Optical Stereometric Analysis of An Experimental Partially-Edentulous Mandible

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Abstract

Background: Stereoptics method have been successfully used in biomechanical studies of models of dental and jaw bone tissues. The aim of this study was to investigate, by optical stereometry, the distribution of occlusal loads, depending on the functional deformities, on casts of a partially-edentulous lower jaw without copings as well as on the dedicated copings and the remaining solid tissue under the copings.

Material and Methods: Precise measurement of strain and displacement of partially-edentulous mandibular control and experimental casts were provided by the digital image correlation method and software ARAMIS which determined the shape of the photographed object with high accuracy, its dimensions, field of three-dimensional (3D) movements, vector of distorted field and features of the biomaterial. Simulated loads were in the range between 0 and 1000 N.

Results: Displacements and deformations of abutment teeth within the control cast of a partially-edentulous mandible were 0.48% for incisor without coping, 10.29% for canine without coping and 6.64% for premolar without coping, and within the experimental cast of a partially-edentulous mandible they were 0.29% for incisor with coping, 7.007% for canine with coping and 4.98% for premolar with coping.

Conclusions: When loading the abutment teeth, the distribution of strain through the remaining tooth substance is specific and various, and abutment teeth covered by protective copings are more resistant to loads.

Background

In dental prosthetics, a particular and constant problem is the rehabilitation of the partially-edentulous (or conditionally-edentulous) lower jaw. In this sense, a very frequently-applied form of therapy and prosthetic rehabilitation is the setting up of a supradental prosthesis on the lower jaw tissue. In this case, the solid support structures, which are the surfaces of remaining teeth, must be especially prepared to accept the surface of the prosthesis. Special preparation consists of making dedicated copings on the remaining solid dental tissues [1,2]. A significant problem, not only from the aspect of scientific research, but also in practical clinical work, is the fact that the copings can be designed differently, which can cause differences not only in retention and stabilization of even the same form of dental prosthesis, but also the mechanical resistance and the stability of the dental tissue itself onto which the copings i.e. caps are placed. In addition, from a biomechanical aspect, due to differences in the occlusal loads, there may be induction of different stresses and deformations within bone structures. The resulting stresses (with or without deformation) can lead to adequate or inadequate responses which will be reflected by the generation or absence of functional adaptation. Therefore, information on the method of transmitting weights through the bone of the orofacial system is necessary to understand the distribution of strains, and also to provide answers to the problems of adapting bone structures to the long-term occlusal loads created by natural teeth as well as various dental compensations.

Optical stereometric methods based on contact and non-contact volumetric measurement mechanisms are increasingly reported in modern literature and applied in biomechanical studies of dental and bone tissues [3-6].

Digital image correlation (DIC) is an optical measuring system for *in vitro* set-ups which can be utilized in dental biomechanical contexts [7]. DIC is an optical full-field technique for non-contact, three-dimensional (3D) deformation measurements [8].

Aim

The aim of this work was to present, by optical stereometry, the distribution of the occlusal loads, depending on the functional deformities, on casts of a partially-edentulous lower jaw without copings as well as on the dedicated copings and the remaining solid parts of the tissue under the copings.

Material And Methods

The materials in this study were two, as symmetric as possible, master casts of a lower jaw, with simulated moderate alveolar ridge reduction. The master casts of a partially-edentated lower jaw, which were used in the study, were characterized with the same topography of missing lower molars, the left lower second premolar and the right missing canine and incisors. Not only the first master cast, but also the second one, presented the situation of a partially-edentulous lower jaw according to the B3 (and C2) classification of Eichner, with the difference that for three of the remaining tooth substances of the first master cast, tooth crowns were reduced. The first—the control cast—was without caps i.e. it was not covered by copings. The experimental cast—the second one—was almost the same as the control, except for the surfaces simulating three copings of oval design covering the remaining teeth. Master casts were fabricated in a 3D printer using specific polymethyl resin material.

The surfaces of the control cast and the experimental cast with simulated oval copings over the remaining teeth were sprayed with a thin coat of white layer paint, followed by a thin layer of high contrast black paint placed on top of the white layer to allow the correct performance of the digital image correlation (DIC) method (Fig. 1, 2). Points of the spray occupy distances that are changed under loading and are registered by cameras.

Measuring devices and methods

Precise and controlled loading was measured using a gnathodynamometer with horizontal extension. Axial occlusal loads were applied centrally and vertically to the distal abutment tooth (the first lower premolar), intermediate abutment tooth (canine) and mesial abutment tooth (the second lower incisor). The direction of loadings to the second experimental cast was the same.

Measurements of strain and displacement were provided by the digital image correlation method. This system consists of two digital cameras and the associated software ARAMIS. ARAMIS software, based on the principle of an objective fine-ground procedure, registered 3D changes in the shape and

distribution of strain on the surface of statically- or dynamically-loaded objects. Moreover ARAMIS also determined the shape of the photographed object with high accuracy, its dimensions and field of 3D movements, vector of distorted field and features of the biomaterial.

Mobile cameras at specific time intervals photographed the distance between reference points before loading, in the calibration phase, and during the action force.

Before measuring the strains of the experimental models, a calibration procedure was performed. To measure 3D strains, two cameras were positioned manually and adjusted in accordance with the measuring volume of the calibration object. Strains within the selected area may be measured over a range from 0.01% up to several hundred % and strain accuracy was up to 0.01% [9]. Small and large objects, from 1 to 2000 mm, can be measured with the same sensor.

Software

The ARAMIS software was selected and used in this study. The software processing of the data measured enables recording of the results and 3D presentation.

Statistical analyses

Descriptive statistics were used to present the deformation and displacements of the teeth and the copings of the experimental casts. The MEANS procedure from the statistical package SAS (SAS Institute 2010) was used. Wilcoxon Rank Sum tests were used for the analyses of numerical values of distortions and displacements of the teeth and the copings. The mean value was presented as a measure of central tendency. Nonparametric statistical methods based on the scores of a response variable (percent of deformation and displacement) were used to define the differences between the mean values of the teeth and the experimental copings.

Results

According to the deformation formula $e = (L_0 - L_1) / L_0 \times 100$, where L_0 and L_1 were the lengths before and after loading, respectively, the strain values were expressed in percentages, and presented on the scale using different colors (Tab. 1, Figs. 3a, b, c, and 5 a, b, c). Additionally, further individual strain values were analyzed with ARAMIS software (Figs. 3a, b, c, and 5 a, b, c).

The vertical line (Section 0) (Fig. 2), was set by the software under the slams point of the load acting (in the direction of load). Any increase in the intensity of load is presented in figures of the corresponding stage. Since the study adopted simulated loading over the range between 0 to 1.000.0 N at intervals of 50.0 N, the obtained multistage view and figures showing dimensional changes of the structure under investigation are presented in only three stages.

Since the incisor without the coping only reached Stage 1 and cracked after switching to Stage 2, the table shows the values of displacement and deformation of all constituent points of the vertical section

at a load of 500.0N (Stage 1). In the table showing comparison of tooth deformities with and without incisor coping, the values obtained in Stage 1 were used, so that differences in deformation values could be observed (Tab. 1).

Strain intensity values are presented as a gradient of colors in the scale on the right side of each figure. Exact values of strain for each intensity of applied force are shown in Figures (Figs. 3a, b, c and 5a, b, c). Separate strain values obtained for each point of the line section in the last stage of the force acting on dental structures under investigation are shown in Figures (Figs. 2, 3, 5).

This study primarily focused on the strain distribution inside the remaining tooth and supporting bone below the prosthesis and around the abutment teeth and strains are presented in different colors. Therefore, the regions of sufficient interest were the abutments second incisor, canine and the first lower premolar [10].

The displacement and deformation values for each point of the observed vertical section at a maximum load of 1.000N (Stage 3) are shown (Figs. 4, 5, 6).

As maximum and significant displacements the maximum displacements were noted for the experimental incisor with coping and for the control canine (Tab. 2, Fig. 4). However, the differences of numerical values obtained were not statistically significant.

The illustrations representing von Misses strains are shown in Figures (Figs. 4a, b, c and 6a, b, c).

A greater deformation value was observed in canines without coping, suggesting that the coping cause a decrease in the maximum deformation value (Tab. 1).

Discussion

Earlier works by authors dealing with the problem of the application of the stereo-optical (stereometric) method, have shown good correlation between mathematical measurements under laboratory conditions [11-15].

In this regard, further research using stereooptic methods will certainly reveal many more important details and facts regarding the treatment of partially-edentulous jaws with remaining dental tissues.

Strains and deformations of remaining teeth in the casts investigated in the present study were differently distributed.

In the control incisor without protective coping, the test did not reach Stage 3 because during Stage 2 the tooth cracked on our 3D printed model. The material then exceeded the tensile strength, which according to the literature is 65 MPa. For this reason, the final deformation of the incisor with and without a coping i.e. cap at a maximum load of 1000 N could not be compared, because the incisor without the coping did not withstand the specified load. Instead, those from stage 1 (Tab. 1) were used to compare deformation

values. The cross-section of the incisor without the coping was smaller, so at an identical force it would have a significantly higher voltage value, thus it would be expected to fracture first. This is evidenced by the results obtained; the incisor covered with a coping withstood a load of 1000 N while the incisor without a coping did not. By comparing the results in Stage 1 for the incisor with and without the coping, we demonstrated that a greater deformity is present in the incisor without the coping.

A major strain field was present around abutment teeth, as reported by previous authors [10]. A lower intensity compared to the major strain field was observed towards the alveolar ridge. The difference in the obtained values may be attributed to the effect of the highest stress on the junction of different structures—the dentinal-cement border, and also the region below the gingival sulcus with the composition of the dentin-cement-alveolar bone junction of the root of the remaining tooth in the alveola. Major strain values for the casts of the partially-edentulous lower jaw showed greater strain of the occlusal portion of the premolars either without or with a covering coping. For the incisor without a coping the major von Misses strains were in a region of remaining tooth substance towards the incisal areas. In contrast, for the incisor with a coping the major von Misses strains were in the gingival areas, towards the gingival sulcus. In addition, loading of incisors, canines and premolars of the experimental casts caused only limited stress transfer to distant portions underneath tooth structures. However, our data show that the bone underlying the remaining teeth could have undergone higher resorption in the buccal region, which is in agreement with the findings of previous authors [16].

Maximum displacements were noted for the experimental incisor with a coping and for the control canine (Fig. 3, 5). It would certainly have been noted for the control incisor too, but for the fact that the control incisor cracked earlier, at stage 1 with a load of 500 N, removing the possibility of additional displacements (Tab. 1).

According to the results of the present study, the risk of bone overload appears to be highest around the dentin–cementum junction in the cervical parts of remaining teeth, confirming that the majority of occlusal loading is transferred to the crestal bone. The biomechanical distribution of stress occurs primarily where the coping is in contact with the crown and enamel (dentin) of remaining tooth substance, therefore the stress distributions along the coping lengths should reflect their design. Although these differences were not extremely marked, they may be an important contributing factor to negative clinical effects and crestal bone loss if associated with other aggravating factors such as coping overloading, non-axial loading, insufficient number of remaining teeth and copings, and poor bone quality [17].

As for the question of selection of the type of partially-edentulous cast for the experiment, this could be discussed from the perspective of the problem of choice of design as well as the topography of the cast. This experiment was performed on a Kennedy class 1 partially-edentulous mouth i.e. B3 (and C2) classification of Eichner, because this type of partially-edentulous jaw is very frequently represented in clinical practice [1,2]. Moreover it remains to be discussed why the remaining teeth were present only on one side of the mandible, taking into consideration the well-known consequent problem that remaining

tooth substance can undergo 'additional loading' as a consequence of the edentulous side of the mandible. This was done due to the objective fact that for many of the patients in everyday clinical practice, overdentures represent the ultimate and transient solution in a situation when quite a number of teeth have been missing due to extractions from the alveolae [1,2].

The optical stereometric method would have revealed whether it would be better for the remaining tooth substance to be covered by a casted coping or better to be left uncovered. Based on the results of this study, we conclude that the better option is for the remaining teeth to be covered by cast (or ceramic) copings. This is because the remaining tooth substance without coping protection could crack even at a low applied force of 500 N, while on the other hand, tooth substances covered and protected by copings, because of the form of the copings and the hardness of the selected material (alloy), will not start cracking until the applied force reaches 800N or more.

The design of the copings on the experimental mandibular cast was also very important but was also original in this study. Firstly, the coping shapes used in this study were such that the form was adapted to minimal dental removals in order to prepare abutments for coping acceptance. In this sense, and secondly, a special design was created of 'semi-anatomical' forms in which the curves were pointed towards the tips of the cusps and nodules and in accordance with the original morphology of the occlusal surface, which is a specific option in relation to the previously applied forms in clinical practice [1,2]. These forms also resulted in specific distributions of forces which were mostly present on the surfaces of the incisor copings and even the canines according to the cervical portions, while on the other hand, the forces applied to the premolar remained concentrated on the occlusal plateau (Fig. 5, 6) [1,2].

Conversely, increasing the strength of the overdenture by reinforcement decreased the deformation of the denture base and decentralized stress to the contralateral side, thereby decreasing stress on the working side, which seems to be true in the present study too, based on the present observations [18].

Fracture of abutment teeth is frequently reported. This possibility is especially likely in situations where the remaining dental substances are only present on one side of the jaw, and even more so if they are at the corner, i.e. at the border of the intercanine and transcanine sectors. Reasons for this could be the unfavorable position of remaining tooth substance in the mandibular arch, inadequate tooth preparation for copings or overloading. However, fracture of the abutment teeth has been reported as a motive for tooth loss much less frequently than caries or periodontal breakdown [19].

Conclusions

The following conclusions can be drawn of subsequent evaluation of the results: when loading the abutment teeth, the distribution of strain through the remaining tooth substance was specific but varied. The applied forces and deformation were mutually linearly dependent. Abutment teeth covered by copings were more resistant to loads.

Based on the evaluation of the results it may also be noted that further research using optical methods of strain measurement should focus on monitoring the deformation of copings of specific types, as well as particularly different forms of copings, as well as the bone under the loaded dental restorations.

Abbreviations

L0= length before loading

L1= length after loading

N= Newtons (measuring units)

3D= three dimensional

ARAMIS= Automated Engineering of Autonomous and Run-Time Evolving Systems

DIC= Digital image correlation

Declarations

Ethic approval and consent to participate

There are no human, animal or clinical experiments in this study.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

SDP, MM and TM collected the data, searched the literature and designed the study. SDP, MM, TM and GMM conducted the experiments. SDP, MM and GMM analyzed the data, and interpreted the results. SDP drafted the manuscript. SB and BT revised the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials.

The data supporting the conclusions of this article are available from the corresponding author on reasonable request.

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Conflict of interest

The author declares that he has no conflict of interest.

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Table

Table 1. Comparison of values of deformation of control teeth without copings and experimental teeth with copings.

Largest actual value of deformation	Vertical load of up to 500N (stage 1)
Control incisor without coping	0.48%
Experimental incisor with coping	0.29%
Largest actual value of deformation	Vertical load of 1.000N (stage 3)
Control canine without coping	10.29%
Experimental canine with coping	7.007%
Largest actual value of deformation	Vertical loading of 1.000N (stage 3)
Control premolar without coping	6.64%
Experimental premolar with coping	4.98%

Figures

Figure 1

Experimental partially edentulous mandible under stress.

Figure 2

Computer display during analysis.

Figure 3

a. Displacements within the control incisor during loading of 500.0N (Final Stage 1); upper left panel– final stage; lower left panel– initial stage; right panel represents distribution of loads and stresses along and within the control incisor. b. Displacements within the control canine during loading of 1000.0N (Final Stage 3); upper left panel–final stage; lower left panel–initial stage; right panel represents distribution of loads and stresses along and within the control canine. c. Displacements within the control premolar during loading of 1000 N (Stage 3); upper left panel–final stage; lower left panel–initial stage; right panel represents distribution of loads and stresses along and within the control premolar.

(a)

(b)

(c)

Figure 4

a. Von Misses strains of the control incisor b. Von Misses strains of the control canine. c. Von Misses strains of the control premolar.

(a)

(b)

(c)

Figure 5

a. Displacements within the incisor with coping under loading of 1000 N (Final Stage 3); Upper left panel–final stage; lower left panel–initial stage; right panel represents distribution of loads and stresses along and within the experimental incisor. b. Displacements within the experimental canine with coping under loading of 1000 N (Final Stage 3); upper left panel–final stage; lower left panel–initial stage; right panel represents distribution of loads and stresses along and within the experimental canine and coping. c. Displacements within the premolar with coping under loading of 1000N (Final Stage 3); upper left panel–final stage; lower left panel–initial stage; right panel represents distribution of loads and stresses along and within the experimental premolar and coping.

(a)

(b)

(c)

Figure 6

a. Von Misses strains of the experimental incisor with coping. b. Von Misses strains of the experimental canine with coping. c. Von Misses strains of the experimental premolar with coping.

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