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Photoelastic Stress Distribution Produced by Different Retention Systems for a Single-Implant Mandibular Overdenture

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Abstract

Purpose: For patients poorly adapted to conventional dentures, the single-implant mandibular overdenture has been proposed as a simplified alternative for the two-implant treatment, together with the use of immediate loading of the implant. The aim of this in vitro study was to compare the photoelastic characteristics of stress transfer around the implant in a single-implant mandibular overdenture using different types of attachments.
Materials and Methods: A photoelastic model of an edentulous mandible with a resilient edentulous ridge and a unique implant located at the symphyseal region was obtained to reproduce a single implant-retained mandibular overdenture. Six 2.0 mm height attachments were selected and inserted in the same photoelastic model in a random order. A universal testing machine was used to induce axial vertical loads of 70 Ncm applied at the central incisor and at the central region of the first right molar without contact on the contralateral side. The photoelastic analysis was performed using a polariscope integrated into the testing machine. Standard separate views were photographed, using only one model per system. A visual qualitative analysis of stress-induced fringes was performed to comparatively rank the different attachment systems.
Results: All attachments showed a similar tension distribution concentrated in the apical third, and the highest stress concentration was at the apical level. There was a low stress concentration at the coronal third of the implant, with no discernible stress in the first threads of the implants, except for Dalla Bona, which showed low stress at the coronal part of the implant (1 fringe). No identifiable fringes were observed when the load was applied in the molar region, which resulted from the low amount of stress transmitted by the implant for all attachments.
Conclusion: The load transferred to a single mandibular implant was evenly distributed around the implant with low stress concentration, irrespective of the type of retention system.

An implant-retained overdenture using two implants in the interforaminal region of the mandible has been recommended as the standard of care for the edentulous patient,[1-3] since it is more satisfying for the majority of patients than conventional dentures are.[4] However, no reliable evidence demonstrates that a particular number of implants offers a better outcome as compared to another.[5] Thus, no single specific treatment modality is recommended for the edentulous mandible. The standard of care is an intervention judged by the well-informed patient, carried out by a trained and experienced prosthodontist, to best meet the needs and circumstances of the patient.[6]

The single-implant mandibular overdenture is a simplification of the protocol with two implants, placed in the symphyseal region of the mandible. This alternative was proposed as an appropriate treatment for geriatric patient groups because of their diminished functional demands and the favorable conditions of local bone quality and quantity to promote good primary stability of the implant.[7,8] Furthermore, clinical studies have shown satisfactory results in terms of patient satisfaction with the denture and other clinical outcomes such as implant survival, marginal bone loss, implant stability, reduction of costs, and the need for adjustment and repair.[9-12] Satisfactory results have also been observed for immediate and early loading of the implant.[11-13]

A high degree of primary implant stability is essential for a successful immediate/early loading procedure,[14] and occlusal load and load transfer to the implant may have an influence on the outcomes of prosthesis failure, implant failure, or bone loss.[15] Cordioli et al[7] suggested that the masticatory stress distribution in a single-implant overdenture uses full mucosal support and develops a more favorable stress distribution in the horizontal dimension, which may limit the problems encountered with the standard mandibular overdenture approach.

Several studies have investigated the biomechanical behavior of implant overdentures under load with different prosthetic designs, the number of implants ranging from 2 to 4 implants, retention systems using ball/O-ring, bar-clip or magnet attachments, and methods for stress distribution analysis.[16-23] Overall, the results have shown that the load to the implants is dependent on the position and distribution of the implants, and that resilient caps directly attached to the implants provide better force distribution, evidenced by uniform stress transfer from the implants to the supporting structures.[16] Conflicting results have been observed regarding the ability of different retention systems (ball/O-ring, bar, and combinations of attachments) to optimize stress transfer and minimize denture movement; however, differences in implant and attachment designs, methods for stress analysis, and loading characteristics make it difficult to compare studies.

Although there is reliable clinical evidence of the effectiveness of the single-implant mandibular overdenture, few studies have explored the biomechanics of this treatment approach.[24,25] Understanding the load distribution around the implant may provide important information to guide the surgical and prosthetic treatment protocol, particularly in the case of immediate or early loading. Maeda et al,[24] in an in vitro study using strain gauges, observed that single-implant overdentures have similar biomechanical effects as two-implant overdentures in terms of lateral forces to the abutment and denture base movements under molar functional loads. Liu et al[25] used finite element analysis (FEA) to conclude that a single-implant overdenture showed low strain in peri-implant bone within physiological limits. Under vertical load on the anterior region, the single-implant overdenture tends to rotate over the implant from side to side; however, no significant increase in strain was observed in the peri-implant region.[25]

In a two-implant mandibular overdenture, the denture base tends to function like a fulcrum, and implants may be submitted to considerable bending moment transferred to the implants by the attachments. Potential denture movement is minimized by the type of attachment, producing different stress distributions on implants.[19,26] We hypothesized that load transfer to the implant in a single-implant mandibular overdenture design results in low stress intensity and is influenced by the retention system, which could encourage the widespread use of an immediate loading protocol. Thus, the aim of this in vitro photoelastic study was to compare the characteristics of stress transfer around the implant in a single-implant mandibular overdenture using different types of attachments.

Table 1 Retention systems

System		Manufacturer
ERA	(ERA)	Sterngold, Attleboro, MA
CNG	(CNG)	CNG Soluções Protéticas, São Paulo, Brazil
Conexão	(CON)	Conexão Sistemas de Prótese, São Paulo, Brazil
Dalla Bona	(DB)	CNG Soluções Protéticas, São Paulo, Brazil
Locator	(LOC)	Biomet 3i, Palm Beach Gardens, FL
Neodent	(NEO)	Neodent, Curitiba, Brazil

Materials and methods

A life-sized polymethylmethacrylate (PMMA) model of an edentulous mandible was fabricated with an external hexagon 3.75 × 11 mm implant replica (Neodent, Curitiba, Brazil) located in the symphyseal region. This model was duplicated using a silicone duplicating material (Silicone Master; Talladium do Brazil, Curitiba, Brazil), and the implant was transferred using a transfer coping. A 3.75 × 11 mm implant (Titamax TI cortical; Neodent, Curitiba, Paraná, Brasil) was incorporated into the model matrix and the photoelastic model was obtained with a photoelastic resin (Araldite GY 278-N and Aradur 2963-C; Araltec Produtos Químicos Ltda., Rio de Janeiro, Brasil). According to the manufacturer's instructions, the base and catalyst components were mixed in a 2:1 ratio, avoiding the inclusion of bubbles and gently poured into the silicone molding.

Prior to the fabrication of the photoelastic model, the original PMMA mandible was duplicated. The gingival supporting area of the edentulous mandible was delimited in the PMMA model, and a uniform 2-mm-thick wax layer was adapted. This area was molded, the wax removed, and the mold repositioned with a soft liner (Soft Confort; Dencril, Pirassununga, Brazil), which was trimmed after setting. Subsequently, this model was duplicated, and a conventional complete mandibular denture was constructed using artificial acrylic resin teeth (Biotone; Dentsply Ind. e Com., Rio de Janeiro, Brasil) and a heat-cured denture base resin (Vipi Wave; VIPI Indústria e Comércio de Produtos Odontológicos Ltda., Pirassununga, Brazil).

Six retention systems for overdentures were selected for this study (Table 1, Fig 1). The 2.0 mm height attachments were inserted into the implant and rotated into position using the specific abutment driver, and 20 Ncm torque was applied with a calibrated torque wrench. The matrices were incorporated into the intaglio surface of the dentures using a direct pick-up technique with the denture in position under light occlusal pressure. All attachments were inserted in the same photoelastic model in a random order.

A universal material testing machine (Instron Corp, Canton, MA) was used to induce the occlusal loading tests. Axial vertical loads of 70 Ncm were individually applied in two schemes: in the central incisor and in the central region of the first right molar without contact on the contralateral side. This load amount was chosen because it is within a range of normal occlusal mastication and near loads in maximal bite force of a patient in the transition from a conventional denture to an implant-retained overdenture.[27] It also provided an adequate visualization of fringes during loading, which was identified in

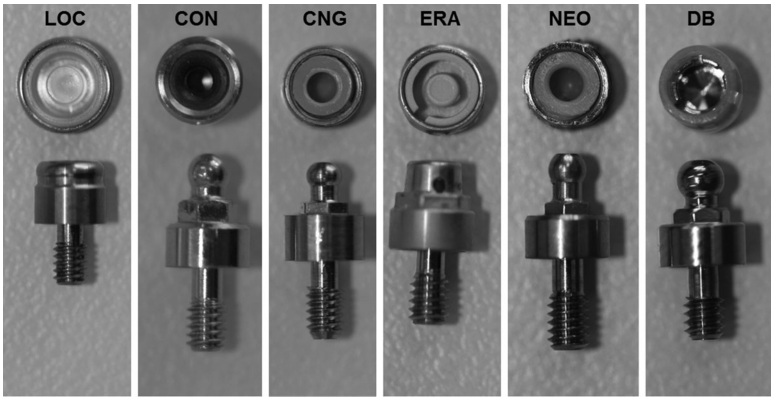

Figure 1 Retention systems: Locator (LOC), Conexão (CON), CNG, ERA, Neodent (NEO), and Dalla Bona (DB).

preliminary tests. The first molar was chosen for loading in the posterior region because maximum occlusal forces are often exerted in this area where there is maximum contraction of all elevator muscles.[21]

After each loading cycle, the model was heated to a temperature of 50°C for 10 minutes to release the stress induced within the model. Subsequently, the model was cooled to the original temperature for the same period of time at room temperature and then rechecked in the polariscope for the absence of residual stresses.[28]

The photoelastic analysis was performed using a polariscope (PS-100 Polarimeter Systems; Strainoptics Inc., North Wales, PA) integrated into the testing machine. Standard separate lateral (right and left) and frontal views were photographed using a digital camera (Canon 7D; Canon, Tokyo, Japan), perpendicular to the buccal aspect of the photoelastic model.

The polariscope was adjusted to allow linearly polarized light to be converted to circularly polarized light. Before loading, the model was analyzed to confirm the absence of any tension within the model. After each loading cycle, the model was photographed to record the stress distributions of the isochromatic fringes around the implant in the photoelastic mandible. All photographs were evaluated visually for stress-induced fringes, to comparatively rank the different attachment systems. The stress intensity (number of fringes) and location were compared subjectively. A greater number of fringes indicated greater intensity of tension, and the closer the fringes were to each other, the greater the stress concentration. Interpretation was performed using the following scale: (1) low stress—one fringe or less, (2) moderate stress—between two and three fringes, and (3) high stress—more than three fringes.[20,29]

Results

A stress-free condition was observed in the photoelastic model prior to load application. For vertical loading applied to the central incisor, all attachments showed a similar tension distribution concentrated at the apical region of the implant (Fig 2). Stress distribution patterns were similar for all attachments, with stress concentrated in the apical third, and the highest stress concentration at the apical level; however, the intensity of the load-induced stress tended to be somewhat higher with the Neodent and Dalla Bona attachments.

There was a low stress concentration at the coronal third of the implant, with no discernible stress in the first threads of the implants, except for Dalla Bona, which showed low stress at the coronal part of the implant (1 fringe). Figure 2 shows a lower number of fringes with the Locator attachment (1 fringe) and a lower spread of stress, compared to the other systems. The Neodent and Dalla Bona attachments showed a greater number of fringes (2 fringes). The Conexão, CNG, and ERA attachments showed intermediary patterns (<2 fringes).

No identifiable fringes were observed when the load was applied in the molar region, which resulted from the low amount of stress transmitted by the implant for all attachments (Fig 3). Similarly, Figure 4 shows a low concentration of stress in the posterior mucosal area for a load applied to both anterior and posterior teeth. Only one fringe was identified in the retromolar area when the load was applied to the first molar.

Discussion

This study showed a favorable concentration and distribution of stress to the implant in the single-implant mandibular overdenture, suggesting that the greatest part of the occlusal load is consistently transferred to the denture-bearing mucosa. The slight differences among different retention systems also suggest that all tested attachments may produce an acceptable level of stress to the implant and surrounding tissues.

The photoelastic experimental model is a commonly used method for stress analysis using optic principles to analyze how the fringes dissipate around implants toward the surrounding photoelastic resin body. The stress-induced fringes are visually evaluated, providing good qualitative information on the overall location and concentration of stresses.[30] However, the photoelastic analysis of implants has inherent limitations in its capacity to simulate the nonhomogeneous and anisotropic characteristics of alveolar bone, associated with certain limitations in predicting the bone biological response to applied loads,[29,30] as well as limited ability of providing a true 3D analysis, in which stress measurement is calculated using arbitrary lines of a 3D model with slicing schemes in x–y and x–z planes.[31]

Nevertheless, this photoelastic model was adequate for the experimental design of our study, depicting the comparative characteristics of stress-related outcomes for the different attachments during their activation under loading. In addition, the axial load force of 70 Ncm applied in our study was defined

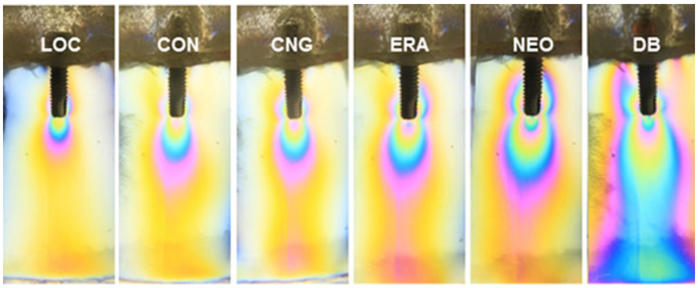

Figure 2 Stress distribution around the implant after axial loading on the central mandibular incisor, according to the retention system: Locator (LOC), Conexão (CON), CNG, ERA, Neodent (NEO), and Dalla Bona (DB).

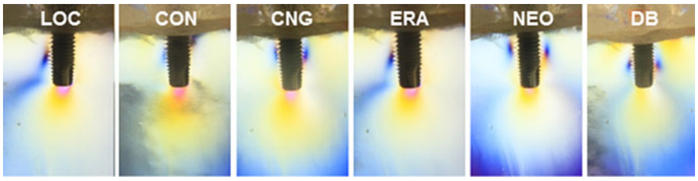

Figure 3 Stress distribution around the implant after axial loading on the central part of the first right molar, according to the retention system: Locator (LOC), Conexão (CON), CNG, ERA, Neodent (NEO), and Dalla Bona (DB).

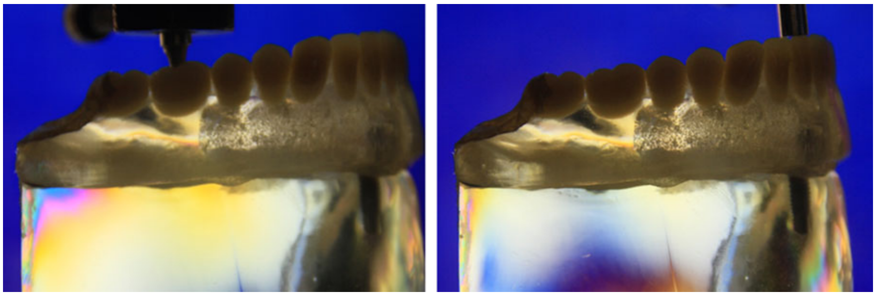

Figure 4 Stress distribution to the posterior ridge under loading to the first molar (right) and central incisor (left).

during preliminary tests, which prioritized the accuracy of the photoelastic method. When fringe multiplication is planned into photoelastic analyses, accuracy of results is improved through improved similitude of model deformations, increased sensitivity (by more than an order of magnitude), reduced risk of human error in measurement and interpretation, increased ability to discriminate between signal and noise, and availability of permanent records of fringe patterns.[32] In our study, a maximum number of three fringes was obtained, since a large number of fringes would complicate the visual analysis and comparison among attachments.

In addition, the shortcomings of the in vitro experiment should be considered. For example, bone density and morphological characteristics may have great variation in different clinical situations, and the patterns of loading in the mouth are far more complex than the application of loads in vitro. Moreover, the simulation of the thickness of the oral mucosa and its properties may change in the mouth, which affects the vertical mobility of the denture.[26]

Our study corroborates the results of Maeda et al,[24] who suggested that single-implant overdentures with dome-type magnet or ball attachments had biomechanical effects similar to two-implant overdentures in terms of lateral forces to the abutment and denture movements under functional loads. These authors hypothesized that loads applied at the midline would result in horizontal denture movements that are transformed into rotational movements around the axis through the implant, thus increasing the lateral force and decreasing denture movements. Hence, it was suggested that the midline area of the mandible might coincide with the center of the denture base in a 3D rotation, providing a biomechanical rationale for the longitudinal clinical success of a single-implant overdenture.[24] Similarly, Liu et al,[25] using FEA, found that a single-implant overdenture tends to rotate over the implant with no deleterious strain concentration around the implant.

This study reinforces the concept that a single-implant overdenture has similar biomechanical features to the conventional denture, with primary mucosal support and with the additional advantage of implant retention. Although a single implant is generally less retentive than the two-implant overdenture, patient satisfaction in clinical studies is greatly improved by increasing retention using a single implant,[7,8] with the additional advantages of lower costs and simpler clinical procedures.

The similarities of tension distribution in the different attachment systems also suggest that they would have similar performance regarding outcomes such as implant survival or marginal bone loss under comparable clinical conditions. Hence, the type of attachment may be of little significance for cases in which the patient has good bone conditions; however, several other criteria may be considered when choosing the retention system for a specific patient, such as perception of system retention, cost, repair and substitution rates, and other relevant clinical outcomes.

The significant improvement in patient satisfaction and other patient-centered outcomes, and the high implant survival rates reported in previous clinical studies corroborate the findings of this in vitro study. Nevertheless, future well-controlled clinical trials are essential to provide reliable evidence regarding the effectiveness of single-implant overdentures, and to support the recommendation of this treatment approach as an intermediary intervention between conventional dentures and two-implant overdentures.

Conclusion

Within the limitations of this study, results show that the load transferred to the implant in a single-implant mandibular overdenture was evenly distributed around the implant with low stress concentration. No discernible differences were observed among the different attachment systems.

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