Plastic Materials Used in Experimental Investigations Regarding Dental Implants Biomechanics

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In order to assess in vitro biomechanical behaviour of dental implants, numerous experimental methods can be used. In our experiment, we use dental implants inserted into the artificial jaws, made of ABS plastic material and Araldite D, and we chose the VIC method (Video Image Correlation), spatial version (3D), to monitor the deformation field of area surrounding implant. For both experiment types, with ABS mandible or Araldite D sheet, the results were similar and controllable. Authors are confident with this technique and hope that experimental methods will serve as a database for research in this area.

Keywords: dental implants, biomechanics, ABS, Araldite D

Endo-osseous dental implants are artificial roots that are designed to replace extracted teeth. The most commonly used in dental practice are screw implants made of titanium alloy (Ti-6Al-4V) [1]. They are placed in the remaining alveolar bone, making closely contact with the surface of the bone. Under favorable conditions, the dental implant being protected from masticatory forces, the alveolar bone rises above the surface of it, entering into intimate and rigid contact with the implant material. This process is called osseointegration and the result is rigid fixation of the dental implant in alveolar bone. Today, it is the only method accepted and viable for long-term success of implantation. But it has one major shortcoming, compared with physiological dentition, represented by lack of ligament system, layer acting as damping forces of mastication.

During the loading of the implant, transmission of masticatory forces to the alveolar bone is made differently than natural teeth, resulting in a particularly mechanical behaviour. Long term success and fulfillment of masticatory function is directly determined by fixing substrate conditions (alveolar bone, in our case). [2-10].

Numerous clinical and technical aspects influence the amount of alveolar bone in the vicinity of the dental implant. In unfortunate cases they have a negative effect on the attachment substrate and induce withdrawal-resorption and lead to loss of dental implant [11-15].

Fortunately most of these factors can be detected and eliminated in time, except the biomechanics ones. Currently, most investigations and experiments are targeting appearance and biomechanical behavior of dental implants and we also note its importance [16].

Experimental part

In order to assess in vitro biomechanical behaviour of dental implants, numerous experimental methods can be used. We chose the VIC method (Video Image Correlation), spatial version (3D), to monitor the deformation field of area surrounding implant. In this case we used system manufactured by ISI-Sys GmbH, Kassel, Germany, with a software from Correlated Solutions, USA [17-20]. The system has many advantages. Being an optical method, it does not interfere with the privacy of the analyzed phenomena, allows examination of specimen deformation in space, with high accuracy. Associated software eliminates corporeal movements of the specimen, and thus does not require any special equipment or anti-vibration laboratory. Analyses can be performed on a variety of materials (isotropic, anisotropic, homogeneous, and heterogeneous) [21-23].

Main parts of the VIC-3D system (with the setup that allows monitoring of displacement and deformation field in three-dimensional space) are: two high-resolution cameras mounted on a rigid tripod, via an aluminum beam also very rigid.

Both cameras will be placed on beam so that the object can be analyzed under the same angles as possible (obviously symmetrically arranged). In principle, the method is based on the use of images recorded simultaneously by two cameras, which like the human eye, will provide a spatial image of the object being analyzed.

Originally, the analyzed object will be painted (sprayed) to obtain patches with size, shape and random distribution that, on the original background colour of the body, will provide a good contrast and easy identification in the future. The scope is therefore to obtain a pixelated image captured by the cameras. The software identifies some characteristic pixels on the captured image and places them in the real space. Their changes in relative spatial position during mechanical deformation of the examined object is monitored and measured. [24, 25]

The chosen substrate attachment (analyzing subject) was made of ABS plastic material (acrylonitrile butadiene styrene), i.e. Araldite D.

ABS results from the copolymerization of the three monomers: acrylonitrile, butadiene, and styrene. Changes in the proportions of each monomer leads to some types

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Fig.1. Measurement ensemble. Loading stand with VIC system (digital cameras placed on a rigid tripod), and monitoring and processing data system

Fig. 2. Loading system. 1- Transducer system for applied forces measurements; 2- dental implant; 3- jaw from ABS plastic material, with painted investigated surface, 4- loading stand, 5- spheroidal joint for loading angle adjustment.

Fig. 3. Key points considered: P2 - in the implant neck area, P5 – at about 1/3 of the implant, P8 - in apical area of the implant

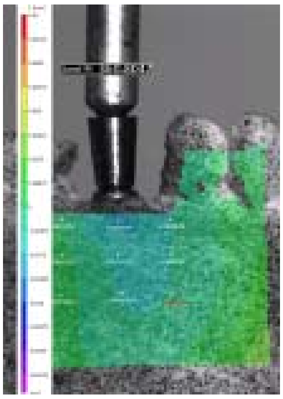

Fig. 4

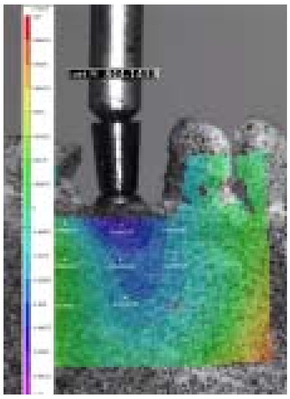

Fig.5

of ABS with different properties. Some advantageous features of this material are: high stiffness, good impact resistance (even at low temperatures), easy processing, good resistance to abrasion and staining (good colour stability), high dimensional stability (low water absorption), chemical coating and good rolling comportment. Chemical properties of ABS are: stable in bases and weak acids, petrol, oil, glycerin, detergents, concentrated ammonia, gasoline; unstable in concentrated acids, esters, ketones, ethers, chloroform. Due to good resistance to solvents and inks, ABS could be painted.

It is used among other things in the automotive industry due to high mechanical strength, but also for 3D printing. From this material has been made a series of mandibles identical to human ones, with high homogeneity by rapid prototyping method. Considering the high mechanical strength of this material, the specimen may be subject to forces of about 600 N, without irreversible damage or deformation, allowing for repeated measurements. High dimensional stability and parts (points) identification ensures repeatability of the experiment. Opaque-white colour and the possibility of surface painting with black ink provides a good contrast, and a good image for measurements with VIC system [26].

Araldite D is an epoxy resin commonly used for photoelasticity measurements. Its high modulus of elasticity (2600 MPa) and high tensile strength prevents deformation or fracture of the model during the mechanical loading. Parts are easy to cast and residual stresses after casting, which may influence the homogeneity of the material, can be emphasized with polarized light. The material is homogeneous and isotropic. So, the measurement results can be compared and verified with finite element method ones, where substrate attachment is considered to be homogeneous and isotropic.[27]. The used sheets, initially white-opaque, were painted with black ink spray, like the first model.

In the models thus prepared, were placed dental implants. Thereafter, the implants were subject to the compressive forces of different sizes and incident angles. For correct holding of the models was created an original testing stand, equipped with transducers for force

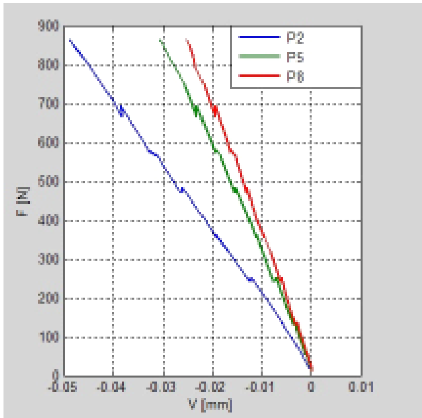

Fig. 6

measuring. Fixing substrate deformation was monitored during loading. Relative movements of key points on the surface of the analyzed specimen were measured and exported to Excel® spreadsheet [25].

Results and disscusions

Case I. The implant was inserted into the artificial jaw, made of ABS plastic material. Analysis of deformation of the supporting substrate and measurements of relative displacement of the key points on the substrate support surface, in the situation of a dental implant inserted at a lower molar, and loaded with axial compressive forces in the range 0…865 N.

The visual aspect of deformation field in the vertical direction, depending on applied forces amplitude on the dental implant is presented in figures 4 and 5. The values of relative movement variation for points 2 (blue), 5 (green), 8 (red) depending on applied force on the dental implant are presented in figure 6.

In table 1 is presented the analysis of obtained data after 60 repeated measurements.

Case II. Dental implants inserted in Araldite D sheet

The visual aspect of deformation field in the vertical direction, depending on applied forces amplitude on the dental implant is presented in figures 8 and 9. The values of relative movement variation for points 4 (blue), 11 (green), 18 (red) depending on applied force on the dental

No. of measurements = 60	P2	P5	P8
Average of relative displacement in vertical direction [mm]	0.02248	0.01403	0.01151
Maximum relative displacement in vertical direction [mm]	0.04888	0.03091	0.02522
Significant differences between the values of relative displacement (t Test, ANOVA)	yes	yes	yes

Table 1
ANALYSIS OF THE OBTAINED DATA

Fig. 7. Key points considered: P2 - in the implant neck area, P5 – at about 1/3 of the implant, P8 - in apical area of the implant

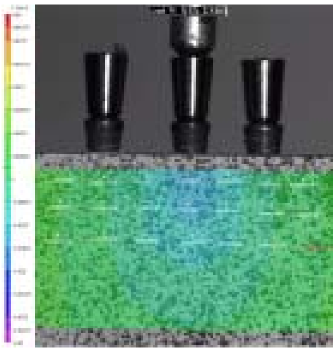

Fig. 8

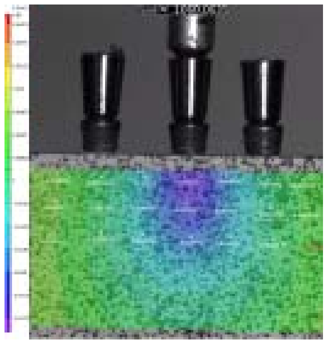

Fig. 9

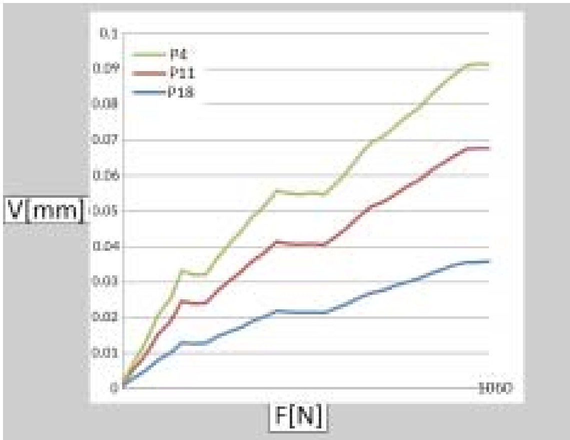

Fig. 10

No. of measurements = 58	P4	P11	P18
Average of relative movements in the vertical direction [mm]	0.01736	0.01537	0.01145
Maximum relative movements in the vertical direction [mm]	0.03585	0.03209	0.02377
Significant differences between the values of relative movements (t Test, ANOVA)	yes	yes	yes

Table 2
ANALYSIS OF THE OBTAINED DATA

implant are presented in figure 10.

In table 2 is presented the analysis of obtained data after 58 repeated measurements.

The presented experimental technique allow us to perform the necessary measurements to investigate the biomechanical behavior of the dental implant. The areas where are the most important micro-displacements are present represents high-risk areas of stress appearance with peak values. Physiological, in vivo, such stresses can induce micro-cracks and osseous resorption at implant-bone interface, and eventually can lead to loss of the implant. In our experiments, most of the micro-displacements were observed in the longitudinal axe of the implant, and the neck of the dental implant, dropping to the top and to the side. The same pattern of distribution of micro-displacements was observed when the dental implant has not been fully covered by the mounting substrate. This micro-displacements model was partially confirmed by other studies by finite element modeling [28, 30], but also by Digital Image Correlation method [30]. For studies based on the Finite Element Method, the substrate attachment is considered to be homogeneous and isotropic one, establishing contact on all dental implant surface. In reality, after a perfect osseointegration, no more than 30% of the dental implant comes in close contact with the surrounding bone. For these reasons we believe it is necessary to perform preliminary experimental measurements, to compare them with the results obtained by the finite element method. The results from experimental methods should be a database as input for further FEM investigations, as part of a series of experiments in order to understand this phenomenon [31]. The substrate attachment material has a decisive role in these experiments.

Conclusions

For both experiment types, with ABS mandible or Araldite D sheet, the results were similar and controllable. Plastic ABS material can be processed with rapid prototyping system, and offers the possibility of experimental analyses on personalized cases, based on the X-ray CT basis. Authors are confident with this technique and hope that experimental methods will serve as a database for research in this area.

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References

1.MISH, C.E., Generic Implant Body terminology. Contemporary Implant Dentistry (3rd edition). Mosby: St Louis. 2008 pg 28-30.
2.ZARB, G.A., SCHMITT, A., The longitudinal clinical effectivenes of

osseointegrated dental implants: The Toronto study, Part I: surgical results, J. Prosthodontic Dent, 1990;63:451.
3.LINDHE, J., KARRING, T., NIKLAUS, P., LANG, A., Clinical Periodontology and Implant dentistry, Munsksgaard, 1999; 851-964
4.BRUNSKI JB, MOCCIA, A.F. JR, POLLACK, SR, et al, The influence of functional use of endosseous implants on the tissue implant interface. II. Clinical aspects, J Dent Res 58:1970-1980, 1979
5.BERT, M., MISSIKA, P., Les implants ostéo-intégrables. Paris, Éditions CdP, 1991
6.BRANEMARK, P.I., ZARB, G.A., Tissue- Integrated Prosthese, Osseointegration in Clinical Dentistry, Quintessenz, Berlin 1985
7.BĂCIUT, M., Etapele vindecării osoase la interfaa os-implant-Implantologie Orală-Ed. Universitas Medicinae et Pharmacinae Napocensis ISBN 973-693- 2087;430-432
8.GOTTLANDER, M., ALBREKTSSON, T: Histomorphometric studies of Hydroxylapatite-coated and uncoated CP titanium threaded implants in bone. Int. J. Oral Maxillofac. Impl. 1991; 19-27
9.KOYAMA, S., SASAKI, H., YOKOYAMA, M., YAMAMOTO, M., SATO, N., REISBERG, D., SASAKI, K., Changes in Bone Metabolisim Around Osseointegrated Implants Under Loading. Implant Dentistry – The Most Promising Discipline of Dentistry Edited by Ilser Turkyilmaz Published by InTech Janeza Trdine 9, 51000 Rijeka, Croatia.Copyright © 2011 InTech cm.ISBN 978-953-307-481-8
10.ALBREKTSSON, T., ZARB, G., WORTHINGTON, P., ERIKSSON, A.R., The long-term efficacy of currently used dental implants: a review and proposed criteria of success. Int J Oral Maxillofac Implants. 1986 Summer;1(1):11-25.
11.PIATTELLI, A., PIATTELLI, M., MANGANO, C., SCARANO, A., A histologic evaluation of eight cases of failed dental implants: is bone overheating the most probable cause? Biomaterials 1998; 19:683–90
12.ERIKSSON, R.A,, ADELL, R., Temperatures during drilling for the placement of implants using the osseointegration technique. J Oral Maxillofac Surg 1986; 44: 4–7.
13.YACKER M, KLEIN M. The effect of irrigation on osteotomy depth and bur diameter. Int J Oral Maxillofac Implants. 1996 Sep-Oct;11(5):634-8.
14.DAVID, B., BURR, MATTHEW, R., Allen-Basic and Applied Bone Biology. Craniofacial Biology, Orthodontics, and Implants Pb. Elsevier 2104. ISBN 978-0-12-416015-6;11 pg. 238
15.SZMUKLER-MONCLER, S., PIATTELLI, A., FAVERO, G.A., DUBRUILLE, Considerations preliminary to the application of early and immediate loading protocols in dental implantology. JHMaxillofac Implants 1996;11:634–638. PubMed.
16.MISH, C.E., Stress treatmant Theorem. Contemporary Implant Dentistry (3rd edition).Mosby: St Louis. 2008; 69
17.*** - VIC-3D 2010, Testing Guide, Correlated Solutions, ISI-Sys GmbH, USA, Germany, 2010.
18.*** - VIC-3D 2010, Reference Manual, Correlated Solutions, ISI-Sys GmbH, USA, Germany, 2010.
19.GÁLFI, B., PhD Thesis , "Transilvania" University of Brasov, Romania, 2012.
20.SUTTON, A. M., ORTEU, J. J., SCHREIER, W., H., Image Correlation for Shape, Motion and Deformation Measurements, Springer Verlag, 2010
21.KHAN, A., WANG, X., Strain Measurements and Stress Analysis, Prentice-Hall, Inc. Upper Saddle River, New Jersey, 2001.
22.KOBAYASHI, A.S., Handbook of Experimental Mechanics, Prentice Hall, Upper Saddle River, New Jersey, 1987.
23.JONES, R., WYKES, C., Holographic and Speckle Interferometry, A Discussion of the Theory, Practice and Application of the Techniques, Cambridge University Press, Cambridge, 1983.
24.SZÁVA I, GÁLFI BP, SZÁVA DT, BÖGÖZI B, MUNTEANU RI, AMBRUS C. Modern experimental approaches on the ships' structural elements. JIDEG. 2014. 9: 45- 52.
25.SZÁVA DT, BÖGÖZI B, GÁLFI BP, SZÁVA I. Video image correlation method involved in dental implants' analysis. JIDEG. 2014. 9: 109- 112.
26.HARPER C.A. (1975) Handbook of plastic and elastomers, McGraw-Hill, New York, pp. 1–3,1–62, 2–42, 3–1, ISBN 0070266816
27.GANESAN, T.P. Model Analysis of Structures-Ed. Orient Blackswan (2000); ISBN-10: 8173711232; pg.121-127
28.QIAN, L., TODOD, M., MATSUSHITA, Y., KOYANO, K., -Effects of Implant Diameter, Insertion Depth, and Loading Angle on Stress/ Strain Fields in Implant/Jawbone Systems: Finite Element Analysis.Int J Oral Maxillofac Implants, Volume 24 , Issue 5, September/October 2009, Pg 877–866 PMID: 19865628
29.MORITA, Y., QIAN, L., TODO, M., MATSUSHITA, Y., ARAKAWA, K., -Strain Distribution around Dental Implants in Cortical/Cancellous Bone Modelsusing DIC Method, Proceedings of the SEM Annual Conference June 1-4, 2009 Albuquerque New Mexico USA©2009 Society for Experimental Mechanics Inc.
30.OKUMURA, N., STEGAROIU, R., KITAMURA, E., KUROKAWA, K., NOMURA, S., Influence of maxillary cortical bone thickness, implant design and implant diameter on stress around implants: a three-dimensional finite element analysis. J Prosthodont Res. 2010 Jul;54(3):133-42. doi: 10.1016/j.jpor.2009.12.004. Epub 2010 Feb 11. PubMed PMID: 20153281.

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