

Stress Distribution Analysis at the Bone–Implant Interface Using Four Different Superstructure Materials in an Implant-retained Mandibular Overdenture: A Photoelastic Study

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ABSTRACT

Aim: To analyze and depict the stress distribution at the bone–implant interface using four different superstructure materials for an implant-retained overdenture, through a photoelastic study.

Materials and methods: The present study included construction of photoelastic models of an edentulous mandible with two implants in the parasymphseal region. On these models, the dentures were fabricated using conventional heat cure acrylic, heat cure acrylic reinforced with NiCr, heat cure acrylic reinforced with a fiber force mesh, and heat cure acrylic reinforced with PEEK. These models were then subjected to photoelastic stress analysis.

Results: The results showed a higher number of fringes in the denture fabricated with heat cure acrylic reinforced with NiCr. The fringes were better distributed in the photoelastic model with denture fabricated using heat cure acrylic reinforced with PEEK.

Conclusion: The stress distribution in the bone–implant interface is markedly improved when an acrylic resin prosthesis is reinforced with PEEK as a superstructure material.

Keywords: Cast metal, Glass fiber, Implant-retained overdenture, Laboratory research, PEEK, Photoelasticity, Polymethylmethacrylate, Superstructure.

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INTRODUCTION

Instability of dentures is the most common complaint reported by any edentulous patients with a highly resorbed mandibular foundation.¹ Complete oral rehabilitation (including dental implants) is a viable treatment option owing to its good acceptance on functional, social, and comfort aspects. However, a fixed implant prosthesis is an expensive treatment option owing to its complexity during surgical and prosthetic phases. However, using two or more implant-retained mandibular overdentures is a better treatment option when compared to the conventional complete denture in terms of the function and success rate. As per the York consensus statement, at least two implant-retained mandibular overdentures have been recommended.² Two implant-retained mandibular overdentures will result in an increased mechanical retention and stability, a better proprioception during speech and mastication, a better oral hygiene, a lower cost and also it provides a provision for converting a removable prosthesis to a fixed prosthesis.¹

However, as discovered by DuBrul and Sicher, the lateral pterygoid muscle, owing to its obliquity, exerts a compressive action on the mandible, resulting in mandibular flexure movement during mandibular opening and protrusion.³ The distal prosthetic saddles on implant supports, resulting in a wide range of stress generation in an implant-retained mandibular overdenture. During function, the biting forces increases on implant supports, resulting in increased hydrostatic stresses at the bone–implant interface, thereby causing increased bone resorption around the implant.⁴

Many studies have been conducted to determine the factors responsible for the success of an implant-retained mandibular overdenture. These factors are mandibular morphology, available bone height and width, maxillomandibular relationship, economic considerations, superstructure material, interimplant distance,

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and a patient's compliance to the treatment.⁵ For the fabrication of an implant-retained overdenture, the most commonly used superstructure material is the heat cure polymethylmethacrylate (PMMA) resin. However, owing to its increased incidence of fracture, various other reinforcing materials (such as metal, glass fibers, PEEK) have been suggested.^{6–8} However, literature is scarce in terms of comparing these reinforcing materials to one another with respect to the amount of the stress distribution at the bone–implant interface in an implant-retained mandibular overdenture.⁹

Regarding the analysis of the stress distribution at the bone–implant interface, photoelasticity is a viable and relatively easy and widely used option to simulate the clinical situation.⁸ It is an optical interference phenomenon that is caused as a result of the passage of a polarized light through a birefringent material of two refraction indices, generating fringe patterns.¹⁰ These isochromatic fringe patterns are the result of a refraction of the polarized light

owing to internal deformation caused by a stress generated in the model. The assessment of the fringe pattern will aid in determining the direction of the stress distribution along with the intensity of generated tension in the analysis area.¹¹

Hence, the aim of this study was to compare and analyze the stress distribution at the bone–implant interface using a conventional heat cure acrylic (PMMA) resin, a Ni–Cr framework reinforced PMMA resin, a fiber force (Everstick net) mesh framework reinforced PMMA resin, and a poly ether ether ketone (PEEK) framework reinforced PMMA resin for an implant-retained overdenture through a photoelastic study.

MATERIALS AND METHODS

Four photoelastic models of an edentulous mandible were fabricated using a photoelastic resin. Two standard MIS SEVEN 3.75 × 11.50 mm solid screw-type implants with platform switching were included in the parasymphseal region of the mandible with an implant distance of 16 mm and aligned perpendicular to the final occlusal plane. Ball attachments (MIS SEVEN Hex 2 mm) were placed on the implants and definitive casts were fabricated using ball attachments and tightened to 20 N cm using a manual caliper wrench (MIS) and definitive casts were fabricated for each of the four photoelastic models. The refractory cast was fabricated for the cast metal alloy framework. The framework was made in wax and the same form of framework was used for the glass-fiber-reinforced and PEEK framework. The PEEK and cast metal (Ni–Cr) framework were fabricated by the lost wax technique. Once all the three different frameworks were ready, denture bases were fabricated on all four different casts using these frameworks followed by teeth arrangement and final acrylization. Hence, we obtained four implant-retained mandibular overdentures reinforced with four different materials.

The photoelastic model with ball attachments and a prosthesis were positioned individually in a circular polariscope adapted to a universal testing machine. An axial load of 15 pounds was applied on the central fossa region of the first molar bilaterally and the stress fringe patterns were documented photographically with a digital camera (Fig. 1). The photographs were then analyzed by two calibrated observers to verify the direction and intensity of stress.

RESULTS

On application of a vertical loading, stress patterns around the implant body were studied. In the case of the conventional PMMA-implant-retained mandibular overdenture, fringe patterns obtained were found to be increased and heterogeneous (Fig. 2).

In case of the metal-reinforced PMMA implant-retained mandibular overdenture, the fringe patterns were found to be uneven, horizontal, and has a high number of fringes (Fig. 3).

The fiber-reinforced PMMA-implant-retained mandibular overdenture, on the contrary, showed homogeneous horizontal fringe patterns (Fig. 4).

In the case of the PEEK-reinforced PMMA-implant-retained mandibular overdenture, the stress fringes were homogeneous, thinner, and decreased in fringe intensity (Fig. 5).

DISCUSSION

Conventional complete dentures may often fail in providing a good retention, stability, clear speech, and masticatory efficiency.² The rehabilitation of compromised ridges using two implant-retained

overdentures has become a golden standard and it provides good retention and stability along with an enhanced masticatory efficiency. During mastication, the forces generated result in a stress at the implant–bone interface. Various studies have suggested the stress distribution in an implant-retained overdenture as a function of the implant length, diameter, geometry, and superstructure material.¹²

This study involves the use of two implants placed in the interforaminal region to support the mandibular overdenture. The flexion of an overdenture noted in this region is minimal owing to the implant supports along with ball attachments, which prevent tissue ward movement of the overdenture and thus result in reduced stresses to the underlying mucosa and at the bone–implant interface.⁵ These findings were in accordance with a study conducted by Tokuhisa et al., which suggests that ball O ring attachments in comparison to bar attachments and magnet provide a better stress distribution and reduced movements of the denture.¹³

In this study, the implant dimension chosen were 3.75 × 11.50 mm as it results in an increased implant stability.¹⁴ A vertical static load of 15 pounds was applied in the region of central fossa of the

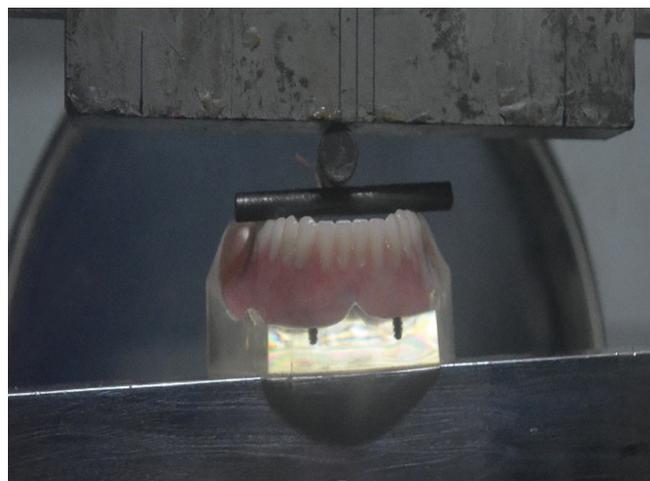


Fig. 1: A photoelastic model with a mandibular overdenture positioned individually in a circular polariscope adapted to a universal testing machine with an axial load of 15 pounds applied bilaterally to the central fossa region of the first molar

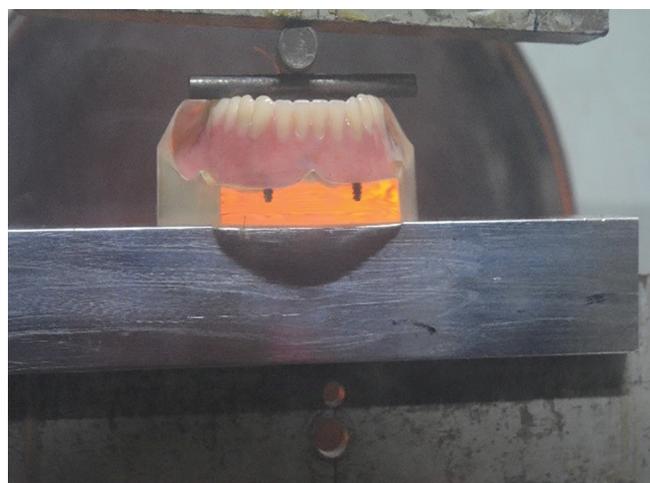


Fig. 2: A conventional PMMA-implant-retained mandibular overdenture: the fringe patterns obtained were increased and heterogeneous

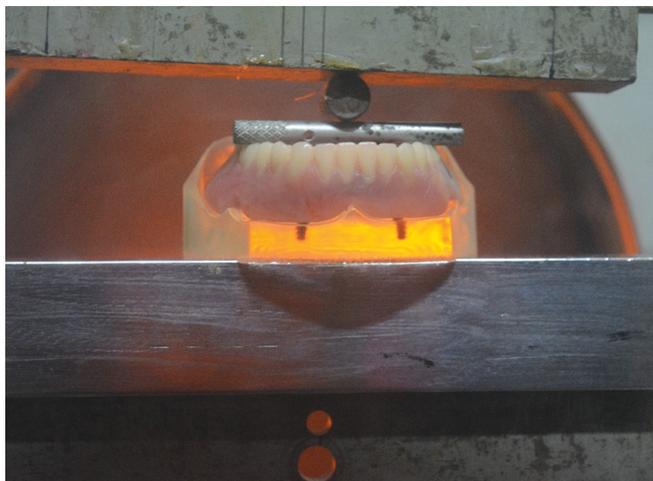


Fig. 3: Metal-reinforced PMMA-implant-retained mandibular overdenture fringe patterns obtained were uneven and increased in intensity

first molar bilaterally. According to a study conducted by Ebadian et al., maximum occlusal forces are exerted in the region of the central fossa of the first molar owing to a maximum contraction of elevator muscles.¹⁵ Haraldson and Carlsson concluded that a load of 15 pounds was used because it is the normal masticatory load and near maximal loads for the implant overdenture patients.¹⁶

The results of this study showed that the stress patterns in PMMA superstructure were uneven around the implant body. The results were in accordance with those of the study of Clunet, who suggested that PMMA is subjected to significant deformation with strong peaks of pressure because of its resistance to flex, impact, shearing, and the alternating stress is poor.¹⁷

Also, the present study suggests the metal-reinforced PMMA resin overdenture showed an increased number of uneven fringes. The results were in accordance with the study conducted by Vojdani and Khaledi, who suggested metal reinforcement increases the resistance to transverse stresses but provides limited resistance to flexural stresses.⁹ Also, Antonio Rodrigue reported similar results.⁸

This study suggests that the fiber-reinforced PMMA shows a homogeneous stress distribution owing to its better resistance to flexural and shearing stresses.¹⁷ Glass fibers improve fatigue and static loading strength of an implant-retained overdenture.

Thinner and homogeneous stress patterns were seen in the case of the PEEK-reinforced superstructure depicting reduced stresses. This may be due to the unique property of PEEK, which has a modulus elasticity of 3.84 GPa similar to that of the cancellous bone and can therefore reduce stresses transferred to the abutment teeth.¹⁸ Andreas and Wolf Dieter also suggested a PEEK-fabricated prosthesis presents a more homogeneous and reduced stress distribution to the surrounding bone.¹⁹ A study conducted by Costa-Palau et al. also suggests that the PEEK prosthesis is biocompatible, weightless, easy to polish, and results in a favorable stress distribution owing to its flexural behavior around the bone–implant interface in comparison to the conventional materials.²⁰

The photoelastic model bears the limitation of being incapable to represent the complexity of the oral biotype. All the findings have been made on the assumption that the structures are homogeneous and isotropic. On the contrary, biological field consists of bones and periodontal ligaments, which are heterogeneous, anisotropic and at a constant state of remodelling. Hence, the exact nature of stresses

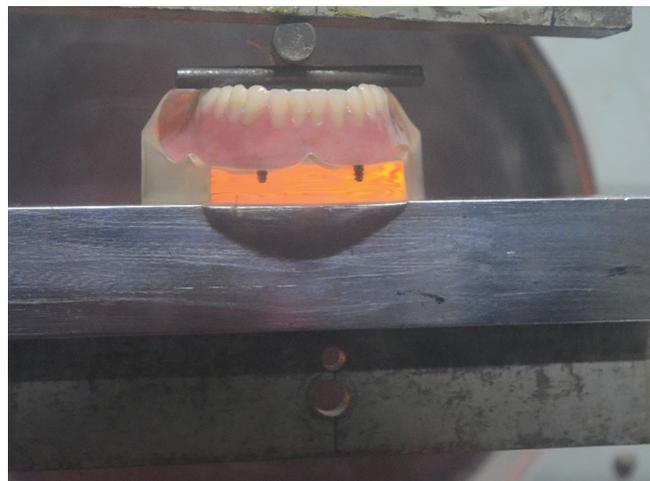


Fig. 4: Fiber-reinforced PMMA-implant-retained mandibular overdenture fringe patterns obtained were homogeneous and horizontal



Fig. 5: PEEK-reinforced PMMA-implant-retained mandibular overdenture fringe patterns obtained were homogeneous, thinner, and decreased in intensity

generated cannot be fully determined using the photoelastic model. However, it can determine the direction and intensity of stresses generated within the medium.

CONCLUSION

Fiber-reinforced and PEEK-reinforced frameworks can be used as an alternative to the conventional PMMA-implant-supported overdenture owing to their better flexural, shearing and impact resistance leading to reduced stresses at the bone–implant interface, thus leading to prosthetic success.

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