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Analysis of the effect of implant distance from the surrounding structure, in the PMMA block model

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Abstract

Strain analysis in the vicinity of the dental implants were the subject of many research papers. In this study, new experimental method was employed for strain determination in the surrounding area of the axially loaded dental implant, which was embedded in the resin block. This studies can improve understanding of strain distribution, and its possible effects on the surrounding structure. Dental Implant Branemark with dimensions of 14 x 3.75 mm was immersed into rectangular block of polymethil methacrylate in vertical position. Implant was distanced 2 mm and 4 mm from the block sides, and they were named as the surface 1 and surface 2, respectively. Axial load, in the range of 0 - 500 N, was applied using Universal testing machine Tinius Olsen. Digital Image Correlation method was used for measuring deformation. Results were presented in the form of horizontal and vertical strains. Horizontal strains were mostly tensile, with maximum value of 0.3 % on the bottom of the surface 1. This values decreased in the upper area of the block side. Vertical compressive strain were 2-3 times higher on the surface 1, when compared to the surface 2, with maximum values of 0.7 % located on the bottom of the surface 1, and 0.3 % on the bottom of the surface 2. Resin block models could be used for determination of strain distribution under axially loaded implants. Greatest strain concentration were located under the implants apex, in the bottom area of the block. It was concluded that, in this region, strain values decreased linearly with increase of distance from the implants surface.

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Introduction

Dental implants load transfer characteristics are subject on many studies in the past (Jian-ying Li, Lau, and Fok 2013; Merdji et al. 2012; Milosevic et al. 2014; Petrie and Williams 2005; Tian et al. 2012; Tiossi et al. 2013). This knowledge could prevent implant failure, which usually occurs due to micro cracks, generally as a consequence of overloading (Merdji et al. 2012). Better understanding of how distance between implant and the surrounding structure affects occurrence of strain could lead to better planning of dental implant placement. Numerical techniques are widely used for investigating load transfer of different types of dental implant and implant loading conditions (Dincer Bozkaya, MS, a Sinan Muftu, MS, PhD, b and Ali Muftu, DMD, MS 2004; Djebbar et al. 2010; Himmlova et al. 2004; Jian-Ping Geng, BDS, MSD, Keson B. C. Tan, BDS (Hons), MSD, and Gui-Rong Liu 2001). Advantages of Finite Element Analysis (FEA) are in virtual/mathematical models, which are easier to develop when compared to experimental models. Also, FEA enables analysis of stresses or strains in any point in the model structure. This is done by dividing virtual model on large number of elements, and then using sets of algebraic equations in order to perform calculations. However, FEA results depends largely on the input material characteristics and boundary conditions which are defined at the beginning of the analysis. From this reason, numerical models should be verified by experimental studies. Some experimental reports already studied strain in the vicinity of dental implants using Digital Image Correlation method (DIC) (I. Tanasić et al. 2015; Ivan Tanasić et al. 2015; Yasuyuki Morita, Mitsugu Todo, Yasuyuki Matsushita 2011) or strain gauges (Hekimoglu, Anil, and Cehreli 2004). Additionally, DIC is used for characterization of load transfer of implant supported prosthesis (Tiossi et al. 2011). In previous studies, polymethil-methacrilate (PMMA) was usually used as a material of choice for the bone substitute (model) (I. Tanasić et al. 2015; Ivan Tanasić et al. 2015; Tiossi et al. 2011, 2012). DIC is a technique for whole field displacements/strain measuring which can provide very precise and accurate analysis of strains which are generated on the model surface (Jianying Li et al. 2009; Milosevic et al. 2011; Mitrovic et al. 2011; Ivan Tanasić et al. 2012; Tanasic, Tihacek-Sojic, and Milic-Lemic 2011; Tiossi et al. 2011). Additionally, strain on the surface of the model could be the reflection of implant design (Ivan Tanasić et al. 2015). This study also applies DIC method for measuring outer strain on the PMMA block surface, in order to determine how different implant positions affect the strain level in its vicinity (Ivan Tanasić et al. 2015).

Methods

Sample in this study consisted of PMMA block with dimensions of 17.33 x 13.5 x 13.3 mm and dental implant Branemark 14 x 3.75. Mold for PMMA block was made from Universal Silicon (Beorol, Serbia). Negative block with outer dimensions of 17.3 x 13.5 x 13 mm was coated with thin layer of Vaseline, and inserted into the liquid silicone and left to dry for 10 days. Afterwards, block was removed, and placed on the cross table of desktop mill machine BF 20 L Vario (Optimum, Germany). Precise movement of mill cross table was used for accurate positioning of the dental implant relative to the implant block. When implant was positioned 2 mm from surface 1 and 4 mm from surface 2, implant was lower in the cavity of mold, using mill head and special adapter which supported top of dental implant. Mold cavity was then filled with liquid acrylate (Akrilat R, Galenika, Serbia), and implant was lowered in into the block, in vertical position. After PMMA hardening, block was removed from the mold.

On the surfaces 1 and 2 was added uniform layer of white color. Afterwards, another layer of stochastic black speckles was added for ease of tracking by DIC system. Block sample was then placed in HK10-S, universal testing machine (Tinius Olsen, USA). DIC system is calibrated according to the measuring volume and according manufacturer's instructions. Load force was axial, in the range of 0 – 500 N, and images of the sample before and after measuring were made. Stroke limit was 1 mm, and loading speed was set to 0.1 mm/min. All images were processed in the Aramis (Braunschweig, Germany) software, and results were presented in the form of images with overlay of von Mises strain components on X and Y axis. Results were shown only for the maximum loading force of 500 N (Figures 2 and 3).

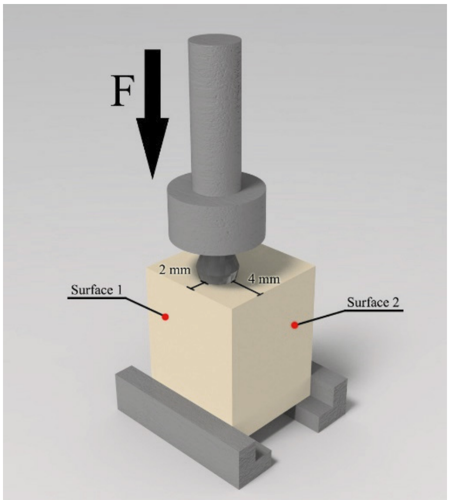

Fig 1. Scheme of experimental procedure.

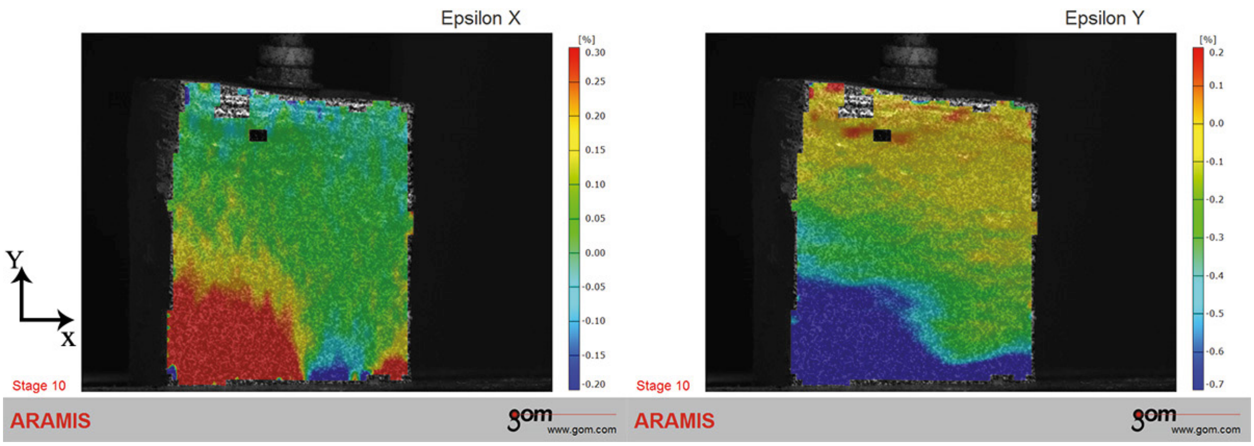

Fig 2. a) Surface strain levels ε_x on the surface 1. b) Surface strain levels ε_y on the surface 1.

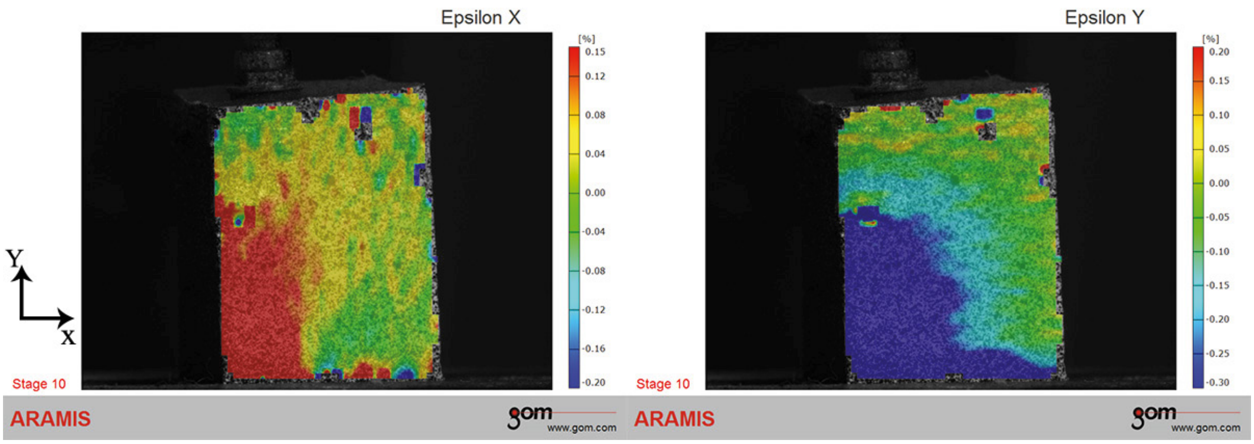

Fig 3. a) Surface strain levels ε_x on the surface 2. b) Surface strain levels ε_y on the surface 2.

Results

Full strain fields were recorded using DIC method during loading stages of an embedded dental implant in PMMA block. This implies that whole surface 1 and surface 2 could be analysed and presented. Images were processed afterwards in Aramis software. Results were shown in the form of sample images recorded with DIC equipment, with layer of strain fields recorded during the analysis. This form of results enabled better visualization of results and better tracking of strain values over the entire surface 1 and 2.

Strain was presented using scale with colour gradient. In colour scale, different values of strain were presented with various color tones. This form of results is acquired using Aramis software based on the DIC. Software also enables placing of reference points and section lines across the whole area of interest, for which the measure is calibrated. In this case, area of interests were surfaces 1 (2 mm) and surface 2 (4 mm). Therefore, it is possible for this software to calculate distance between any of this two points, within mentioned surface. In this study, this measuring process is conducted in order to obtain values of strain components of von Mises strain (Mitrovic et al. 2011) for X and Y axis, marked as εx and εy, respectively. When von Mises strain was analyzed maximum obtained values for surface 1 were in the range of 0.5 % and for surface 2 in the range of 0.3 %. Below are presented its corresponding values in the form of εx and εy. Maximum and minimum εx and εy were obtained using colour scale which is placed to the right side of the sample figures. Most prevalent colours were green and red (Fig. 2a and 3a), for the εx, and green and blue (Fig. 2b and 3b) for εy. Additionally, εx and εy could be characterized as tensile or compressive. Tensile strain implies elongation of the sample, and here it is mostly the case for εx (Fig 2a and 3a). Compressive strain suggests shortening of the sample, and it is prevalent for the εy (Fig. 2b and 3b). Maximum εx strain was 0.30 % for the surface 1 and 0.15 % for the surface 2 (Fig 2a and 3a). Both maximum εx values were detected in the apical area of the PMMA sample. In the neck region of the implant, compressive εx of 0.05 % occurs on the surface 1, while on the surface 2, εx is tensile with value of 0.04 %.

In the Fig. 2b and 3b, εy for surface 1 and 2 is presented. According to the results, maximum εy is also located in the apical part of the sample, for surface 1 and 2, and it is mostly compressive. Maximum compressive εy of 0.7 % for the surface 1, and 0.3 % for the surface 2 were observed, in the apical and marginal part of the sample. In the neck region, tensile εy of 0.2 % on the surface 1, and 0.05 % on the surface 2.

Discussion

DIC is one of the optical metrology techniques which is becoming increasingly popular in more recent research (Jian-ying Li, Lau, and Fok 2013; Pan et al. 2009). It is based on the correlation of the grey values of the consecutive images taken with set of stereo cameras. This grey value correlation is the reason why every sample must poses stochastic pattern on the surface of interest. Afterwards, consecutive images taken during deformation process, are processed by the appropriate software (Aramis). Accuracy of this method is related with several factor such as: camera resolution, quality of stochastic pattern and input data in the Aramis software (Panis 2004). It is reported that DIC method can provide measurements with subpixel accuracy, in the order of 0.08 pixels (Luo 1994; Martinsen, El-Hajjar, and Berzins 2013). Additionally, this method is much less sensitive to ambient vibrations (Shahar and Weiner 2007), and indicates very good reproducibility with variation factor of 0.5% (Windisch et al. 2007). Results in this study show occurrence of higher strain values (ε_x and ε_y) for surface 1 (2 mm layer). Maximum values were measured in the apical region of the implant. This indicates that highest part of the occurred strain is usually below the implant, even though the distance between implant and surface of interest varies. This coincides with similar studies which reported that high strains usually occur near the implant apex, especially for the all cancellous bone models (Jian-Ping Geng, BDS, MSD, Keson B. C. Tan, BDS (Hons), MSD, and Gui-Rong Liu 2001). This study used PMMA block with elasticity modulus closer to the value of cancellous bone elasticity modulus than to the cortical bone(Guan et al. 2009; Tiossi et al. 2013).

ε_x on the surface 1 and surface 2 were different, which can be attributed to the different implant position relative to the axis of the sample. Different strain distribution can also be noticed for the different surfaces. Excluding the values, this distribution difference should be attributed to different position of the implant relative to the axis of the block implant. Nevertheless, strain values between surfaces suggests that there is decrease of strain with greater distance in the sample. This study used PMMA block as the supporting material for the axially loaded dental implant. And although modulus of elasticity is higher for the mandibular and maxillary bone than for PMMA, this analysis could provide biomechanical insight on the effect of dental implant on the surrounding structure. Goal of this study was to provide correlation between different distances of dental implant and surface of interest, during axial loads. When axial loads are used, bending moments are smaller, and more optimal load distribution is achieved(Brown and Payne 2011; Gul, B. E. 2014; Markarian and Ueda 2007). Axial load was applied on the top of dental implant, and line of action is collinear with the longitudinal axis of the implant. Although force was increased continuously from 0 N – 500 N, results only for 500 N were presented because deformations of the PMMA blocks were greater and easier to measure, while the intensity of the force remained in the range of maximum human bite force (Müller, Heath, and Ott 2001). With that approach, it was possible to measure and compare strain levels for different implant to block surface distances.

Conclusion

This study shows that values of horizontal and vertical strain components decrease when surface of interest is located further from the block-implant interface. Strain for both cases were highest in the apical region of the sample, when vertically positioned implant is axially loaded. Strains were higher for the surface which was closer to the block-implant interface. Simplified models could be used in order to determine better position of dental implant relative to the supporting structure. Additionally, it is shown that it not only possible to experimentally determine von Mises strain values, but also to acquire components of strain tensor in order to provide more detailed insight into the block behaviour when subjected to axial load for different dental implant positions.

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