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Design of 3-part Immediate Implant and Study of Behaviour under Different Loading Conditions using FEA

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Abstract— The study is to design and analyze an implant having 3-parts associated with it to form a single stable and rigid structure between implant and jaw bone. The 3-part immediate implant consist the upper part of called abutment and next to it is mimic shape of extracted teeth and length of that part depends on the extracted tooth, the third part comes is conical screw structure which get inserted into the jaw bone. This part provides the primary support to the whole structure and makes forces to get distributed equally along the implant length to root. A bite force of maximum 200N is applied under axial and oblique load to the implant. The modeling and FEA analysis is performed using Dassualt System Solidworks 2017 software. The plastic printed parts developed using 3-D plastic printer. The maximum stress and displacement is observed under oblique loading condition.

Keywords— Immediate Implant, Mimic, Oblique loading, Axial loading, 3-D plastic printing

I. Introduction

Dental implant is an artificial dental root that is used to regain the function of one or more missing teeth of edentulous patients. It is the safest, most functional and efficient way among the techniques for missing tooth replacement applied by dentists. A dental implant is basically composed of two parts. The lower part is surgically inserted into the jaw bone and fixed in the location of priorly existing natural tooth roots. It is directly in contact with bone. During a period of healing, bone grows around the implant and provides a strong structural support similar to the roots of natural teeth. The upper part, called abutment, is mounted on the portion of the lower part that is exposed to the oral cavity beyond the level of gum line. The false tooth, called the crown that replaces the missing tooth is fitted on to the abutment.

Many times, a periodontist, oral surgeon or specially trained dentist can place an implant directly into the extraction socket immediately following tooth removal. It is imperative that the extraction of the failing tooth be performed very carefully and without damage to the surrounding gum and bone tissue. This is known as an immediate dental implant. Traditionally the socket is allowed to heal and fill in with new bone first before a dental implant is placed into the socket. The benefit to having an implant placed an immediate dental implant is that only a single surgical procedure is necessary as opposed to two separate procedures. Initially the dental implant is held securely in place by mechanical forces. As the dental implant heals, it forms a microscopic bond with the surrounding bone which is known as osseointegration. It is more difficult to place and secure an implant at the time of tooth extraction because there is less bone available, and the security comes from being able to fit the implant as closely as possible into the remaining socket and to the bone beyond it.

During the period between 1970 and 1980, researchers carried out many experimental studies to obtain better designs and geometric forms for titanium dental implants some of which are the IMZ Implants, TPS Implants, ITI Hollow-Cylinder Implants [1]. Throughout this period, Dr. Bränemark continued his research and in 1971 he introduced titanium hollow screw implants which resulted in increased success rate, clinical applicability and reduced rate of complications compared to blade-form implants. In 1977, Dr. Bränemark published a paper which covered all the data obtained in his studies, and this report provided the scientific data for the development of currently implemented implantation procedures and implant systems [2]. In 1978, he established a commercial partnership with a Swedish defense company, Bofors AB. In 1981, based on the partnership, Nobel Biocare, one of the largest current dental implant producers in the world, was founded with the aim of focusing directly on dental implantology.

In 1982, the Toronto Conference on Osseointegration in Clinical Dentistry set the first guidelines for successful implant dentistry [3]. The successful integration of hollow screw geometry into bone and high biocompatible characteristics of titanium resulted in that screw form dental implants have become the preferred method of tooth replacement and a standard dental treatment technique. Providing a high rate of success and a wide range of restorative options, today, dental implants, under various brand names, are extensively used worldwide. Current studies are mainly focused on improving aesthetics, reducing healing period and simplifying the use of dental implants.

A weak primary stability is one of the major causes contributing to the flaw of implants. Therefore a high primary stability assures a high resistance of the implant to micromovements, which is very important for a successful osseointegration, since the implant shall not be subject to micromevements higher than 150 μm [4]. The factors that influence the primary stability are bone density, the type of surface and the surgical technique used. When an implant is placed, the primary stability will depend firstly on the quantity and quality of cortical and trabecular bone available for the fixation of the implant [4]. Bone density is, amongst all, the most related influencing factor of primary stability.

II. METHODS AND MATERIAL

The steps were taken for the extraction of tooth from maxilla and then the modification/ modeling was performed in a CAD software. The 3-D parts were printed in plastic for demonstration purpose.

1. *Three Dimensional Modeling*

- *Extraction of Tooth:* Computer Tomographic (CT) datasets of the fractured tooth were acquired using a modern cone beam scanner. CT datasets were transferred to a specific 3D reconstruction software (MimicsR, Materialise) as shown in Fig. 1. The software is to construct a 3D projection of the maxilla and the residual root, simulating a "virtual" extraction of the root.

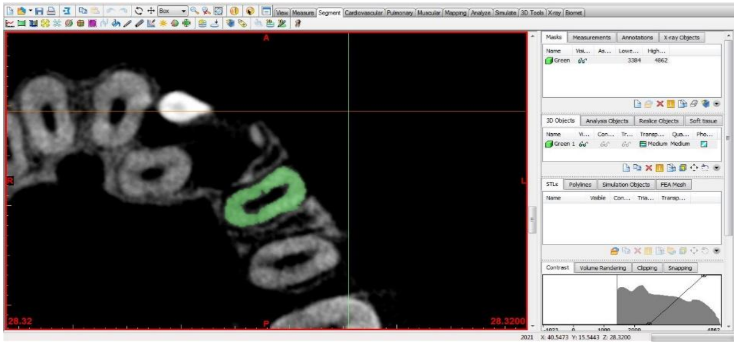


Fig. 1. Graphic view of CT file

- *CAD Software:* After the geometry improvements the file transfer to solidworks CAD software (Dassault systems, USA) where implant and mid-part of implant is designed and a reduction of the diameter of the implant neck next to the thin vestibular cortical bone was made. The entire implant structure consists of an externally threaded part which is inserted to the bone structure, onto which another part called implant mimic part is placed over it, then abutment is fastened using thread. Each component are separately modeled and then assembled together to obtain the final implant structure as shown in Fig. 2.

Fig. 2. Anatomy of proposed implant

The implant screw section having a conical shape with length 8mm and diameter 4mm, 6mm with screw thread of M2 inside for tighting of mimic part. The mimic part of implant developed having length of 8mm and screw thread of M3 at top inside surface for abutment placement. Fig. 3 shows the 3-D plastic printed part of implant.

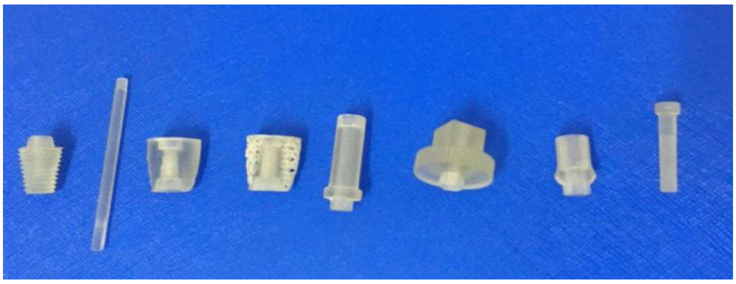
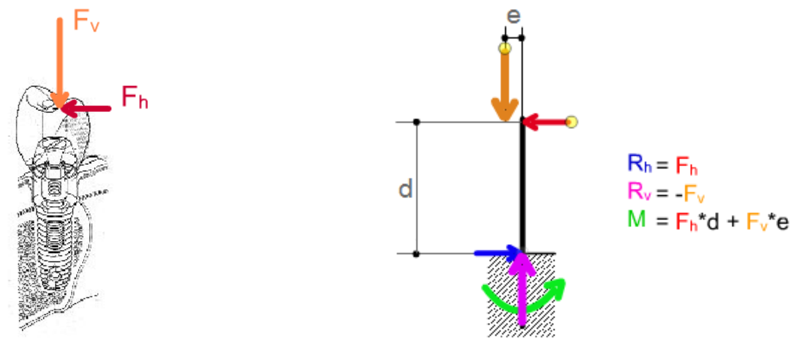


Fig. 3. 3-D Plastic printed parts of implant

2. *Loading Condition*

The forces on dental implant systems are vector quantities that create reaction forces and moments at the side of fixation in bone. As represented in Fig. 4, two types of loading, namely horizontal (lateral) and vertical (axial, occlusal), may act on a dental implant. The combinations of these forces form oblique loading which simulate a more realistic loading condition. It is reported that oblique loading could result in highest local stresses in cortical bone [5]. It is difficult to define the forces and investigate the mechanical behavior of such complex systems by analytical methods, especially when the implant is a part of bridge restoration. Therefore, researchers have commonly benefited from the complex problem solving capabilities of finite element (FE) analysis technique to analyze dental implant systems.



(a) *(b)*

Fig. 4 Forces acting on an implant-supported tooth: (a) Forces on a 3-D model, (b) Action and reaction forces and moments on a simplified model

The resultant forces of the stresses within the load-bearing components of the implant-supported restorations are counterbalanced with the reaction stresses that occur within the surrounding bone. The reaction stresses create a resultant reaction force with the same total magnitude as the external load but in the opposite direction. As a result, the static equilibrium is maintained.

The forces in vertical direction are shown to be better tolerated [6] and it is reported that the magnitude of vertical forces are up to ten times the magnitudes of horizontal forces [7]. On the other hand, the location of application of load is important that it affects the magnitude of axial component. In the molar region the bite forces are higher than four times the values in the incisor region [1].

3. *Material Properties*

The mechanical properties of bone is related to bone mass, bone remodeling frequency, bone size and area, bone microarchitecture and the degree of bone mineralization. In addition, factors like age, anatomical site, liquid content, etc. are influential on the mechanical properties. Adopted from literature, typical values of Young's modulus and Poisson's ratio, for bone tissues and implant, are presented in Table I. Various types of metals such as gold, platinum, stainless steel, cobalt-chromium alloy have been tried to serve as implant material; however, in the long run most of these metals caused negative tissue reactions and non-biocompatible properties of them were observed.

Titanium is a nontoxic, reactive material. When it is in contact with any other electrode, an oxide layer is formed on the surface and this layer resists chemical attacks. It is also inert in living tissues so that it is not rejected by these tissues. Bone regeneration and bonding on the surface of a titanium dental implant occur perfectly [1].

TABLE I
MECHANICAL PROPERTIES OF BONE AND METAL FOR IMPLANT

Material	Young's Modulus (GPa)	Poisson's Ratio
Cortical Bone	14.5	0.32
Cancellous Bone	1.37	0.30
Ti-6Al-4V (annealed)	110-114	0.33

4. Analytical Model

After the abutment screw is tightened to the implant with a certain tightening torque, the artificial crown is placed onto the abutment. Then, implant supported restoration becomes ready for patient use. During mastication or biting, the implant is subjected to functional loading. Under functional loading, unlike the tightening and loosening cases, the friction force at the tapered region is not along the helical path. The screw preload, when a biting force F_b is applied on the system, can be determined from the free body diagram given in figure 4 as follows.

$$F_{FL} = (F_N + F_{Nb})(\mu_s \cos\theta + \sin\theta) - F_b \quad (1)$$

Where F_{FL} is the screw preload under functional loading, F_N is the resultant normal contact force due to initial interference during tightening, F_{Nb} is the additional normal force due to the biting force F_b.

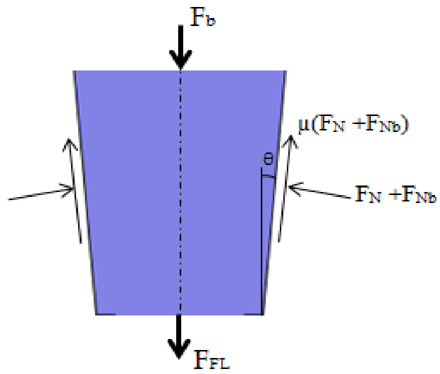


Fig. 5. The free body diagram of the conical section during functional loading

For the implants involving screw connection only, the compressive biting forces lower the pretension in the screw possibly leading to loosening of the screw. In contrast, in tapered interference fit abutments, loosening problem is less significant. The biting forces acting in the direction of abutment insertion increase the degree of engagement in the conical region, thus, contribute to secure the connection instead of causing loosening. Only application of a loosening torque may cause the tapered interference fit connection to loosen. As a result, it can be concluded that in a taper integrated screw connection, the tapered section dominates the resistive behavior against loosening.

5. Creation of finite element model and boundary condition

FEA uses a complex system of points called nodes which make a grid called mesh into lots of points which have relationships to each other. This mesh is programmed to contain the material and structural properties which define how the structure will react to certain loading conditions. Then applying the balance equation to each point and the boundary condition to the boundary, there will be a set of equations. By solving these equations, the distribution of the system's property can be found. Nodes are assigned at a certain density throughout the material depending on the anticipated stress levels of a particular area. Regions which will receive large amounts of stress usually have a higher node density than those which experience little or no stress. The FEA is performed in Solidworks simulation module and the meshing parameters taken from the software are shown in Table II.

TABLE III
MESHING PARAMETERS OF FEA MODEL

Parameter	Value
Element Size	0.373809 mm
Total nodes	99465
Total elements	63782
Maximum Aspect Ratio	24.674

III. RESULTS AND DISCUSSION

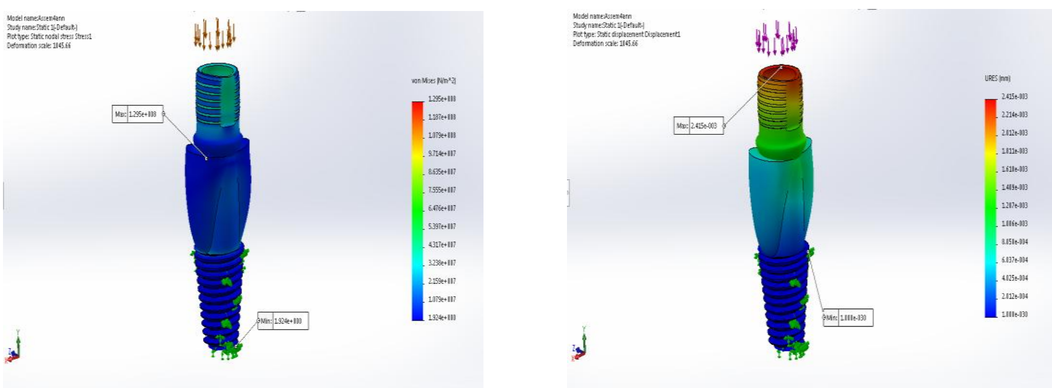
The maximum forces, created due to chewing and biting, have been determined by several experimental studies. Graf et al. conducted a study to measure the functional forces generated during mastication by placing transducers within fixed and removable prosthesis. The results indicated that in humans, maximum biting forces could reach up to 800 N in the molar region, and 100 to 200 N in the incisor region [8]. On the other side, Anderson reported that maximum occlusal forces due to chewing and swallowing (70 to 150 N) are considerably lower than maximum bite forces. Moreover, it was stated that in most cases these forces do not exceed even 10 N.

It is asserted that bite forces are affected by gender, age, height, weight, type of functional dental occlusion depending on facial type (short, average or long) and presence of parafunctional habits. Abu Alhaija et al. carried out a study to compare the effects of different factors on maximum occlusal bite force (MBF) in first molar region, in Jordanian students. According to the results of this study, those with a short face had highest MBF (679 ± 117 N) while the long face types had the lowest MBF (453 ± 98 N). The average MBF (599 N) for males was higher than the value for females (546 N). On the other hand, a positive correlation was derived between average MBF, weight and height. The average MBF in Jordanian adults was 573 N [9]. Bakke reported that bite force has an increasing pattern with age (until the age of 50), weight and height [10]. Carlsson et al. recorded higher level of bite forces for those having parafunctional habits like bruxism [11].

Holmgren EP et al. [15] In study a parasaggital model was digitized from a computed tomography (CT)-generated patient data set, and various single-tooth, osseointegrated, two-dimensional dental implant models were simulated. The specific aims of the study were to: (1) examine the effect of implant diameter variation (3.8 mm-6.5 mm) of both a press-fit, stepped cylindrical implant type and a press-fit, straight cylindrical implant type as osseointegrated in the posterior mandible; (2) compare the stress-dissipating characteristics of the stepped implant versus the straight implant design; and (3) analyze the significance of bite force direction (vertical, horizontal, and oblique 45 degrees) on both implant types. The results of the FEA suggested that (1) using the widest diameter implant is not necessarily the best choice when considering stress distribution to surrounding bone, but within certain morphological limits, for both implant types, an optimum dental implant exists for decreasing the stress magnitudes at the bone-implant interface; (2) stress is more evenly dissipated throughout the stepped cylindrical implant when compared to the straight implant type; and (3) it is important in FEA of dental implants to consider not only axial forces (vertical loading) and horizontal forces (moment-causing loads), but also to consider a combined load (oblique bite force), since these are more realistic bite directions and for a given force will cause the highest localized stress in cortical bone.

1. Stress Due to Loading

The axial load is applied to the implant along its length. The bite force of 200N is applied to the top face of the abutment which will be in contact with the crown, the force applied is perpendicular to the face of abutment. The outcome of the loading shown in Fig. 6(a) and 6(b), shown stress and displacement on implant.



(a) *(b)*

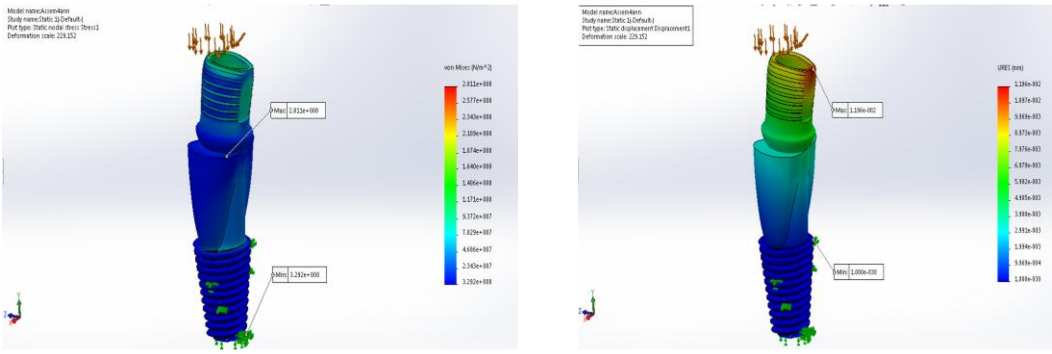
Fig. 6. Stress and displacement on implant interface under axial loading

Outcomes of model under axial loading:

- The stress within the prosthesis, maximum stress was generated at the junction of mid part and abutment.
- The evaluating displacement at the implant interface, it was noted that maximal displacement came out is at abutment top surface, which is around the negligible value.
- The design came under the marked factor of safety values, so the design is safe under the given loading condition.

2. Stress Due to Oblique Loading

The oblique load is applied to the implant along its length and to the corner angle surfaces which leads to the uneven forces on implant geometry. The bite force of 200N is applied to the abutment which will be in contact with the crown, the force applied is perpendicular and at 30˚ of angle to the face of abutment. The outcome of the loading shown in Fig. 7(a) and 7(b).



(a) (b)

Fig. 7. Stress and displacement on Implant Interface under oblique loading

Outcomes in model under oblique loading:

- The evaluated stress within the prosthesis, maximum stress noticed at the junction of mid part (mimic) and abutment.
- While evaluating displacement at implant interface it was noted that maximal displacement value observed in oblique loading is more as compared with the axial loading conditions.
- The design came under the marked factor of safety values, so the design is safe under the given loading condition.

TABLE IIIII

OUTCOME VALUES OF IMPLANT

Loading Type	**Max. Stress N/m^2**	**Max. Displacement mm**
Axial loading	1.295e+008	2.415e-003
Oblique loading	2.811e+008	1.196e-002

IV. CONCLUSIONS

Within the limitations of this study, it is concluded that the maximum stress around implants is affected by type of attachment used and direction, location of load application.

- The oblique loading showed the highest maximum of Von Mises stresses.
- Overcomes the problem of loosening of the internal screw.
- Withstands axial and lateral biomechanical loads without failure.
- The study of effects of various variations in the model using FEA is cost effective and time saving as compared to traditional techniques.

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