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ANALYSIS OF STRESS WITHIN THE BRIDGE AND DENTAL PERIODONTAL AGGREGATE WITH ONE AND TWO TEETH SUPPORT USING PHOTOELASTICITY

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This study's aim is to analyze, using photoelasticity, the distribution of stress within experimental models under forces similar to those that occur during chewing. The experimental models were manufactured from photoelastic material. They imitate the bridge and dental-periodontal support aggregate in a hemimandible. The bridges had single tooth or two teeth support with vertical abutments. Based on the isochromatic bands, quality and quantity analysis of stress can be carried out, which shows and explains the behaviour of the bridges with the analyzed shapes. In conclusion, the use of photoelastic models can yield useful information that can increase the therapeutic and prophylactic efficiency of treatment with dental brigdes.

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Keywords: Photoelasticity, Stress, Load, Abutment

1. Introduction

In most fields, the study of a phenomenon by a group of scientists that focus on just one research direction and isolating it from other related fields is no longer possible. Lately there is a successful interference of research from technical fields and medicine.

Biomedical engineering focuses on applying mechanical principles to biological systems, and using the results in diagnosis and therapy [1].

Fixed dental restorations and the dental-periodontal support (the abutments) form an inseparable biomechanical complex [2]. Thus, as the dental bridge distributes the occlusal forces to the abutments, the biological and morphological response of the structures of the oral and maxillary apparatus under the influence of theses forces and biomechanical laws has to be assessed [3]. These influence the functional balance of the brigde-abutments aggregate. One of the main goals of dental prosthetics is to reestablish the balance between the two groups of forces with opposite direction that occur during chewing. The result of these forces actions is stress that can lead to a limit-situation (breaking) of the structure (prosthesis) that can no longer fulfill its purpose. Functional occlusal forces are the result of the contraction of masticatory muscles during the functions of the oral apparatus (chewing, swallowing, speech). Reaction forces oppose the occlusal forces and maintain the teeth in their natural position, and also restore them to their initial position after the action of the functional forces stops [3].

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The stress on dental structures has been studied using numerous techniques: the brittle shell method, holography, two and three dimensional photoelasticity, the finite element analysis and other numerical methods [4]. Research on experimental models have led to the development of the theory and technique of modelling. This technique studies the geometrical and physical relationship between the model and the prosthetic restorations and also projecting, manufacturing and testing the models, processing and interpreting the results of the measurements on the models. The strain within an object that is subject to a known force determines its behaviour.

Photoelasticity-based stress analysis has been introduced in dentistry in 1935 by Zak, cited by Aydin [5]. Photoelasticity is a research procedure that is based on the phenomenon of accidental birefringence of light, that indicates the main directions of the strains that occur, under the action of forces, within experimental models that have well defined characteristics; these strains are analyzed under polarized light. The method analyzes the directions of the main lines of stress within the dental structures (toth, jaw etc) and the material of the prosthetic restoration.

2. Material and method

For the manufacturing of the two dimensional models, we used 8 mm thick Araldit plates, and reproduced on a 1:1 scale a mandibular half arch and two fixed prosthetic pieces for the lateral madibular region along with their dental – periodontal support.

The models' shape resulted from cutting a laterally partially edentulous mandible along a longitudinal plane α.

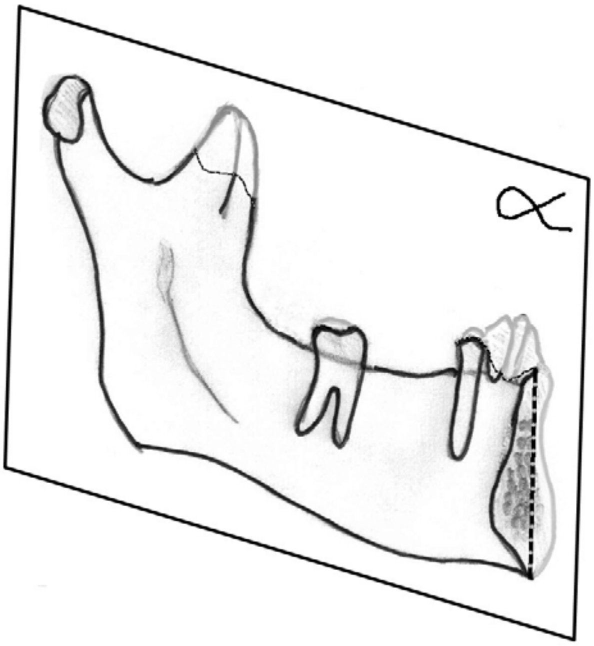

Fig. 1. The laterally partially edentulous mandible

The design of the bridges has been simplified in order to eliminate disturbing factors, regarding, in this case, the number, position, orientation of the abutments and the profile of the pontic (Fig. 2). Measurements of the teeth sizes were carried out since 1870 by Mühlreiter, then Black in 1902 and others (Tonn, Moorrees, Filicori). From literature, we used the mean values of the mesio-distal sizes of lateral lower bicuspids and molars as well as the mean sizes of the root-lenghts of the same teeth [6, 7]. Lower bicuspids have a single root, while lower molars have two diverging roots. The teeth were fastened into the artificial sockets with an elastic, adherent, addition-silicone-like substance (Vinil Polisiloxano ELITE P&P LIGHT), that insures a slight mobility, similar to the physiological mobility of the teeth.

Support of the bridges varied according to the number of abutments:

a. single point support – mesial cantilever bridge
b. double, linear support – on two parallel and vertical abutments (second molar and first bicuspid); rectangular, non-arched profile of the pontic.

Fig. 2. Simplified representation of the studied bridges

Surface forces were applied on to the photoelastic model using a mechanical device (lever system) that meets the following conditions: it accurately simulates the nature of the real-life loads, it insures a stepwise increase of the force, it is able to aplly separate or simultaneous loads on to the model. The direction of the forces does not change and there are no additional forces, every load is measurable. The system is easy to design and build and insures precise measurement of the forces.

The experimental models were exposed to loads similar to those that occur during chewing; the forces were applied onto different areas of the restoration: along the direction of the abutments, on the centre of the pontic and on the entire occlusal surface of the restoration.

The examinations were carried out using a plane circular polariscope within polarized light. The digital photographs were taken with a Fujifilm Finepics S5000 camera and were then downloaded to the computer. By analyzing the images, the quality and value of the strains that occured within the models were evaluated.

3. Results

The most significant images are shown below:

1. Bridge with single support and mesial cantilever.

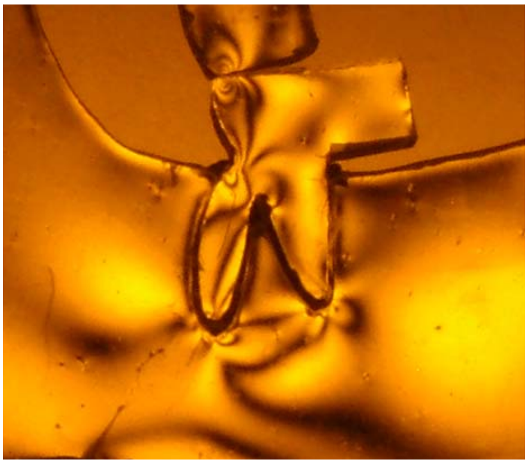

Fig. 3. Model with mesial cantilever and load along the direction of the abutment

During loading of the abutment, the distribution of strains is shown in Fig. 3. The largest compression strains occur in the area of the root fork, that is similar to a stress concentrator. In this strongly stressed area, a borderline situation – such as a root fracture – can occur. Contact strains can be observed in the coronal part of the restoration, whereas the cantilever is not loaded.

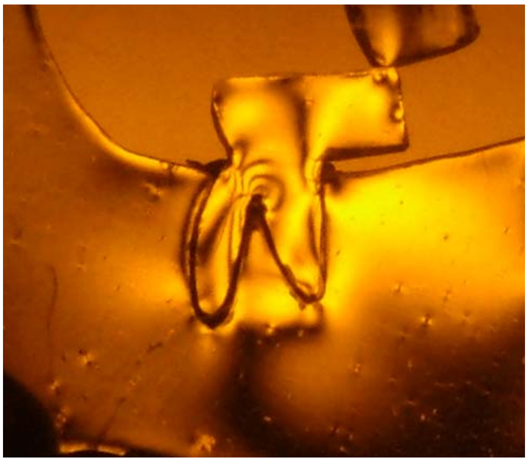

Fig. 4. Mesial cantilever model with the load at the extremity of the cantilever.

The same bridge is subject to a force at the extremity of the cantilever (Fig. 4) and the following can be observed: the root-tip area of the mesial root is strongly stressed (composed stress state), while the apical area of the distal root is poorly stressed (low pulling stress). In the coronal area of the abutment, there is significant bending stress, as are the contact strains on the cantilever. There is strong and uneven loading of the abutment and the bony structures in the mesial periapical area, and the restoration has a tendency to tilt.

2. Bridge with double linear support on two parallel and vertical abutments.

During loading of the distal abutment (Fig. 5), an uneven distribution of the strains occurs within the bridge and dental-periodontal support aggregate. Compression stress is high in the coronal contact area and the periodontal tissue of the tooth. Via the pontic, stress also occurs in the mesial abutment, but its values are realtively low, both within the mesial tooth and the pontic. There is more load on the outer alveolar wall than the inner alveolar wall. The findings are the same when loading the mesial abutment (Fig. 6).

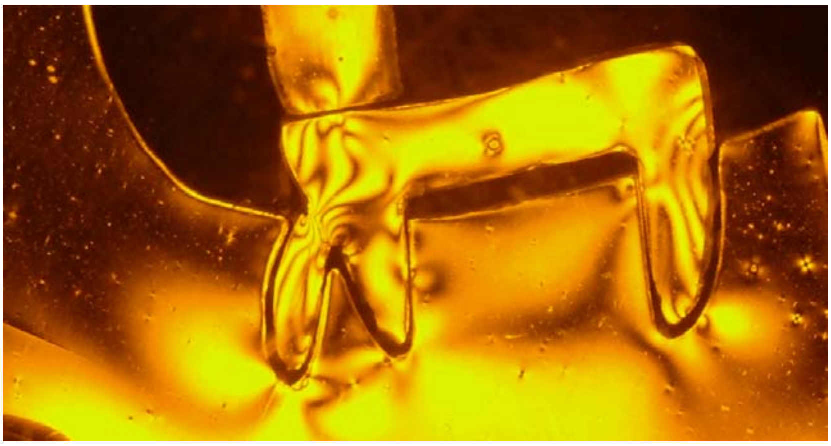

Fig. 5. Model with linear support on two vertical abutments - loading of the distal abutment

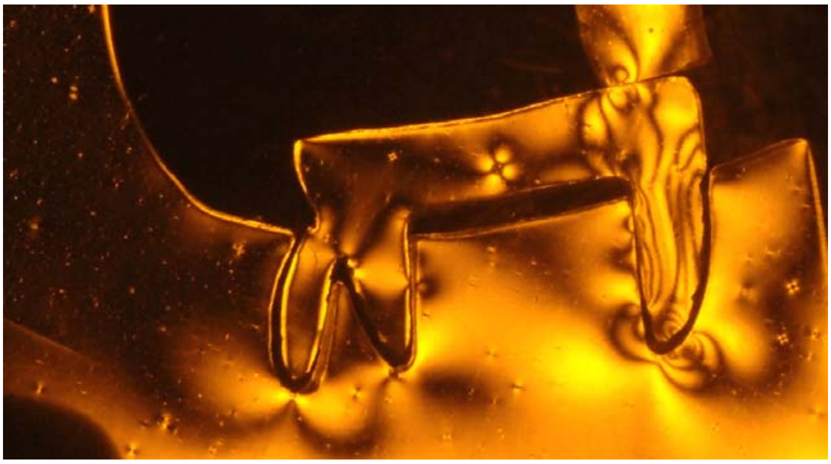

Fig. 6. Model with linear support on two vertical abutments - loading of the mesial abutment

The load that is concentrated in the central area of the pontic (Fig. 7) and on the whole occlusal surface of the bridge (Fig. 8) leads to a symmetrical distribution of stress in both the bridge and the dental-periodontal tissue. The stain is higher within the dental-periodontal support of the mesial tooth (a single root tooth) than the distal abutment (a two root tooth).

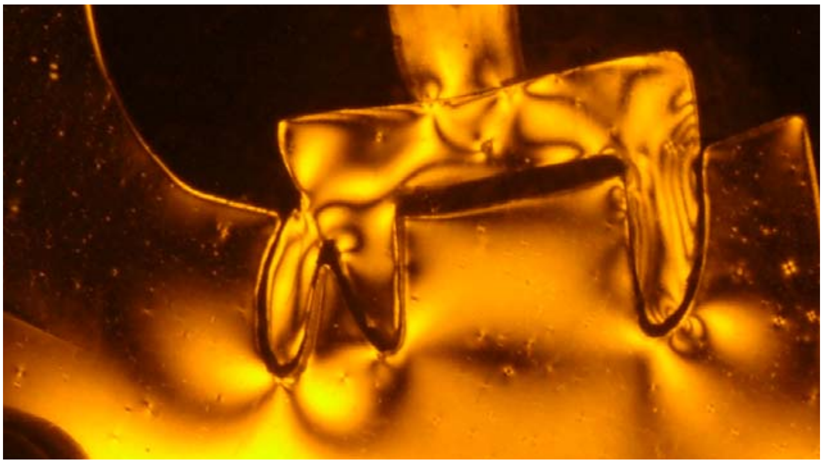

Fig. 7. Model with liniar support on two vertical abutments with the load concentrated in the central area of the pontic.

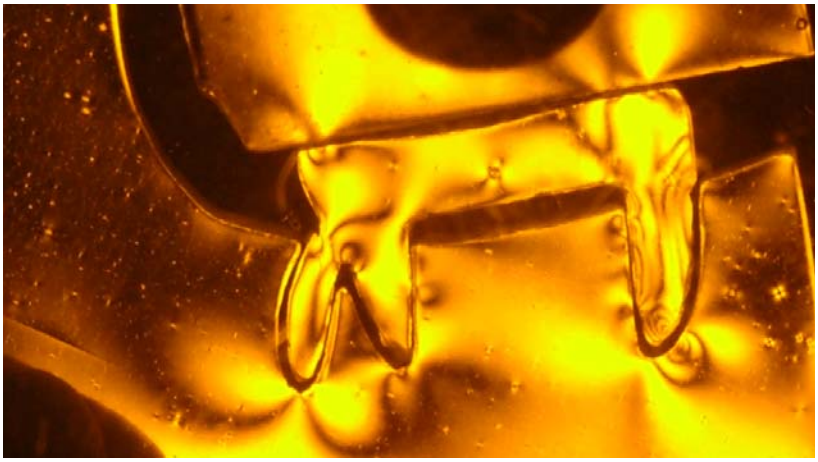

Fig. 8. Model with liniar support on two vertical abutments with the load distributed along the whole occlusal surface

4. Discussion

The brigde and the dental-periodontal support form a biomechanical complex that needs to be statically and biodinamically balanced in order for the prosthetic treatment to be succesfull and lasting.

Since the beginning of the past century, authors like Sandrin, Ante, Beliard, Duchange, Dubois have tried to explain the biomechanical mechanisms that the balance, stability and resistance of fixed restorations are based on. The oro-dental system can be compared to a 2nd stage lever system in which the acting force is the result of the contraction of the masticatory muscles, the resisting force is giving by the food and the hinge is at the condyles of the mandible [8]. The forces that act on the bridges cause see-saw, tilting, torsion and flexion movements [2,3].

Beliard has demonstrated that an object that is supported in only one point can turn in every direction, an object that is supported by two points can rotate around an axis that joins the two points and an object that is supported in three points is dinamically stable. Thus, a bridge that is supported by only one abutment is not in dynamic balance [8].

According to Duchange [8], liniar support on two abutments is precarious, polygonal support on three teeth insures good stability conditions if the surface of the polygone is large, support on more than three teeth insures static balance if the teeth are situated in different planes and fulfills Roy's law.

Dubecq takes into account the direction of the axes of the abutments, that should be vertical and the force that acts on the abutments should have the same (physiologic) direction in order to allow the dental and periodontal structures to oppose the sinking. Thus, balance is insured without bending of the pontic [8].

Studies have shown that long bridges (over 4 units) have a low survival rate [9,10]. Therefore, the pontic should not be longer than three succesive missing dental units [3]. Bridges that close a four-tooth gap have an unfavourable prognosis and are therefore contraindicated [11]. According to this reasoning, a fixed restoration in the upper jaw, due to its arched design, is more resistant to bending forces than a mandibular bridge; due to the saggital curve, abutments of mandibular bridges are subject to paraaxial forces [8].

Asessment of the stability of bridges using only the laws of mechanics is incomplete, as biological factors have to be taken into account [3,8]. The biomechanical value of abutments depends on several aspects like: their clinical situation, the chewing stereotype, the position of the abutments, occlusion, dental morphology, the quality of the supporting tissues. Authors like Ante (1926), Watt (1958) and others have tried to express the biomechanical value of teeth by biomechanical indices. According to Ante's law, the root surface of the remaining teeth should be equal or larger than the root surface of the teeth that are to be replaced. The polynome law takes into account the ratio between the active and the passive force, leading to clinical elements-conditioned biomechanics [8]

From the many situations described in literature (see above), we have studied the behaviour of linear bridges that are supported by one or two teeth that are adjacent to the gap. These clinical situations are frequent throughout dental practice.

The fixed mesial cantilever bridge with single-tooth support is usually used when the patient does not understand the necessity and importance of preparing two teeth in order to replace one tooth. The study that we conducted confirms the unfavourable distribution of stress for this type of prosthetic design. The abutment has to present favourable periodontal support, as we have observed high stress levels within the tooth and the supporting tissues with a tendency of a tipping movement of the restoration.

According to mechanical principles, the stability of fixed restorations is based on their support by at least three abutments that are not positioned along a straight line. Although the bridges that are supported by two abutments are not considered to be properly balanced by mechanicists, they do have a favourable prognosis. We have found that by loading one of the abutments, some of the stress is transmitted to the other abutment via the pontic. Thus, a distribution of the load is insured.

5. Conclusions

1. This optical method yields information regarding the distribution of strains that occur under the action of a known force in a photoelastic model that is similar to the biomechanical complex bridge and dental-periodontal support.
2. The quality analysis by photoelasticity of the stress field within the experimental models that simulate single-tooth supported bridges confirms the unfavourable prognosis of this type of prosthetic design.
3. For bridges with linear two-teeth support, the study shows a different distribution of stress. By loading one abutment, the forces are not fully supported by it, but are distributed to the other abutment as well, via the pontic. A load that is concentrated in the central area of the pontic and one that is distributed along the whole occlusal surface of the prosthetic piece, leads to an approximately symmetrical distribution of stress in both the restoration and the dental-periodontal tissue.
4. A positive biological factor is the resilience of the periodontium of the abutments, that allows for elastic deformation; this decreases the tension caused by occlusal forces, as seen in this study.
5. Asessment of the biomechanics of dental bridges solely according to mechanical laws is incomplete. Linear bridges that are supported by one tooth on each side of the gap are fairly resistant if correctly designed according to biological factors (occlusion, status of the dental-periodontal supportive tissue).
6. Studies of photoelasticity yield useful information, that are obtained in vitro, and prove useful for finding optimal solutions of fixed prosthodontic treatment.

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