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Experimental Methodology for Analysis of Influence of Dental Implant Design on Load Transfer

Deformations in the vicinity of dental implants are affected by their design and if threshold level of 0.3 % is surpassed, bone resorption could occur. The goal of this study is to present a novel experimental approch for the analysis of effect od dental implant geometry on the surrounding structure strain values.
A bone block model, with dimensions of 68x25x9 mm, was made from polymethyl-methacrylate. 3D printed block mold also provided a fixture for vertically placed Strauman ø4.0x12 mm. The sample was loaded in a three-point bending setup. The axial force of 600 N was applied on the dental implant. The Digital Image Correlation method was used for strain and displacement measurement.The highest von Mises strain of 0.7 % is located in the area of implant neck. The maximum displacement value in loading direction was 0.466 mm. Surface strain and displacement are correlated with implant geometry. This experimental methodology can be utilized to estimate dental implant load transfer characteristics.

Keywords: *dental implant, von Mises strain, displacement, axial loading, Digital Image Correlation method*

1. INTRODUCTION

The main purpose of dental implant is to replace natural root of the tooth and enable placement of a single crown or larger superstructure. Dental implant establishes firm connection with bone through the process called osseo–integration, which was discovered and described by professor Branemark [1]. In some cases implant failure occurs, which is mostly noticed through bone resorption in the vicinity of the implant [2, 3]. One of the reasons for this process is the implant overload. Bone resorp–tions occurs when bone strain surpasses value of 3000 με or 0.3 %. Additional strain over this threshold is considered to be pathological overload [4, 5]. Dental implant design has a significant influence on the bio–mechanics and load transfer of dental implants [6, 7].

Dental implant design can be divided into several individual parameters: implant shape, diameter, length and thread characteristics. Implant length and diameter are one of the greatest influences on stress and strain values near contact surface of the dental implant [8, 9, 10-12]. Shape and thread type and profile are also pro–ven to affect stress and strain in the surrounding bone [10, 13].

In spite of many numerical studies and recent advances in prosthetic dentistry there is no consensus about the best dental implant type. One of the reasons could be the difference between patient bone type and bone mass [14], which also affect contact surface size [15]. Additionally, it is estimated that over 1300 different types of dental implants exist on the market [16]. Also, many types of dental implants were created as a result of marketing research and not as a result of scientific research[17]. Therefore, choosing the right implant for the patient could be the difficult task.

Many studies investigated different implant design - effect of length [8, 9, 11, 18–20], diameter [8, 10, 11], 13], shape [3], [21–23] and thread types and pro–files [15, 24, 25], but they mostly relied on the finite element method. Additional experimental data about the influence of dental implant load transfer would lead to better design [26]. Aforementioned studies provided many important clues on the biomechanics of dental implant load transfer. Nevertheless, this method relies on many assumptions concerning material characteristics, geometry and surface contact. For this reasons, results should be verified by experimental techniques and models.

The most popular experimental methods for strain and stress measurement are strain gauges and photo–elastic analysis. These methods are used on appropriate models in order to evaluate different types of super–structures [27-29] and abutment angulations [30]. Analysis which used experimental models in order to analyse design parameters of dental implant are very rare [31].

Recently, 3D Digital Image Correlation (DIC) met–hod is gaining popularity as a more precise and convenient method for strain and displacement measu–rement [32]. Similar to the photoelastic method, it belongs to the group of optical contactless methods. An additional advantage of this method is that it can measure strain with accuracy of 0.01 %. It is reported that this method provided good results in combination with dental implants and acrylate blocks [33–35]. This experimental study also employs consumer grade FDM

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3D printing technique which is already used in dental application [36, 37].

The goal of this study is to present methodology for experimental analysis of dental implant design and its effect of load transfer in a qualitative manner, using 3D Digital Image Correlation method.

2. METHODS AND MATERIALS

In order to create block models, appropriate mould was designed in SolidWorks (Dassault Systems, USA), with interior dimensions of 68x25x9 mm. The mould was printed on the 3D printer Ultimaker 2+ (Ultimaker, Netherlands), using poly-lactic acid (PLA) plastic. A mixture of Polymer Triplex Cold (Ivoclar, Vivadent, Lichtenstein) and Monomer Triplex Cold (Ivoclar, Vivadent, Lichtenstein) was mixed to make polymethyl – methacrylate (PMMA). The mixture was prepared accor–ding to the manufacturer specifications (13 g of polymer, 10 ml of monomer). Before pouring liquid acrylate into the mould, mould interior was coated with thin layer of medical vaseline. This step prevents PMMA to melt the walls of the mould during its exothermic polymerisation. Before pouring, dental implant Strauman ø4.0x12 mm was placed into the mould, into the groove which was placed in the middle of mould sides (Figure 1). This way an implant is fixed in vertical position during whole process. The mould with a fixed implant was turned upside down and liquid acrylate was poured.

The mould and acrylate were placed into special heating oven UN 30 (Memmert, Germany) for 15 minutes at 40°C, in order to aid polymerisation process, according to the manufacturer's guidelines. After cooling down, the mould was removed.

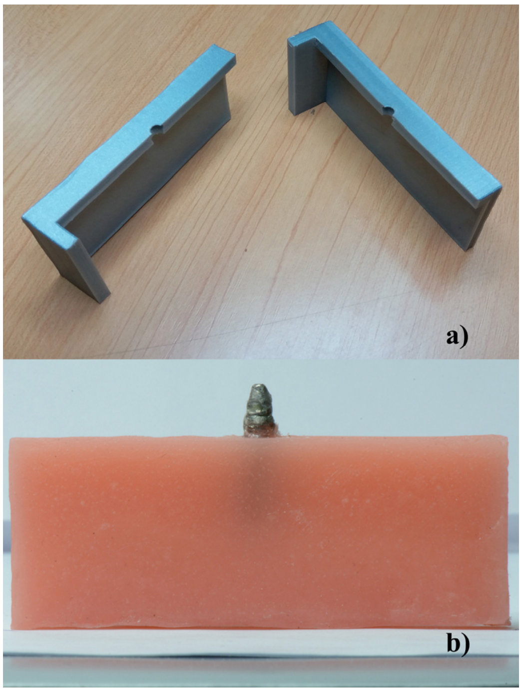

Figure 1. a) 3D printed mold from PLA material; b) hardened model

One side of the sample was painted using white colour spray and after drying, a stochastic pattern was added using black spray to enable easier tracking for DIC system.

The sample was then placed into the three point bending support. The axial force was applied on the implant neck, using Universal Testing H10K-s machine with 5 kN load cell (Tinius Olsen, USA). The force intensity was increased gradually with a maximum intensity of 600 N. Load increment was 0.1 mm/min. Therefore, the force was considered static.

DIC was used for displacement and strain measu–rement. The system consists of the cameras with Schneider 50 mm f1.8 lenses, tripod with adjustable distance between two cameras and a PC. Additional LED light was placed on the light stand to ensure uniform lighting. The system calibration is performed using calibration panel and according to the manu–facturer's instructions [32].

3. RESULTS AND DISCUSSION

Results are processed using Aramis software (GOM, Germany) and displayed in the form of displacement in the loading direction (Displacement Y) and von Mises strain fields. Additionally, along the implant longitudi–nal axis (Y axis) section V0 was placed. This section presents the set data points on the areas of interest, which are the closest to the dental implant.

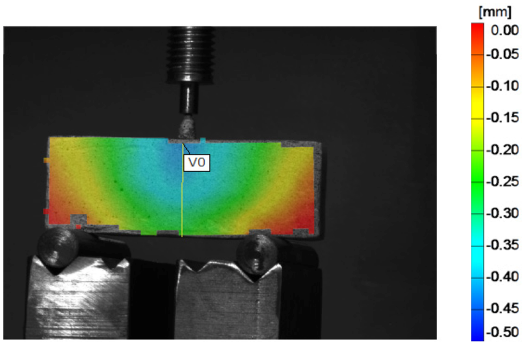

Figure 2. Displacement field overlay

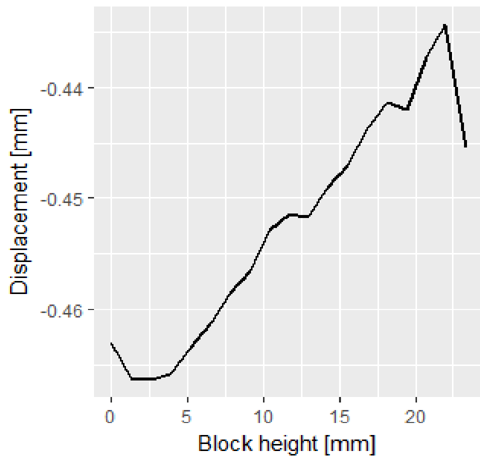

Figure 3. Displacements along section V0

Figures 2 and 3 show displacement field overlay on the area of interest and along section V0, respectively. Highest displacements were located in the first 4 mm of implant height and almost uniformly decreasing towards the bottom of the block. Maximum displacement was 0.466 mm, at around 2.5 mm below the top edge of block model. Negative values of displacement in Figu–res 2 and 3 were due to the axis Y direction. Disp–

lacement results in the top region of the block suggested that good bonding was achieved between implant neck and surrounding block.

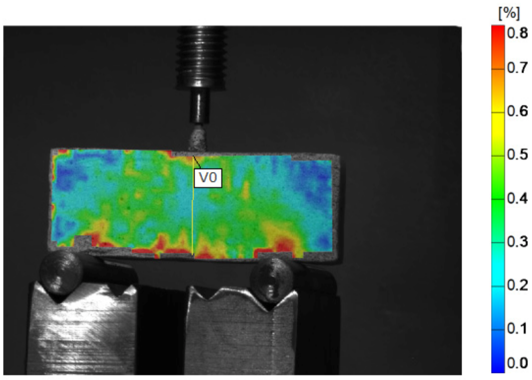

Figure 4. Von Mises strain field overlay

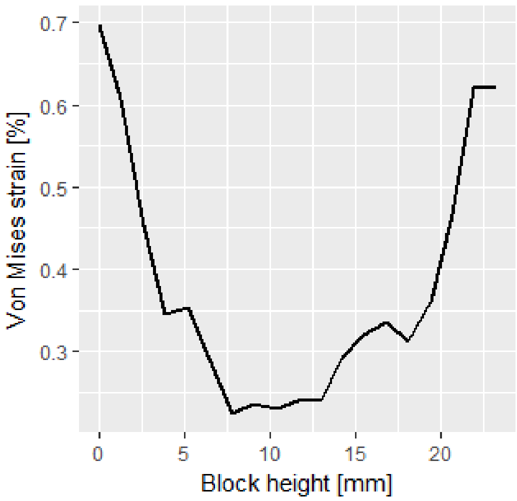

Figure 5. Von Mises strain along section V0

The highest von Mises strain values were also located in the region of the implant neck, with values of up to 0.7 %. Strain decreased along the implant body and the lowest values were located in the lower part of the implant body, between 6 and 12 mm block height. Strain values started to increase after 12 mm of block height, which is also the total length of dental implant. This suggests that von Mises strain field on the area of interest is directly affected by the implant length. In models which simulate cancellous bone, higher strain and stress values usually occur in the apical area of the dental implant[38]. Jaw bone consists of different types of bone, compact and cancellous[39]. Here, the highest stress is usually found at cortical bone[40], but strain values are higher at cancellous bone, below the neck region of the implant, due to much lower elasticity modulus. Elasticity modulus (E) of cortical bone is around 14 GPa [41]–[43], while for cancellous bone, E is ten times lower [1.4 GPa [42], [44]]. Modulus of elasticity of PMMA is around 3GPa and it possesses isotropic properties[45], while bone is anisotropic [46], [47]. Tiossi et al. used this technique in order to analyse load transfer of implant supported restorations[34] and influence of different crown materials[35], [48]. They also used PMMA models and successfully measured strain values on the model surface. These values could reflect the design of dental implants and superstructures [49].

Better bonding between dental implant and PMMA is achieved by turning the mould upside down, while PMMA was poured. Alternatively, dental implant could be placed in the already poured PMMA, which leads to higher air bubble content, smaller contact surface at the block implant interface, and consequently lower bond strength. Used method provided similar bonding condi–tion as in natural bone, where highest contact surface is achieved in the region of the implant neck, as it is the case with the jaw bone[50]. Higher contact surface between implant and surrounding structure consequ–ently leads to lower stress values. Implant design should encourage uniform strain distribution, and avoid stress concentrations, which are detrimental to the bone [51].

A common conclusion in previously mentioned papers was that more experimental studies on the influ–ence of geometrical characteristics of dental implants on surrounding structures are needed. Cehreli et. al. used strain gauges and photoelastic models to analyse the effect of dental implant design on stress and strain in its vicinity which resulted in highest stress concentration in the apical region of the implant[31]. Although succes–sfully used, these methods have some disadvantages. Strain gauges require special surface preparations, provide only local measured results and must be in contact with the experimental sample. Photoelastic method requires the application of special birefractive materials and usually provides mostly qualitative measurements, while quantitative information's are lacking [52]. The idea behind this methodology is to experimentally analyse the effect of implant geometry on the displacements and von Mises strain values in its vicinity.

Width of this model can be varied in order to see how certain implant design affects strain and displa–cement fields when bone buccolingual width varies[53]. Current buccolingual dimension of 9 mm was already used in some previous finite element model study[54]. Finite element method provides results of immense value, due to its versatility in different combinations of loading conditions and materials. However, all these calculations are based on the assumptions and require verification by experimental methods.

One of the limitations of this study is the material for block model, polymethyl-methacrylate. Although PMMA was used as a substitute for osteoporotic bone and overcoming some bone defects, its mechanical characteristics do not completely represent natural bone [55-57]. Nevertheless, the point of this study was not to estimate the effect of dental implant design on load transfer in quantitative, but in a qualitative manner. Also, strain and displacement fields measured on the edges of the block should not be taken into consi–deration.

However, due to relative simplicity of this experimental procedure and model, this methodology provides, besides scientific, great practical value. Additionally, standardized model enables easier com–parison between results, which is required for a large number of dental implants that currently exists on the market[16]. From this perspective, this methodology could present a new experimental approach to dental implant design analysis.

4. CONCLUSIONS

The application of PMMA blocks with embedded dental implants could provide additional insight into the load transfer of dental implants. Strain and displacement in the area of interest are affected by the dental implant design, primarily by its length and diameter. The highest values of displacements and Von Mises strain are found in the area of implant neck, with the values of 0.466 mm and 0.7%, respectively. This experimental model should be used together with Digital Image Correlation method for strain and displacement measuring, which provides higher accuracy and non-localized measurements.

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ЕКСПЕРИМЕНТАЛНА МЕТОДОЛОГИЈА ЗА ОДРЕЂИВАЊЕ УТИЦАЈА ДИЗАЈНА ДЕНТАЛНИХ ИМПЛАНАТА НА ПРЕНОС ОПТЕРЕЋЕЊА

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Дизајн денталних имплантата утиче на вредности деформација које настају у њиховој околини, и ако се пређе гранична вредност од 0.3 %, може доћи до ресорпције кости. Циљ ове студије је да представи нови експериментални приступ за анализу утицаја геометрије денталних имплантата на деформације околне структуре.

Модел кости, са димензијама од 68x25x9 mm, је направљен од полиметил-метакрилата. Калуп за модел који је је направљен помоћу технике 3Д штампе, је такође служио и као фиксатор положаја за вертикално постављени имплант Штрауман ø4.0x12 mm. Узорак је оптерећен на савијање у три тачке. Аксијална сила од 600 N је примењена на дентални имплант. За мерење деформација и помераја је коришћена метода Дигиталне корелације слика. Највеће вредности Вон Мизесових деформација од 0.7 % су измерене у подручју врата имплантa. Максималне вредности помераја у правцу оптерећења су износиле 0.466 mm. Површинска деформација и помераји су повезани са геометријом имплантата. Ова експериментална методологија се може користити у циљу одређивања карактеристика преноса оптерећења денталних имплантата.