically strong enough to withstand the repeated forces of a lifetime. Understanding the properties and behavior of living material is vital in the design of implant materials. Certain problems linked with dentistry are identified and an attempt is made to resolve it in the present work. Replacement of natural tooth by some artificial material and its life is to be studied. So its fatigue strength and fracture strength is to be studied is essential. This requires a brief knowledge of dental structure as well biomechanics.

Keywords: fracture strength; fatigue strength; flexural strength; occlusal stress; restored molar tooth; static loading; finite element method;

1. Introduction

Recently there have been only a few people who can boast of healthy teeth without any intervention by a dentist. Teeth are an integral part of the oral cavity and each person uses them several times a day for receiving and processing food. The next important role is their irreplaceable place in the overall personal appearance. In case of the extensive damage or loss of the tooth it is either possible to insert a dental implant into a vacant place or use a dental bridge. Both of these solutions are very expensive and time consuming. For these reasons it is very important to take care of the teeth and mouth and keep them in good condition. Although the teeth consist of the most resistant and hardest material in the human body, it can still be damaged by mechanical, chemical and biological processes. The most common damage of the dental tissues is dental caries. The treatment of dental caries belongs to the branch of restorative dentistry. Dental caries is removed by using dental instruments and the newly vacant place is ready for the application of a filling material and covering it with a cap which is nothing but a crown of a tooth. This procedure is called tooth restoration. A well executed restoration of the tooth helps to prevent the spread of further dental caries and it maintains the basic function of teeth like separating and crushing food. In this activity the crown are significantly mechanically loaded. Restoration of the teeth significantly changes the coherence and mechanical properties of the impaired dental tissue, which also affects the deformation and stress of the loaded tooth. For the restored tooth there is a sudden change in stiffness, resulting in stress concentrations

That may cause an undesirable fatigue in the crown of the tooth .so it's essential to select a proper material for a crown which may have a greater strength and withstand the fracture of a restored tooth. So fatigue strength of metal ceramic and zirconia crown is been studied.

2. Material and methods

Material used is metal ceramic , porcelain, tooth metal and metal crown For solving this problem the finite element method (FEM) was chosen and the FEM software ANSYS was used. To obtain the computational model it is necessary to create sub-models. These are a model of geometry, a model of materials, and a model of loads and boundary conditions, which clearly define the object in space. [1]

2.1 DENTAL STRUCTURE

Man, like all mammals, have two sets of teeth . The first set comprising of 20 teeth in all, is called primary, deciduous or milk dentition. These teeth first begin to appear in the oral cavity at the mean age of 6 months and the last one erupts into the mouth at about 28 ± 4 months. Then, commencing at six years, first of the permanent or succedaneous, teeth appears. There are then three periods of dentition in man (i) the primary dentition (6 months to 6 years) (ii) mixed dentition (6 to 12 years) and (iii) permanent dentition (12 + years). If man is assigned an average life span of 70 years, it is obvious that he spends only 6% of the time chewing with his primary teeth and 91% masticating with his permanent dentition, if he is fortunate. To begin with there are two dental arches as shown in figure the maxillary which is the part of cranium and is immovable part of it, and the mandibular, which is the part of the lower jaw and is the movable part of the skull. Looking at the two arches, the total tooth bearing apparatus can be divided into four quadrants: a right maxillary, a left maxillary, a right mandibular and a left mandibular. There are eight teeth in each quadrant. The vertical line dividing the arch into right and left halves is denoted as mid-saggital plane. On the basis of form and function, in the primary dentition, there are only three categories: incisors, canines and premolars. The permanent dentition falls in four categories: incisors, canines, premolars and molars. Canines are primarily piercing teeth while molars are grinders. The compressed crowns of the incisors make them cutting teeth.

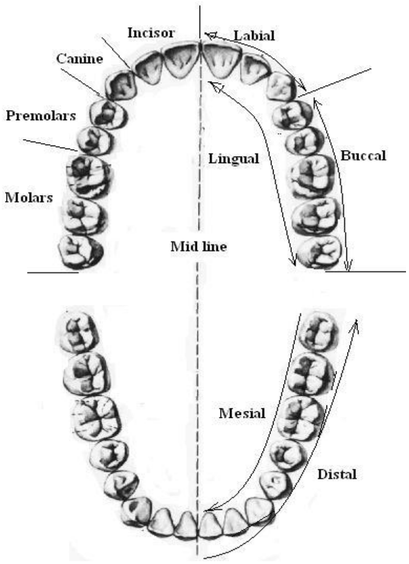


Figure 2.1: The Permanent Arch

The eight teeth in the permanent dentition shown in the fig. 2.1 are designated as:

1. Central incisor
2. Lateral incisor
3. Canine
4. First premolar
5. Second premolar
6. First molar
7. Second molar
8. Third molar (wisdom tooth)

2.1.1 DENTAL ANATOMY

A basic anatomical terminology, which describes on the basis of form and function, in the primary dentition, there are only three categories: incisors, canines and premolars. The permanent dentition falls in four categories: incisors, canines, premolars and molars. Canines are primarily piercing teeth while molars are grinders. The compressed crowns of the incisors make them cutting teeth. The Molars are the last teeth towards the back of our mouth. Molars are much bigger than the Premolars and have bigger, flatter chewing surfaces because their job is to chew and grind the food into smaller pieces. so to solve the problem crown of molar tooth is taken into consideration.

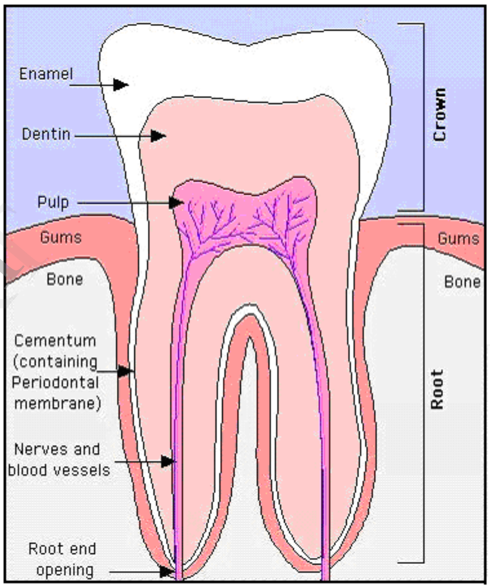


Figure 2.1.1: Tooth Anatomy

Some of the important terms of orientation related to tooth and oral cavity as shown in figure and are as follows:-

Labial: next to or towards the lips

Buccal: next to or towards the cheek

Distal: away from median line

Mesial: towards the median line

Apex: the terminal end or the tip of the root

Occlusal: towards the biting surface of posterior tooth

Crown- The visible part of the tooth above the gums

Root - the anchor of a tooth that extends into the jawbone

Gums: the soft tissue that surrounds the base of the teeth.

Nerves: they transmit signals (conveying messages like hot, cold, or pain) to and from the brain.

Cementum: a layer of tough, yellowish, bone-like tissue that covers the root of a tooth. It helps to hold the tooth in the socket. The cementum contains the periodontal membrane.

Enamel: Outer layer of the crown

Cemento-enamel junction: The junction of enamel and cementum.

Axial: pertaining to the longitudinal axis of the tooth

Apical: towards the apex of the roots

Cervix: a narrow portion of the tooth in the junction of crown and root.

Cervical line: a curved line formed by the junction of enamel and the cementum of the tooth.

2.1.2 MOLAR TOOTH.

The Molars are the last teeth towards the back of our mouth. Molars are much bigger than the Premolars and have bigger, flatter chewing surfaces because their job is to chew and grind the food into maller pieces .Different views of mandibular right first permanent molar.

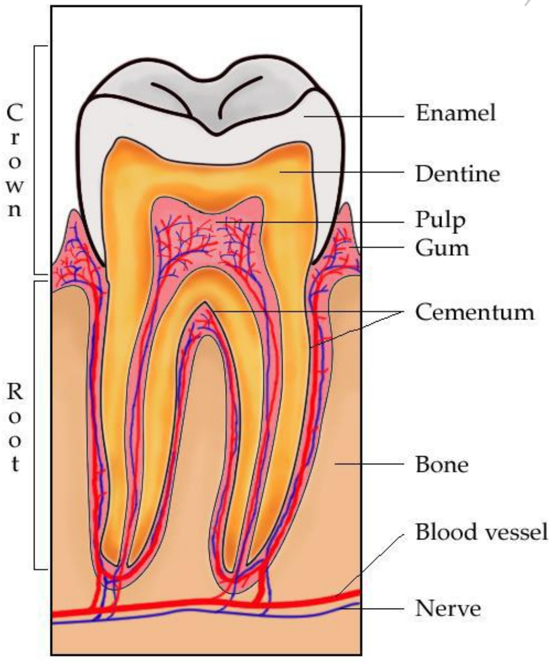


Figure 2.1.2: Mandibular Molar

2.1.3 CROWN

A crown is an artificial restoration that fits over the remaining part of a prepared tooth, making it strong and giving it the shape of a natural tooth as shown in figure 2.6. A crown is sometimes also called a ―cap‖. Porcelain bonded to metal has been the traditional way to produce a tooth-coloured crown. A metal base is made to provide strength and is coated with a layer of tooth coloured porcelain.

A **crown** is a type of dental restoration which completely caps or encircles a tooth or dental implant. Crowns are often needed when a large cavity threatens the ongoing health of a tooth. They are typically bonded to the tooth using a dental cement. Crowns can be made from many materials, which are usually fabricated using indirect methods. Crowns are often used to improve the strength or appearance of teeth. While inarguably beneficial to dental health, the procedure and materials can be relatively expensive. The most common method of crowning a tooth involves using a dental impression of a prepared tooth by a dentist to fabricate the crown outside of the mouth. The crown can then be inserted at a subsequent dental appointment. Using this indirect method of tooth restoration allows use of strong restorative materials requiring time consuming fabrication methods requiring intense heat, such as casting metal or firing porcelain which would not be possible to complete inside the mouth. Because of the expansion properties, the relatively similar material costs, and the aesthetic benefits, many patients choose to have their crown fabricated with gold. As new technology and materials science has evolved, computers are increasingly becoming a part of crown and bridge fabrication, such as in CAD/CAM Dentistry.

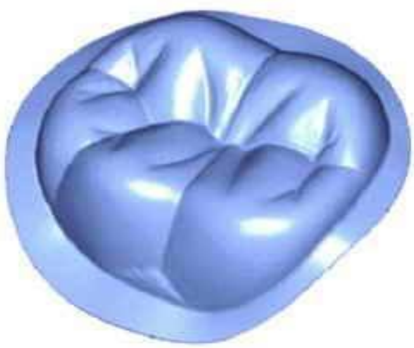


FIGURE 2.1.3 THE OCCLUSAL SURFACE OF CROWN

Crowns can be made out of porcelain (or some other ceramic material), gold (or metal alloys), or a combination of both. Dental crowns are often referred to as "dental caps" or "tooth caps" Since dental crowns cup over teeth, any dental crown that has a porcelain surface can be used as a way to idealize the cosmetic appearance of a tooth. Actually, getting teeth "capped" just to improve its appearance can be at times a very poor choice. Dental crowns are best utilized as a way to improve the cosmetic appearance of a tooth when the crown simultaneously serves other purposes also, such as restoring a tooth to its original shape (repairing a broken tooth) or strengthening a tooth (covering over a tooth which has an excessively large filling). The strengthening capability of dental crowns is related to the fact that they cup over and encase the tooth on which they are placed, thus serving as a splint which binds the tooth together. Dental crowns are a very important means by which a dentist can strengthen a tooth new outer surface.[1]

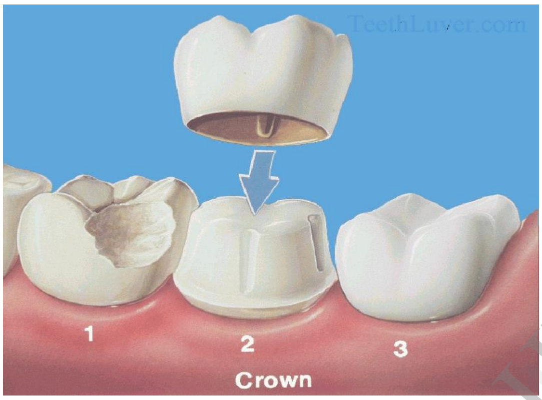


FIGURE 2.1.4: ASSEMBLY OF RESTORED TOOTH AND CROWN

FIGURE 2.1.5: CERAMIC CROWNS

3. ORAL ENVIRONMENT

The wet system of the oral cavity is well suited for the destruction of the food boli, which may otherwise cause gastric troubles. The chemical environment of the oral cavity is also an important factor. Not only the normal ph of one's mouth, but also the acid contained in food and beverages react with dental materials thus affecting their service. Similarly the temperature of the food consumed, if too high or too low may have an effect on the dental materials. The average biting force is 750 N in the posterior and 150 N in anterior teeth. Thus, a weakened tooth if subjected to such a large biting force may lead to fracture. Hence, oral environment is an important factor which should be considered for successful treatment.[11]

4. BIOCOMPATIBILITY

A dental material that is to be used in the oral cavity should be harmless to all oral tissues. Furthermore it should contain no toxic, leak able or diffusible substance that can be absorbed into the circulatory system, causing systematic toxic responses. Corrosion of dental materials causes release of its components in the mouth causing toxicity and allergy. Unintended side effects may be caused by dental restorative materials which may be local or systematic. Local reactions involve the gingival, pulp and hard tooth tissues including excessive wear on opposing tooth from restorative materials. Systematic reactions are expressed generally as allergic skin reactions. Hence, the dental materials should be non reactive and absolutely neutral in oral environment so that no back reactions from the body are triggered.[3]

5. MATERIALS USED FOR CROWNS:

5.1 Ceramic:

It is made of Porcelain, and is most commonly used these days. Ceramics are tooth-colored. They are more resistant to staining and abrasion than composite resin. Ceramics are more brittle than composite resin.

5.2 Dental porcelain:

Dental is porcelain used by a dental technician to create biocompatible lifelike crowns, bridges, and veneers for the patient. Evidence suggests they are effective (they are biocompatible, esthetic, and insoluble and have hardness of 7 on the Mohs scale), although for three-unit molars porcelain fused to metal or in complete porcelain group only zirconia-based restorations are recommended.

5.3 Zirconia:

Zirconium also called Zirconia (Cercon) is rapidly becoming the material of choice for dental crowns. It is a very strong material able to withstand the wear and tear of everyday use. Aesthetically, it is translucent very similar to a natural tooth, reflecting light in much the same way

The zirconia metal provides the strength whilst the porcelain provides the outward appearance on a normal tooth. Zirconium crowns allow light to pass through as with a normal tooth giving a natural look, unlike other metal cores which block the light. Some resources are also calling them as Non-Allergic Crowns and say Zirconia is “Biocompatible" because the body does not reject it. Unlike Amalgam Fillings and metal alloys, the human body accepts zirconium, zirconia as a natural material, so you would not need to worry about allergies or adverse reactions.

5.4 METAL CERAMIC CROWN:

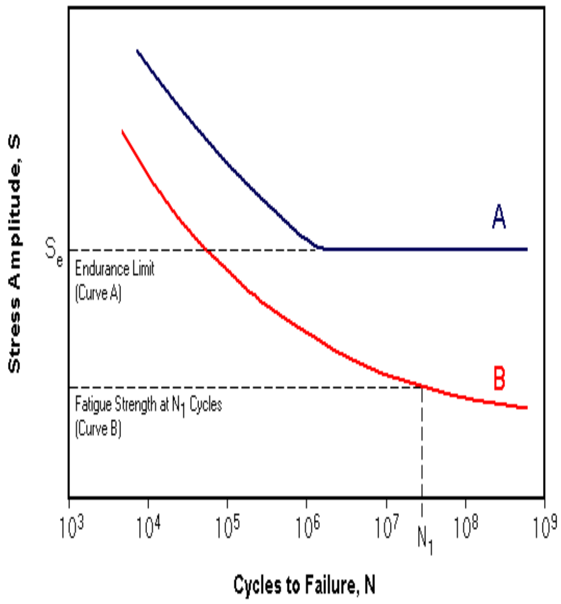
Metal ceramic crowns are a traditional type of crown often used in bridges plus crown and bridge cases. They are often fitted onto back teeth and are considered a strong, robust type of crown. But they are viewed as less than attractive. Many people choose the all ceramic crowns, zirconium or the E-Max crown for their greater aesthetic appeal. This type of crown is both robust and long lasting. It is considered a better fit than many other types of crowns and to have greater strength as well. They are often cheaper than other types of crowns, for example all ceramic crowns. The cost of a crown depends upon the material/s used, the location in the jaw (e.g. front or back tooth) and the extent of the procedure. As you might imagine, the more crowns you need the longer this will take which will increase the cost.

6. FATIGUE STRENGTH:

In materials science, **fatigue** is the weakening of a material caused by repeatedly applied loads. It is the progressive and localized structural damage that occurs when a material is subjected to cyclic loading. The nominal maximum stress values that cause such damage may be much less than the strength of the material typically quoted as the ultimate tensile stress limit, or the yield stress limit.

Fatigue occurs when a material is subjected to repeated loading and unloading. If the loads are above a certain threshold, microscopic cracks will begin to form at the stress concentrators such as the surface, persistent slip bands (PSBs), and grain interfaces. Eventually a crack will reach a critical size, the crack will propagate suddenly, and the structure will fracture. The shape of the structure will significantly affect the fatigue life; square holes or sharp corners will lead to elevated local stresses where fatigue cracks can initiate. Round holes and smooth transitions or fillets will therefore increase the fatigue strength of the structure.

Fatigue limit, endurance limit, and fatigue strength are all expressions used to describe a property of materials: the amplitude (or range) of cyclic stress that can be applied to the material without causing fatigue failure Ferrous alloys and titanium alloys have a distinct limit, an amplitude below which there appears to be no number of cycles that will cause failure. Other structural metals such as aluminium and copper do not have a distinct limit and will eventually fail even from small stress amplitudes. In these cases, a number of cycles (usually 10^7) is chosen to represent the fatigue life of the material. fatigue strength is defined as , S_{Nf}, as the value of stress at which failure occurs after N_f cycles, and fatigue limit, S_f, as the limiting value of stress at which failure occurs as N_f becomes very large. some definitions does not define endurance limit, the stress value below which the material will withstand many load cycles, but implies that it is similar to fatigue limit. Some authors use endurance limit, S_e, for the stress below which failure never occurs, even for an indefinitely large number of loading cycles, as in the case of steel; and fatigue limit or fatigue strength, S_f, for the stress at which failure occurs after a specified number of loading cycles, as in differentiate between the expressions even if they do differentiate between the two types of materials.



7. Methods used for solving the problem:

For finding the fatigue strength of a dental crown calculation of stresses on that crown is necessary simultaneously no. of cycles is must. With the help of modeling, model of molar crown and molar tooth can be created. Material properties are required to for finding out the stress. Analysis can be done by using ansys software

MATERIAL PROPERTIES:

Materials	Youngs Modulus (gpa)	Poisons ratio
Enamel	84.1	0.33
Dentin	18.6	0.31
Ceramic	5×10^4	0.01
Zirconia	210	0.30
porcelain	8×10^4	0.01

8. Conclusion:

Since fatigue is the failure of a material under varying loads, well below the ultimate static loads, after finite number of cycles of loading and unloading .This is frequent cause of failure of a molar tooth, because it is subjected to repetitive chewing and biting process, so it is essential to find out the fatigue strength of molar crown.

The main goal is to gain a depth understanding of the mechanical performance of the different material of dental crown, subjected to masticatory loads. Further, study suggests that which would be the best material for the dental crown; it would give the evidence of life of material and its fatigue strength. It will thus contribute to the decision making capacity of dentist to decide upon the type of proper selection of material for the crown required for a particular case and gives the best prognosis for longevity without any destructive testing, in the least possible time

References:

[1]Jiˇr´ı Val´aˇsek, Petr Marci´an, Kamil ˇReh´ak, David Krpalek, Zdenˇek Florian, Engineering MECHANICS, Vol. 19, 2012, No. 2/3, p. 131–141

[2] Takahashi Y and Chai J. Assessment of shear bond strength between three denture reline materials and a denture base acrylic resin. Int J Prosthodont 2001; 14:531-5.

[3] Bor´ak L.: Biomechanical Study of Disk Implants Part I, Engineering Mechanics, Vol. 17 (2010), No. 1, pp. 49–60, ISSN 1802-1484

[4] Marci´an P.: Biomechanical Study of Disk Implants Part II, Engineering Mechanics, Vol.17 (2010), No. 2, pp. 111–121, ISSN 1802-1484

[5] Zukerman GK. A reliable method for securing anterior denture teeth in denture bases. J Prosthet Dent 2003; 89: 603-7.

[6] Vallittu PK and Ruyter IE. Swelling of PMMA resin atthe repair joint. Int J Prosthodont 1997; 10(3): 254-58.

[7] Cunningham JL and Benington IC. A survey of the prebonding preparation of denture teeth and the efficiency for de-waxing methods. J Prosthet Dent 1997; 25(2):125-128.

[8] Marci´an P., Koneˇcn´y O.: On the level of computational models in biomechanics depending on gained data from CT/MRI and micro-CT, MENDEL 2011, ISSN 1803-3814, BUT FME Brno,2011, (in press)

[9] Hellwing E., Klimek J., Attin T.: Z´achovn´a stomatologie a parodontologie, Grada Publishing a.s., Aviceum, Praha, 2003, ISBN 80-247-0311-4

[10] Beatty M.W.: Elastic and fracture properties of dental direct filling materials, Biomaterials,Vol. 14 (1933), Issue 13, pp. 999–1002, ISSN 0142-9612

[11] Cattell MJ, Clarke RL, Lynch EJ. The biaxial flexural strength and reliability of four dental ceramics – part II. J Dent 1997;25:409–14.

[12] Gorman CM, McDevitt WE, Hill RG. Comparison of two heat-pressed all-ceramic dental materials. Dent Mater 2000;16:389–95.

[13] Fradeani M, Redemagni M. An 11-year clinical evaluation of leucite-reinforced glass–ceramic crowns: a retrospective study. Quintessence Int 2002;33:503–10.

[14]Isabelle Denry * and Julie A. Holloway*Materials* 2010, *3*, 351-368; doi:10.3390/ma3010351.

[15]Hikmat J. Aljudy, B.D.S., M.Sc., Ph.D. (1)
Ali N. A. Hussein, B.D.S., M.Sc. (2)
Ihab N. Safi, B.D.S., M.Sc. J Bagh College Dentistry Vol. 25(1), March 2013.

[16] Beata Dejaka, Andrzej Młotkowskib, Cezary Langota ,Three-dimensional finite element analysis of molars withthin-walled prosthetic crowns made of various materials, dental materials 28(2 0 1 2)433–441.