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Optical stereometric analysis of an experimental partially-edentulous mandible

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Abstract

Stereooptics method have been successfully used in biomechanical studies of dental models. The aim of this study was to investigate, on the basis of functional deformities, the distribution of occlusal loads on the casts of a partially-edentulous mandible without and with dedicated copings. Precise measurement of strain and displacement of partially-edentulous mandibular control and experimental casts were provided by the digital image correlation method and ARAMIS software. Simulated loads ranged from 0 to 1000 N. 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. Wilcoxon matched pairs signed ranks sum test was not statistically significant for the majority of the examined parameters, except for the differences between deformations of teeth and copings under pressure $p \leqslant 0.05$. When loading the abutment teeth, the distribution of strain through the remaining tooth substance is specific and various. Abutment teeth covered by protective copings are more resistant to loads.

Keywords

Dentistry, stereooptic method analysis, copings, partially-edentulous mandible

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Introduction

The surfaces of remaining teeth must be particularly prepared to accept the surface of the prosthesis, if indicated. Poštić[1] suggested that special preparation consists of making dedicated copings on the remaining solid dental tissues. Conversely the copings can be designed variously otherwise. Poštić[1] and Ilić et al.[2] stated that various designs of copings can cause differences not only in the retention and the stabilization of even the same form of dental prosthesis, but also to the mechanical resistance and the stability of the dental tissue itself onto which the copings are placed. In addition, from a biomechanical aspect, there may be induction of a different stresses and the deformations due to differences in the occlusal loads. The resulting

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stresses (with or without deformation) can lead to adequate or inadequate responses which will be reflected to the functional adaptation of oral tissues.

Shahr and Weiner,[3] Ahn and Kim,[4] Kultchin et al.,[5] and Durbin and Durbin[6] reported the optical stereometric methods based on volumetric measurement mechanisms as up-to dated practice of the biomechanical studies.

Kahn-Jetter and Chu[7] and Brynk et al.[8] established the use of the digital image correlation (DIC) as an optical full-field technique and measuring system for *in vitro* non-contact three-dimensional (3D) deformation assessments.

Aim

The aim of this study was to investigate the distribution of occlusal loads on the casts of a partially-edentulous lower jaw without copings and with dedicated copings.

Materials and methods

The materials in this study were two, as symmetric as possible, master casts of a partially edentulous lower jaw which were made of specific polymethyl resin material (Photopolymer Resin, Formlabs Inc., Somerville, MA, USA) after processing and manufacturing in a 3D printer. The control and the experimental master casts of a partially-edentulous lower jaw was characterized with the same topography of missing lower molars, the left lower second premolar, and the right missing canine and incisors. Three of the remaining tooth substances of the control master cast were moderately reduced. The remaining teeth of the control cast were not covered by copings. The experimental cast was almost the same as the control, except for the surfaces simulating three copings of oval design covering the remaining teeth.

The surfaces of the control and the experimental casts were sprayed (Primer can spray Motip, Wolvega, Netherlands, Europa) 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 (Figures 1 and 2). Points of the spray occupied distances that were changed under loading and registered by cameras.

Measuring devices and methods

Precise and controlled loading was measured using a gnathodynamometer (SiemensAG, Erlangen, Germany) 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 experimental cast was the same.

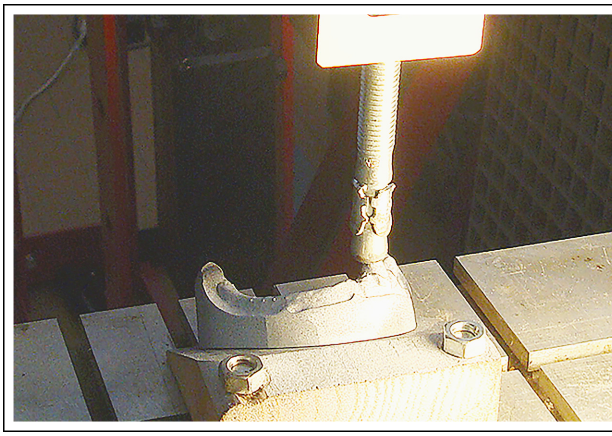

Figure 1. Experimental partially edentulous mandible under stress.

Measurements of the strain and displacement were provided by the Digital Image Correlation Method (GOM-Optical Measuring Techniques, Braunschweig, Germany). This system consists of two digital cameras and the associated software ARAMIS (Version 6.2.0; GOM-Optical Measuring Techniques Correlate Pro software, Zeiss, Europa, https://www.gom.com/en/company). 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, the field of 3D movements, vector of distorted field, and features of the biomaterial.

Two 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. Windisch et al[9] suggested that strains within the selected area may be measured over a range from 0.01% up to several 100% and strain accuracy was up to 0.01%. Small and large objects, from 1 to 2000 mm, can be measured with the same sensor.

The vertical line (Section 0) (Figure 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 and 1.000.0 N at intervals of 50.0 N, the obtained multistage view and figures

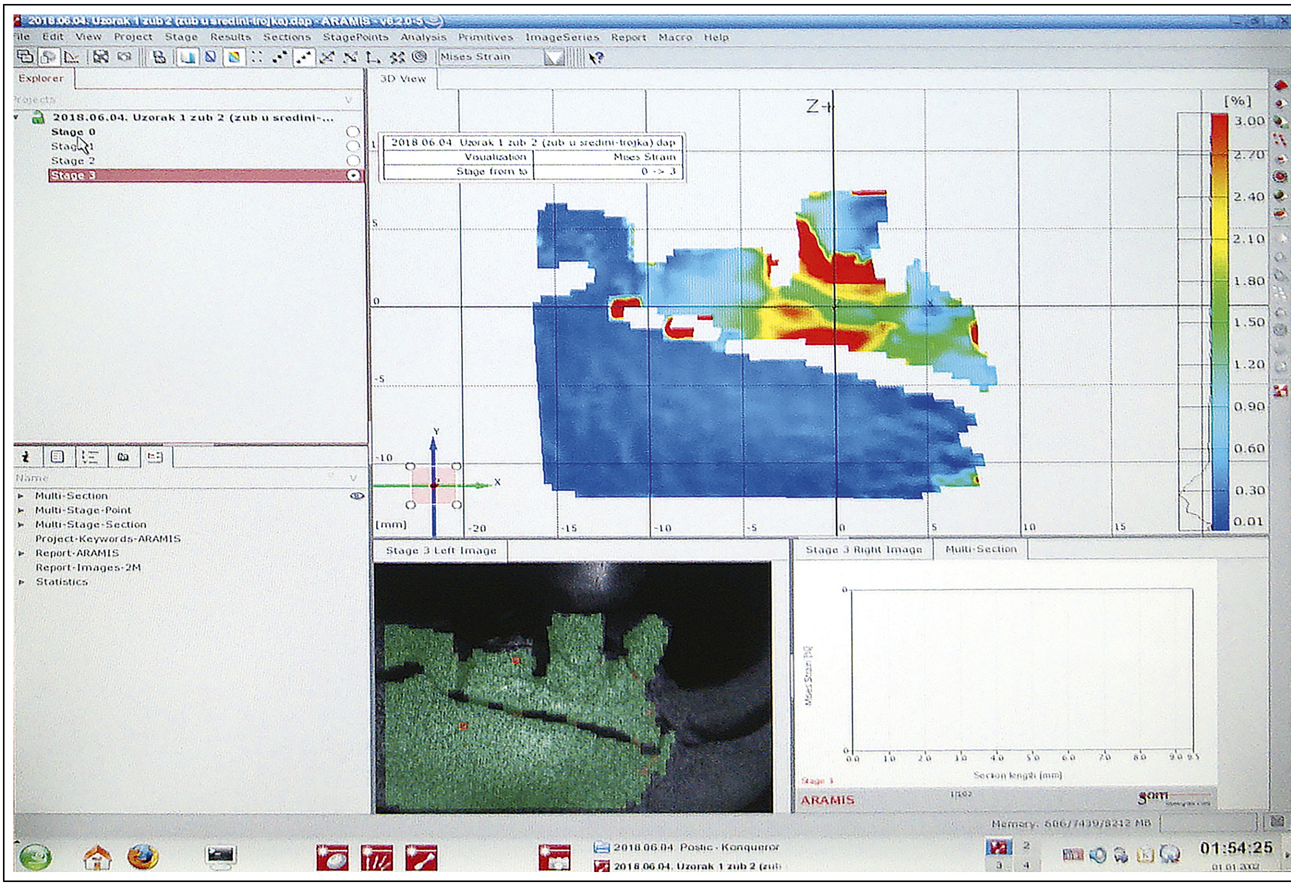

Figure 2. Computer display during analysis.

showing dimensional changes of the structure under investigation are presented in 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 500.0 N (Stage 1).

This study primarily focused on the strain distribution inside and around the remaining abutment teeth of the control and the experimental casts. The strains are presented in different colors. The regions of sufficient interest were the abutments second incisor, canine, and the first lower premolar.[10]

Sample size calculation was provided on the basis of the analyses of coordinates of selected points. Points were determined on the vertical line under the slams point of the direction of action of the load. From 20 to 22 separate points were analyzed for every tooth observed—the incisor without coping, canine without coping, and premolar without coping—the control master cast, as well as for incisor covered by rounded coping, canine covered by rounded coping, and the premolar covered by rounded coping—the experimental master cast. In all cases the points were distributed along the direction of action of the force.

Statistical analysis

Descriptive statistics were used to calculate the deformation and displacements of the teeth of the control cast and the teeth of the experimental casts covered by the copings. The MEANS procedure from the statistical package SAS (SAS Institute, Inc 2010, the SAS System for Windows, release 9.3, Cary (NC): SAS Institute USA) was used. Wilcoxons' Lambda—matched pairs signed ranks sum test was used for the analyses of numerical values of distortions and displacements of the teeth and the copings with significance level of $p \leqslant 0.05$. 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 coordinates and positions of selected points along the direction of the force on the teeth of the control cast and the experimental teeth covered by copings.

Results

According to the deformation formula $e = (L0 - L1)/L0 \times 100$, where $L0$ and $L1$ were the lengths before

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

and after loading, respectively, the strain values were expressed in percentages, and presented on the scale using different colors (Table 1, Figures 3(a)–(c) and 5(a)–(c)). Additionally, further individual strain values were analyzed with ARAMIS software (Figures 3(a)–(c) and 5(a)–(c)).

In the table showing comparison of tooth deformities with and without incisor coping, the values obtained in Stage 1 were used indicating differences in deformation values (Table 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 3(a)–(c) and 5(a)–(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 2, 3, and 5.

This study primarily focused on the strain distribution inside and around the remaining abutment teeth.

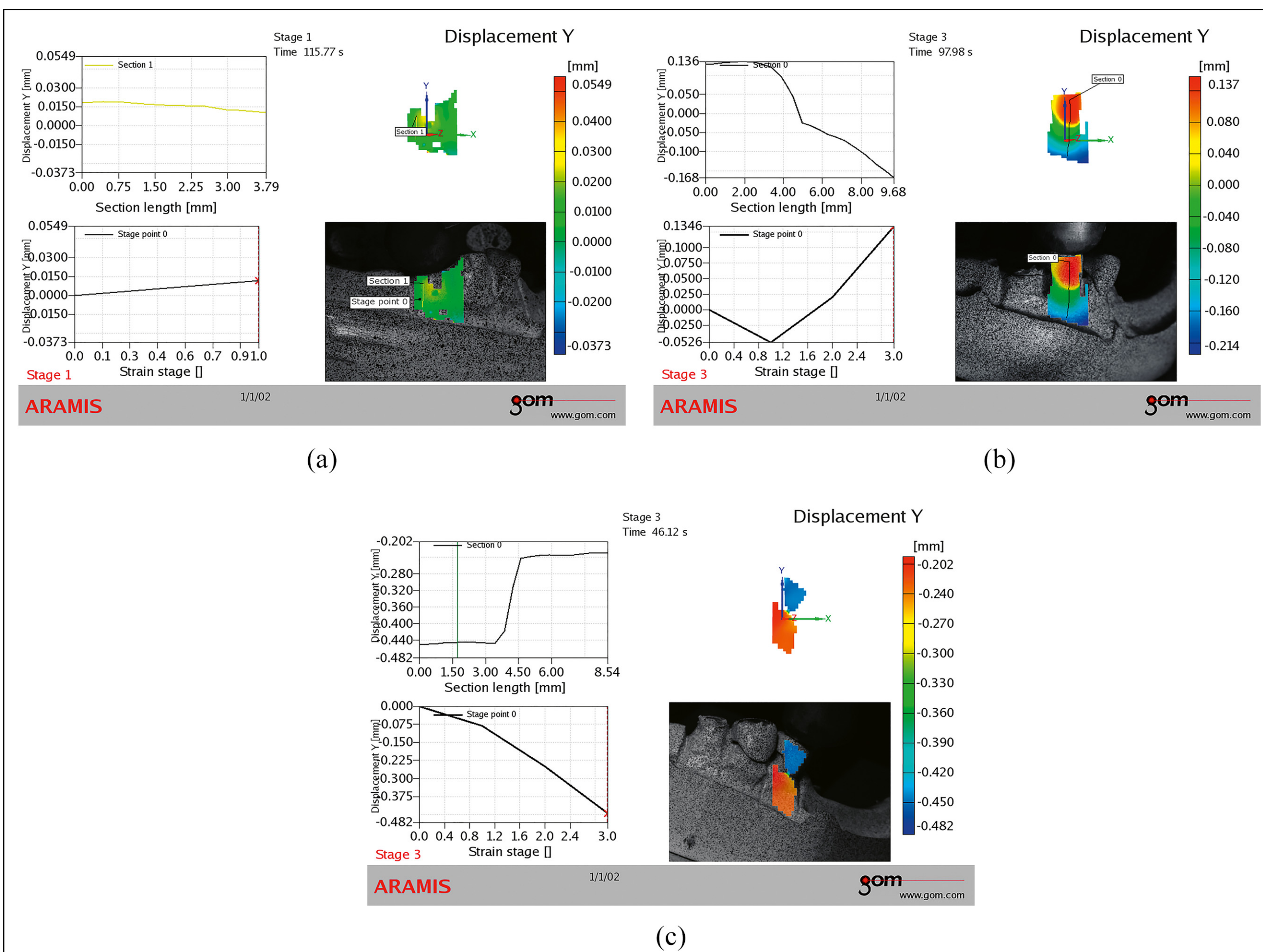

Figure 3. (a) Displacements within the control incisor during loading of 500.0 N (Final Stage 1); upper left panel—final stage; lower left panel— initial stage; right panel represents distribution of loads and stresses along and within the control incisor.
(b) Displacements within the control canine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

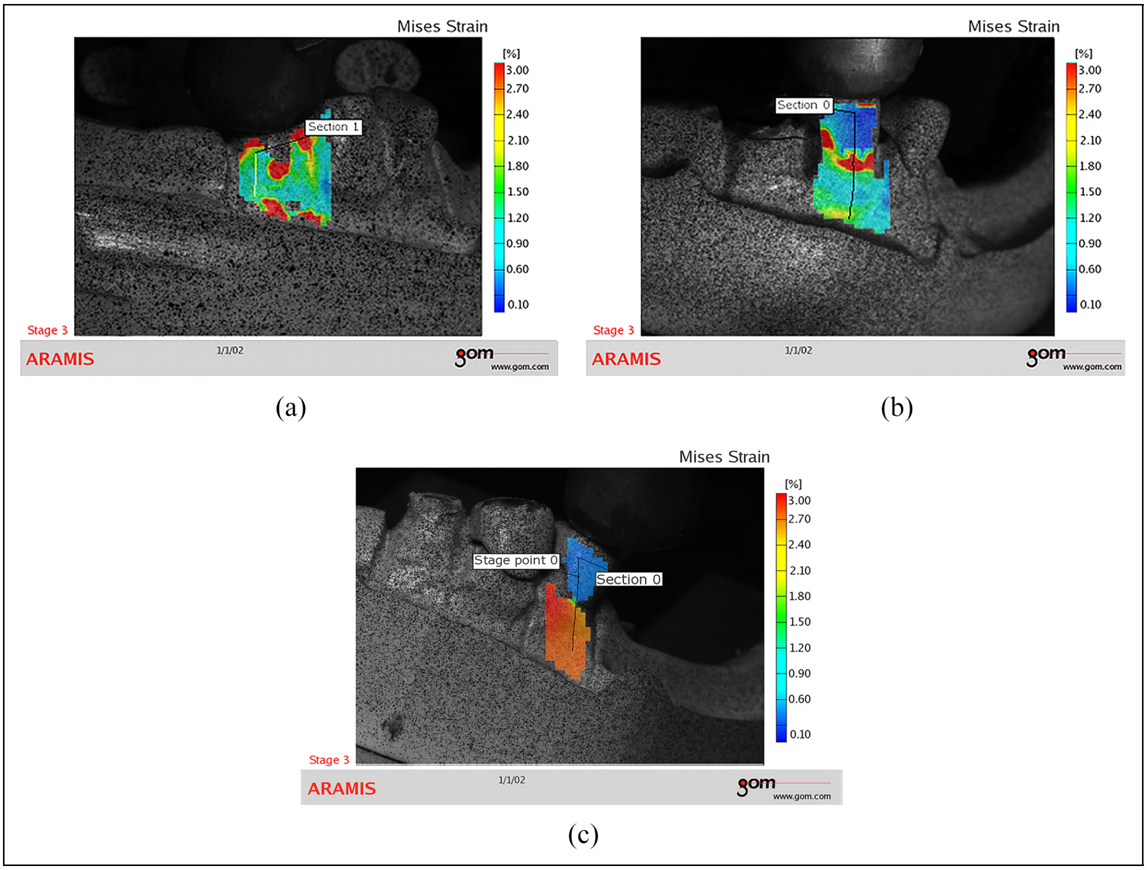

Figure 4. (a) Von Misses strains of the control incisor.
(b) Von Misses strains of the control canine.
(c) Von Misses strains of the control premolar.

The 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 1.000 N (Stage 3) are shown (Figures 4–6).

As maximum and significant displacements the maximum displacements were noted for the experimental incisor with coping and for the control canine without coping (Table 2, Figure 4). However, the differences of numerical values obtained were not statistically significant.

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

The most intensive deformation value was recorded in canine without coping. (Table 1).

The statistical significance of the differences between deformations of the teeth of the control master cast and the teeth covered by coping of the experimental master cast under pressure are represented in the Table 2. The significance of the differences between displacement of the teeth of the control master cast and the teeth covered by coping of the experimental master cast under pressure are represented in the Table 3. The results of Wilcoxon test showed a direct link only between the percent of the deformation of the teeth of the control master cast and the teeth covered by the presence type of the coping of the experimental cast ($p = 0.029$). Analyses showed statistically significant greater deformation of teeth without copings comparing to teeth covered by round copings (Table 3). These findings are relevant for all of three referent pressure stages (under 500 N, at 500 N, and up to 1000 N)

Discussion

Previous works by authors dealing with the problem of the application of the 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 more important details and facts regarding the treatment of partially-edentulous jaws with remaining dental tissues.

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

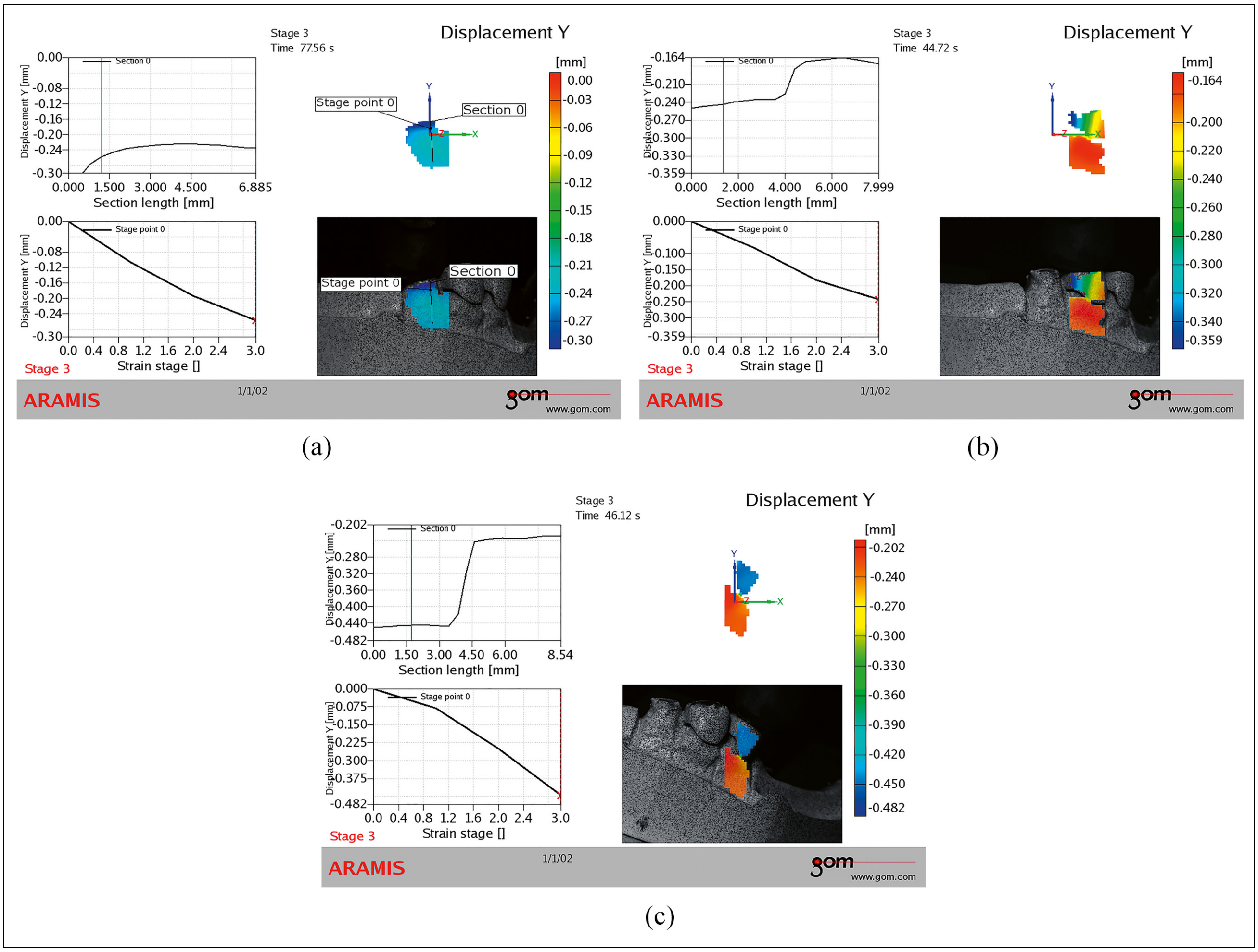

Figure 5. (a) Displacements within the incisor with coping under loading of 1000 N (Final Stage 3); Upper left panel—final stage; lower left panel—initial stage; right panel represents distribution of loads and stresses along and within the experimental incisor.
(b) Displacements within the experimental 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 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 premolar and coping.

distributed. In the control incisor without protective coping, the test did not reach Stage 3 because the tooth of the 3D printed model cracked during Stage 2. 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 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 (Table 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.[10–15]

Tanasic et al.[10] reported that a major strain field was present around abutment teeth. 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. 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 the coping. For the incisor without a coping the major von Misses strains were in a region of remaining tooth substance toward the incisal areas. In contrast, for the incisor with the coping the major von Misses strains were in the cervical areas. Field et al.[16] advocated that loading of incisors, canines, and premolars of the experimental casts caused

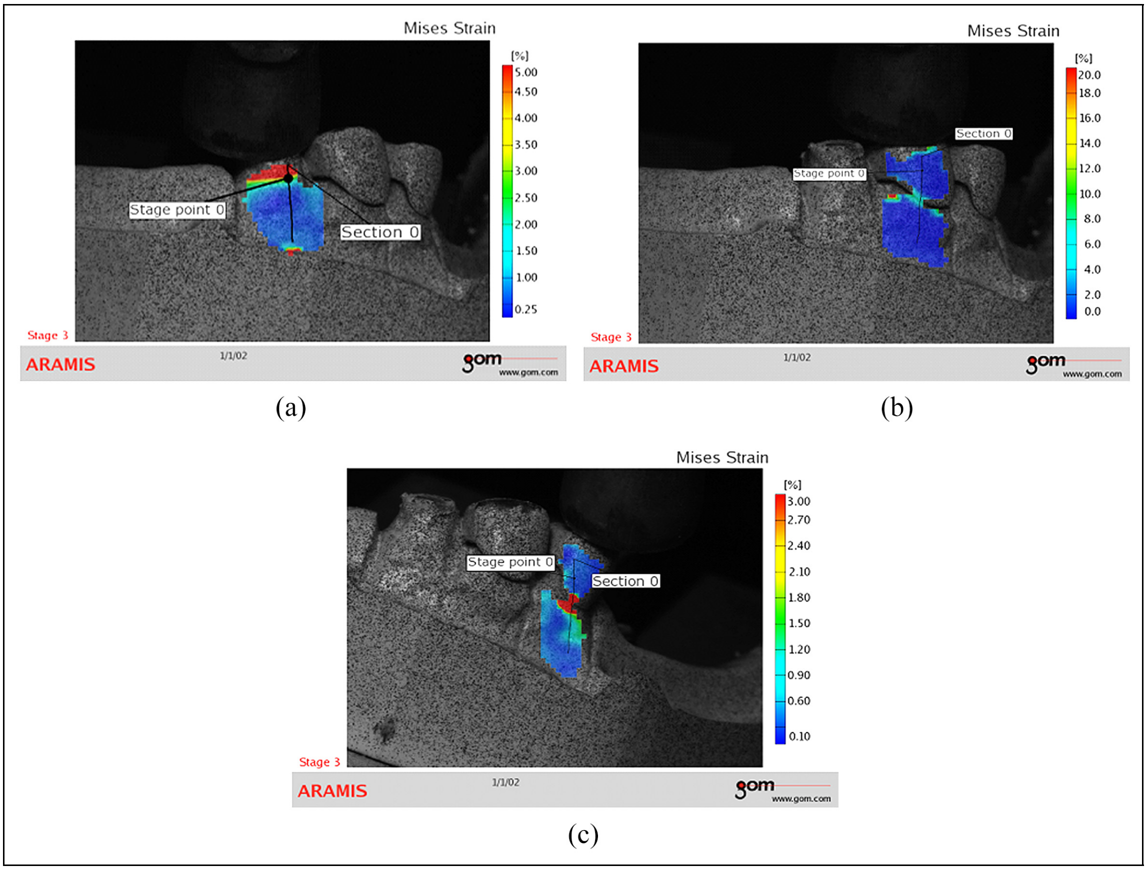

Figure 6. (a) Von Misses strains of the experimental incisor with coping.
(b) Von Misses strains of the experimental canine with coping.
(c) Von Misses strains of the experimental premolar with coping.

Table 2. The significance of the differences between deformations of two types of the remaining teeth (without copings and covered with copings) under pressure.

	Deformations
Wilcoxon two-sample test	
Type of remaining tooth	Mean score
Without coping	10.0
With coping	5.0
Normal approximation Z	2.172
Two-sided Pr≤|Z|	0.029

$p \leq 0.05$.

Table 3. The significance of the differences between displacements of two types of the remaining teeth (without copings and covered with copings) under pressure.

	Deformations
Wilcoxon two-sample test	
Type of remaining tooth	Mean score
Without coping	7.0
With coping	9.0
Normal approximation Z	0.698
Two-sided Pr>|Z|	0.667

$p \leq 0.05$.

only limited stress transfer to distant portions underneath tooth structures.

The maximum displacements were noted for the experimental incisor with a coping and for the control canine (Figures 3 and 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 (Table 1).

The most intensive deformation value, which was observed in the canine without coping, suggested that the coping caused a decrease in the maximum deformation value (Table 1).

According to the results of the present study, the risk of overload appears to be highest around the cervical parts of remaining teeth. The biomechanical distribution of stress occurs primarily where the coping is in contact with the 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 effects of coping overloading, non-axial loading, and insufficient number of remaining teeth and copings.[17]

The optical stereometric method would have revealed whether it would have been better for the remaining tooth substance to be covered by a casted coping or to left uncovered. Based on the results of this study, we concluded that the better option for the remaining teeth was to persist covered by casted (or ceramic) copings. This is because the remaining tooth substance without coping protection could crack even at a low applied force of 500 N. 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 800 N or more.

The design of the copings of the experimental mandibular cast was original for the purposes of this study. Firstly, the coping shapes used in this study were adapted to minimal dental removals in order to prepare abutments for coping acceptance. In this sense a special design was created of "semi-anatomical" forms in which the curves were pointed toward the tips of the cusps and nodules and in accordance with the original morphology of the occlusal surface.[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 (Figure 5).[1,2]

Fracture of abutment teeth was frequently reported in the literature. This possibility is particularly expected 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 border of the intercanine and transcanine sectors. Reasons for this could be the unfavorable position of remaining tooth substance, inadequate tooth preparation for copings or overloading. However, Mercouriadis-Howalda et al.[18] assigned the fracture of the abutment teeth as a motive for tooth loss.

The present report performed optic stereometric analysis of forms of teeth—supporting hard tissues. Future studies are needed to evaluate other variables previously tested with other dental materials, such as compressive strength[19] and flexural properties.[20]

Limitations of the study

The present study has certain limitations. Firstly, this research was focused to the supporting specifics of the lower jaw without end review to the upper jaw. The second limitation regards to the fact that hard tissues—predominantly the bone under the copings and the teeth were not possible to analyze using the method of optical stereometric analysis. Thirdly, in the present study were applied forces which are excessively over the range of habitual masticatory forces within stomatognathic system of a living human, which could have increased a number of choices to be taken into consideration while making decision on probable resistances or cracks. It is an issue whether this could be comparable to increased number of supporting teeth and copings and whether predictions would have hold across selected type of toothlessness. Finally, a small number of remaining tooth samples ($n = 6$) were involved in the present research project indicating observations only to a limited and complex situation in the mouth.

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, different forms of copings as well as some other variables of testing.

Authors' note

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Declaration of conflicting interests

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Data availability

The data that support the findings of this study are available from the corresponding author and the first author upon reasonable request.

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