Experimental Analysis of Dental Implant Biomechanics Related to Vertical and Horizontal Dimensions of the Fixating Substrate Using Digital Image Correlation Method

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Dental implantology is a frequently applied method for prosthetic restoration of edentulous dental arches. In the past 50 years it has been evolving most dynamically among other branches of dental sciences. According to several reviews and meta-analysis of literature, it seems that the most predictable phase that influences success rate of dental implants is limited only to the surgical stage of treatment [1]. The long term success of dental implants is highly influenced by their biomechanical behaviour, load transfer and osseous tissue reactions to local mechanical tensions around dental implants [1-3]. This in vitro study was aimed to investigate and locate peak tensions inside the fixating substrate of dental implant intimacy. Three root form dental implants were installed, with 14 mm length and 4.5 mm diameter, in tripodistic alignment in a highly rigid and resistant plastic sheet (Araldit-D) also used for photo-elastic measurements. The dental implants were compressed simultaneously and grouped with linear, vertical forces. The mechanical stress distribution and the displacement field of the fixating substrate were analyzed with Digital Image Correlation method (DIC). This modern, non-contact optical investigational method offers highly accurate measurements with great precision (in order of microns, mainly pixel by pixel) practically eliminating all disadvantages and limitations of the most used, classical, experimental methods [4, 5]. Peak tensions were found at the neck area of this type of dental implants. The thickness of the fixating substrate influenced more the appearance of peak tensions rather than the distance between two dental implants. Tripodistic alignment of dental implants might be reconsidered in areas where bone thickness is limited. Virtual, biomechanical simulations should be used in future for surgical treatment planning.

Keywords: dental implant biomechanics, tripodistic alignment, strain field, digital image correlation method

Dental implantology is a frequently applied method for prosthetic restoration of edentulous dental arches. In the past 50 years it has been evolving most dynamically among other branches of dental sciences. Practically, it is based on the osseointegration of the titanium alloy dental implant placed inside the mandibular or maxillary alveolar crest. The principle of osseointegration was first introduced by P.I. Bränemark and it means that osseous tissue tends to overgrow the surface of the titanium implant, coming in close intimicy with it [1-3].

In this manner, the dental implant replaces a missing tooth's root, and serves as a support for dental crown. In many points of view though, it behaves differently from a natural tooth, mainly because it does not have periodontal ligaments, which serve as anti-shock sistem, attenuating the masticatory forces, and protecting the surronding osseous tissue from overload and fracture. Although there were several attempts to induce periodontal ligament-like tissue formation near the dental implants, their success rate were inacceptibly low from clinical point of view [4]. Nowadays, the single accepted and correct treatment with dental implants is based on the principles of osseointegration.

Regardless of the chosen tehnique, there are considered two different phases of an osseous dental implant. The first stage, includes the osseointegation of the dental implant, which can be achieved in a highly predictable manner, presenting high rates of success, variing around 99.2% [5]. This phase is also called as the surgical phase, and is influenced by numerous factors, among which it is important to mention the material of the dental implant. The Ti-6Al-4V alloy is an inert biomaterial, which does not induce any inflammatory reaction from the host organism, or clinical signs of rejection/granulomatous encapsulation, permitting the overgrowth of osseous tissue [6].

The second stage is the functional stage, and it includes the period in which the artificial root (dental implant) is loaded with masticatory and other functional forces. The predictibility of this stage is lower than the first phases, mainly because it is influenced by the masticatory and other functional/parafunctional forces applied on the dental implant, but also by it's position in the edentulous arch, and the condition of the supporting osseous tissue. In this phase, 5 year period success rates vary around 94.1% [5], and 10 year period success rate variing around 92.8% [7].

After several reviews and meta-analysis of literature, it seems that the most predictable success rate of dental implants is limited only on the surgical phases of implantology. The long term succes of dental implants is highly influenced by their biomechanical behaviour, load transfer and the implant sorrounding osseous tissue reactions to local mechanical tensions [8]. In cases where three or more implants are needed for the dental restauration, some authors suggest, that implants should

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be inserted in a staggered position (tripodeffect-tripodistical placement) for a better support, and force reduction whereas collinear insertions should be avoided. Those who choose the linear insertion argue, that tripodistical insertion produces a greater torque forces than linear insertions, overloading the supporting osseous tissue [9, 10]. Excentric insertion, paraaxially of the midline of the alveolar crest, such as tripodistical placement method is recommended in cases when not sufficent mezio-distal space is left for the certain needed number of implants, in particular in the lateral positions of dental arches [11].

Our goal was to investigate and locate peak tensions inside the fixating substrate of the dental implants intimacy, in case of three tripodistically inserted implants, given a certain deterioration stage of the fixating substrate.

Experimental part

There were installed three root form, dental implants, each having 14mm length, and 4.5mm diameter in tripodistic alignment in a highly rigid, and resistant plastic sheet (Araldti-D) (fig.1). Theese implants were screw-type implants, made by dental implant producer Protetim Plus, Hungary; simulating the deterioration of the fixatig substrate by partially inserting the dental implants, to the level of the neck area.

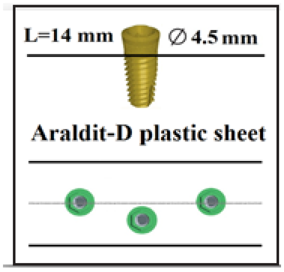

Fig. 1. Tripodistic alignemement of the screw-type dental implants, in Araldit-D plastic sheets

The fixating substrate was made of Araldit-D plastic sheets which is an epoxi-resin, frequently used material in photoelastic measurments. It's high module of elasticity (2600 MPa), and resistance for traction and compression prevents the fracture, and deformation of the model, while solicitated mechanically, having a low producing cost. Residual stresses remaining inside the model, during the casting process which influence the homogenity of the material can be evidenced easily, with the help of the polarized light. It is considered to be homogenous and isotropic. Theese advantegous properties ensure the repetability of the experiments, making possible to compare the obtained results with finite-element method (FEM) [12].

The dental implants were installed than compressed simultaniously with linear, vertical forces, for 30 s, at 0-1200N, during which a number of 80 measurements were made. The applied forces were measured with the load cell, which monitors the real load magnitude (applied by means of a special loading frame); a special screw, fixed into the lower part of the load cell, acted on the implant's abutment.

The deformation, the biomechanical phenomena and strain distribution, occurring inside the fixing substrate, given by the different stages of deterioration of the fixing substrate surrounding the dental implant of the fixating substrate was measured by a non-contact optical method: the Video Image Correlation 3D version (VIC-3D) from ISI-Sys GmbH, Kassel, Germany (system producer) and the Correlated Solution Company, USA (software producer).

This system offers both the displacement field and the corresponding strain field along all three coordinate axes with the same accuracy (up to 1μm). Mainly, the system consists of two video cameras, fixed on a very rigid aluminium rod, mounted on a tripod.

Between the main advantages of the system, can be mentioned that its software eliminates the rigid body movements from the acquired images and consequently it can be applied, not only in high-accuracy vibration insulated laboratory conditions, but also in normal working conditions. Being an optical investigational method it does not need direct contact with the surface of the examined specimen, regardless of its materials properties. In consequence, it does not intervene in the modification process of the examined field of displacement and deformation of the structure thanks to external factors (such as mechanical or thermal influences) or internal ones (such as modification of the crystalline structure, etc.). It can be applied to a large sort of materials (homogenous, un-homogenous, isotropic, orthotropic, anisotropic), like metals, human bones, human tissues, wood-based materials, plastics, or composites. Other significant advantage of this system consists in its potential, allowing a very high-accurate analysis (practically pixel-by-pixel) of the investigated surface, which cannot be guaranteed in the classical experimental methods [13-16].

Also, the software of VIC-3D offers the facility of monitoring the obtained results, either in colour graph (similarly with the FEM analysis results), either can be exported in Excel-files, destined for drawing-up several useful graphs [18, 19].

For statistical analysis one-way ANOVA, Kruskal-Wallis and multiple correlation Dunn tests were used by GraphPad Prism version 5.03 statistical software. The level of significance was set at $p<0.0001$.

Results and discussions

In this particular case, we measured the vertical displacement of six characteristic points of the fixating substrate, which were situated in the longitudinal axes of the implants, at an upper level (close to the cervical zone) and a lover level, close to the apex of the dental implant (fig. 2). The obtained data was exported in Excel files for further analysis. Figure 3 presents the mean values of the vertical displacements.

One-way ANOVA, Kruskal-Wallis and multiple correlation Dunn tests revealed that significant differences of the vertical displacements were found between the apical zone of implant no.1 and the cervical zone of implant no.2; the apical zone of implant no.1 and cervical zone of implant no. 3; the apical zone of implant no.1 and the apical

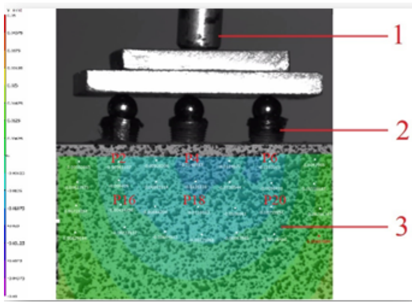

Fig. 2. The image of the vertical displacement field obtained with the VIC-3D system when loading with 1000N. 1. the loading pin and steel plates placed over the dental implants; 2. from left to right, implant no. 1, 2, 3 where implant no. 2 is placed excentric, outside the midline of the Araldit-D sheet. 3. the studied area of the fixating substrate, with the characteristic measuring points, where P2, P4, P6 represent the cervical areas of the implant no 1, 2, 3, and P16, P18, P20 represent the apical areas of implant no. 1, 2, 3. Distance between implant no.1 and no.2 was 3mm, and between implant no.2 and no.3 was 4,5mm. Implant no 2 was placed with 1mm excentric, outside the midline of the plastic sheet.

zone of implant no.2, where significance was set at p<0.0001.

Though statistical analysis confirmed only few significant differences between vertical dispacements of the characteristic points of the fixating substrate, further data analysis revealed that regardless of the size of the substrate's deterioration, the largest displacements were measured in the cervical area of the dental implant, decrasing towards the apical zones (table 1). This type of strain pattern was observed by other finite-element measurmants. In some cases, though it is considered that the apical zones are more solicited, contrary to our findings [13, 14, 15]. The highest deformations were observed in case of implant no.2 (marked with green and purple on fig. 3), which suggest that tripodistic alignement of the dental implants is highly influenced of bone thickness, and in certain cases, where bone quality and quantity is not sufficient, the overload and implant failiure might occure. Based on our findings, it seems that the thickness of the sheet influenced relative motions more than distance between dental implants (table 1). Further biomechanical analysis are needed to decide wheather fewer implants should be placed in cases when not sufficinent antero-posterior space is left rather than more, tripodistically aligned implants.

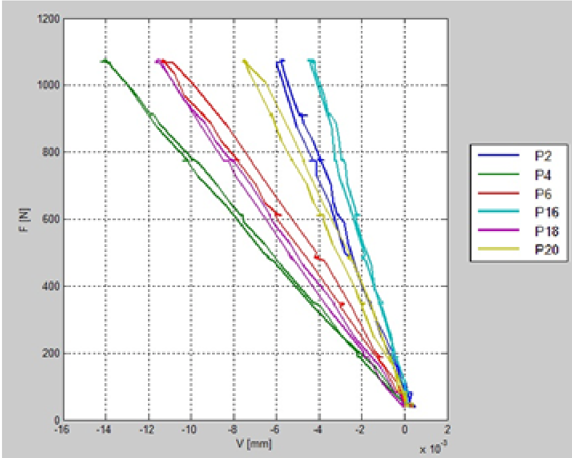

Fig. 3. Grafic illustration of the vertical displacements of the characteristic points, in function of the applied forces

Table 1

MEAN AND MAXIMUM VALUE OF VERTICAL DISPLACEMENTS IN mm

MEASURMENTS NO. = 80.	P2	P4	P6	P16	P18	P20
MEAN VALUE OF VERTICAL DISPLACEMENTS [mm]	0.00312818	0.00689362	0.00611962	0.00184082	0.00575356	0.004160823
MAXIMUM VALUE OF VERTICAL DISPLACEMENTS [mm]	0.00725854	0.0163954	0.0146712	0.0045575	0.0135212	0.0519000

Conclusions

Though the plastic sheets, which served as fixating substrate for the dental implants do not correspond from biomechanical points of view to the osseous tissue's properties, data obtained with VIC measurments might serve as useful imput data for further FEM analysis. The authors consider, that biomechanical investigations and individualized biomechanical plannig would serve important informations as part of treatmant plannig, applied before dental implant surgery.

Acknowledgement: This paper was partially sustained by the Project Nr. 912/2015 financed by S.C. OPTOMED SRL in colaboration with UMF Tg. Mures.

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Manuscript received: 9.02.2015