

Influence of Attachment Systems on Load Transfer of an Implant-Assisted Maxillary Overdenture

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Purpose: This photoelastic study compared the load transfer characteristics of 2 retention mechanisms in an implant-assisted overdenture prosthesis.

Materials and Methods: Four implants were incorporated into a photoelastic model of a moderately resorbed edentulous human maxilla. Two retention mechanisms were studied by changing components on the same model and the palateless overdenture. The retention mechanisms studied were bar splint with anterior clip and distal resilient attachments, and solitary ball/O-ring attachments. Loads, ranging from 1.4 to 14.4 kg, were applied to the palatal incline of central incisors and buccal incline of premolars with and without balancing contacts. Stresses developed around all the implants under each loading condition were photographed in the field of a circular polariscope.

Results: With both retention mechanisms, protrusive and laterotrusive loads without balancing contacts caused instability of the overdenture, producing minimal stress around the implants in the supporting structure. High intensity stresses indicating intrusion of the posterior implants were noted when the bar/distal resilient attachment overdenture had balancing contacts for protrusive and laterotrusive loads. The posterior implants of ball/O-ring attachment overdenture exhibited high intensity stresses indicating not only intrusion, but also bending, when the occlusion was balanced.

Conclusions: Balanced occlusion was required in both retention mechanisms for stability of the implant-assisted overdenture when clinically acceptable loads were applied. The protrusive and laterotrusive loads were not distributed equitably in either mechanism, since highest stresses occurred at the posterior implants.

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INDEX WORDS: occlusion, photoelastic analysis, stress distribution

THE IMPLANT-ASSISTED overdenture is the treatment of choice for many patients with edentulous maxilla. In comparison to fixed hybrid prostheses, lip support, phonetics, and access for hygiene are facilitated with the maxillary overdenture. Two or four implants are usually planned for overdentures. Palatal coverage can be reduced if soft tissue support is not needed. Various methods

have been proposed for connecting overdentures to underlying implants. Independent connections to each implant abutment or continuous bar retainers are the most common approaches. In either case, retention and stability are provided primarily by implants through attachments, and support is shared by implants and edentulous posterior ridges.¹

Load transfer characteristics of various retentive devices, together with 2 different supporting structures, present a complex load distribution situation in overdenture function. An in vitro study by Ichikawa et al suggested that the difference between the displacement of the implants and the soft tissue causes stress concentrations around the implants.² The number and distribution of implants, as well as prosthetic design of the overdenture, affect the loading of implants and supporting bone.

Overdentures supported by a few implants appear to be highly successful in the edentulous mandible.³ In contrast, treatment outcomes

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Accepted April 20, 2004.

Presented in part at 78th General Session of International Association for Dental Research, April 2000, Washington, DC.

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1059-941X/04

doi: 10.1111/j.1532-849X.2004.04041.x

with maxillary overdentures seem to be less predictable.⁴ Goodacre et al recently reviewed clinical implant studies and reported that the highest failure rate (21.3%) for any type of prosthesis occurred with maxillary overdentures.⁵ The lower success rates have been attributed primarily to the quality of bone in edentulous maxilla, since a looser arrangement of trabecular bone with a thin, or even absent, cortical plate is generally considered to be less capable of stabilizing and supporting implants.^{6,7} The retentive components transfer loads to implants and supporting bone. The nature of this force transmission is not well documented. In a prospective clinical study Bergendal and Engquist showed more implant loss with ball retained overdentures (38.8%) than with bar retained overdentures (20.6%). Significance of these findings was not tested, but the authors proposed that optimization of individual loading conditions with different attachments may contribute to a higher survival rate.⁸

The choice of retention mechanism in planning the overdenture might be critical in promoting equitable load transfer within the maxilla. The purpose of this study was to compare the load transfer to the underlying bone when 2 retention mechanisms are used with an implant-assisted maxillary overdenture prosthesis.

Materials and Methods

A model of an edentulous maxilla with moderate residual ridge resorption was fabricated utilizing a photoelastic resin (PLM-1, Measurements Group, Raleigh, NC). PLM-1 simulated the edentulous maxillary bone, which is anatomically characterized as thin cortical bone covering cancellous bone. The elastic modulus of the bone tissues and the corresponding property of the photoelastic simulant are presented in Table 1. The resin simulant with its elastic modulus represents a composite value for the natural bone tissues in relation to anatomic distribution of cortical and cancellous bones. Four 13 × 3.75 mm threaded titanium implants (Implant Innovations Inc., Palm Beach Gardens, FL)

Table 1. Elastic Modulus Values for Bone Tissues⁹ and Simulant

	<i>Elastic Modulus (GPa)</i>
Cortical	14.0
Cancellous	1.4
Simulant (PLM-1)	2.9

were embedded in the maxillary model, representing complete integration. Anterior implants were located in the canine tooth positions and posterior implants were at the second premolar positions.

Two retention mechanisms were studied. These were bar-ERA [Hader bar splinting 4 implants and an anterior clip (Centraux-Metalex, Bienne, Switzerland) with 2 distal resilient cap attachments (ERA-orange color/moderate retention, Sterngold-ImplaMed, Attleboro, MA)] (Fig 1) and the O-ring [4 individual ball/O-ring attachments (Implant Innovations Inc., Palm Beach Gardens, FL)] (Fig 2).

Baseplate wax, approximately 2 mm thick, was adapted to the edentulous areas of the model to represent the thickness of the soft tissue. An impression was made incorporating implant components for the fabrication of the bar and the overdenture. A dental stone (Denstone, Heraeus Kulzer, Armonk, NY) cast was fabricated with implant analogs. Direct connection of the implant to the abutment was established using UCLA abutments (Implant Innovations Inc., Palm Beach Gardens, FL). The Hader bar assembly consisted of 4 implants with 2 distal ERA attachments. The passive fit of the bar was confirmed through tightening one screw and observing the full seating at the other 3 implant-abutment interfaces. When passivity of fit was not seen, the bar was sectioned and soldered until no movement occurred, while one screw was placed in any of the prosthetic cylinders and tightened to 10 Ncm. The overdenture was fabricated through conventional dental laboratory techniques using polymethyl methacrylate material (Lucitone 199, Dentsply International, York, PA). Part of the buccal flange and corresponding palatal area in the overdenture were removed to provide an unobstructed view of the implants in the photoelastic model. Metal inlays were placed at the palatal inclines of the central incisors and the buccal inclines of the



Figure 1. Photoelastic model with splinted bar-ERA attachment system.

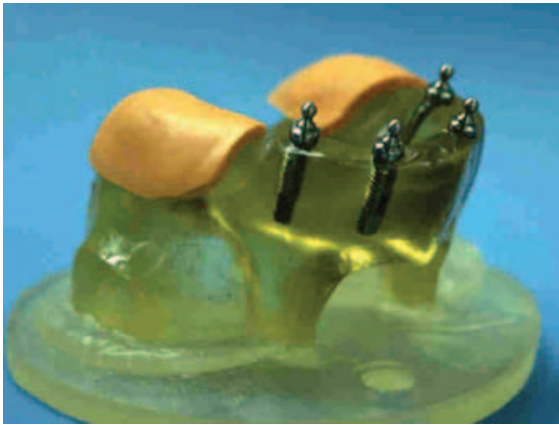


Figure 2. Photoelastic model with solitary O-ring attachments.

premolar teeth to establish loading contacts. The space beneath the denture, provided by the baseplate wax, was filled with a light body silicone impression material (Reprosil, Caulk/Dentsply, Milford, DE) to simulate the resiliency of the oral mucosa.

The model was mounted on an acrylic resin base, which was secured to the bottom center of a circular oil bath. By immersing the model in a tank of mineral oil, surface refraction was minimized, and photoelastic observation was facilitated. The overdenture was sequentially fitted with each retention mechanism and placed on the model with corresponding components. Axial loads from 1.4 to 14.4 kg in an increasing order of 0.1 kg were applied at the inclines of the central incisors and premolars. Two static stops were placed at 1 mm above the molars to establish simulated balancing contacts (Figs 3 and 4). The den-

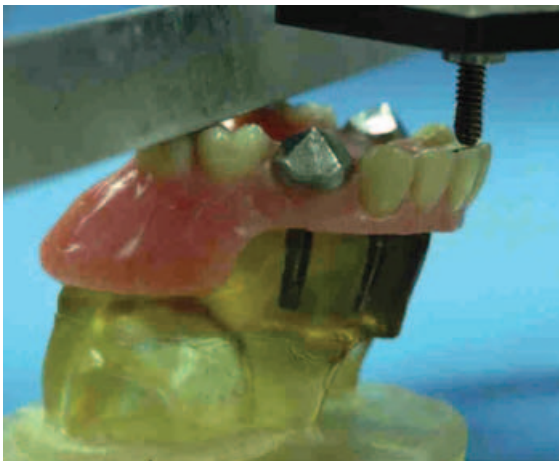


Figure 3. Protrusive loading of the overdenture with simulated bilateral posterior balancing contacts.

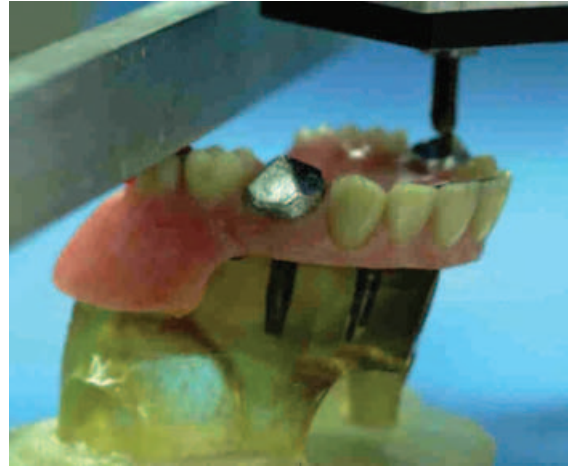


Figure 4. Laterotrusive loading of the overdenture with simulated unilateral non-working balancing contact.

ture was subjected to simulated protrusive and laterotrusive loads with and without contralateral balancing contacts. Loads were applied in a loading frame by means of a calibrated load cell mounted on the movable head of the frame and monitored by a digital read-out (Model 2130 and 2120A, Measurement Group, Los Angeles, CA). The minimum loads that caused the instability were recorded for each retention mechanism.

Photoelastic stress analysis is based on the property of some transparent materials to exhibit colorful patterns when viewed with polarized light. The patterns that develop as a result of applied loads are related to the distribution of stresses within a model. In this study, the stresses developed in the photoelastic maxillary model under load were observed and photographed in the field of a circular polariscope. Each loading and observation sequence was repeated 2 times to ensure reproducibility of results. Three separate views of the model (right posterior, anterior, and left posterior) were recorded for each loading configuration. The views were oriented perpendicularly to the buccal surface of the maxilla in the center of the view. Observations of fringe patterns due to the various loading configurations were made on scanned data photographs, which were subsequently viewed with a computer graphics program (Photoshop 4.0, Adobe Systems, Inc., San Jose, CA). The stress intensity (number of fringes) and their locations were subjectively compared. In the interpretation of the stress data, the following terminology has been adopted (Fig 5):

- (1) Low stress—1 fringe or less
- (2) Moderate stress—between 1 and 3 fringes
- (3) High stress—more than 3 fringes

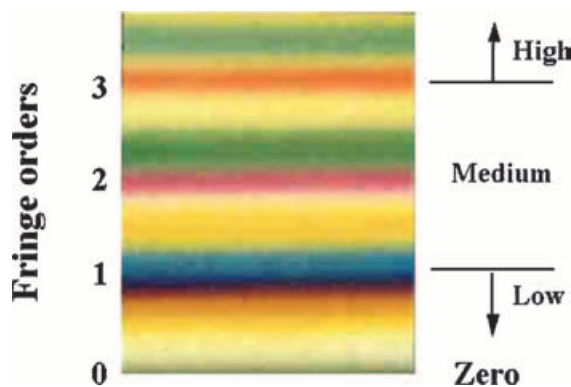


Figure 5. Relation between stress level and fringe order used to describe results.

Results

Examination of the photoelastic model prior to testing revealed an essentially stress-free condition. This condition was maintained after the placement of retention mechanisms and the overdenture at each testing condition. Therefore, stresses observed in the model were induced by the applied loads only. Loading on the right and left side produced similar fringe patterns; therefore, only the results from the right side are presented.

Loads Without Balancing Contacts

Protrusive loads produced instability at 4.6 kg for bar-ERA design and at 1.4 kg for O-ring design. Laterotrusive loads caused instability at 2.3 kg for bar-ERA and 4.6 kg for O-ring. Under these conditions, low level stresses were observed around the implants. The instabilities were eliminated with simulated balancing contacts through bilateral molar contacts in protrusive, and contralateral molar contact in laterotrusive.

Protrusive Load with Balancing Contacts

Load transfer from the palatal incline of the central incisors to the supporting structure produced similar stresses with both retention mechanisms. Low-level stresses were developed at the crestal supporting areas of the anterior implants (Figs 6A and 7A). Increased stresses were noted at the apical portions of the posterior implants in both retention situations, indicating intrusion and distal bending of the posterior implants. With the

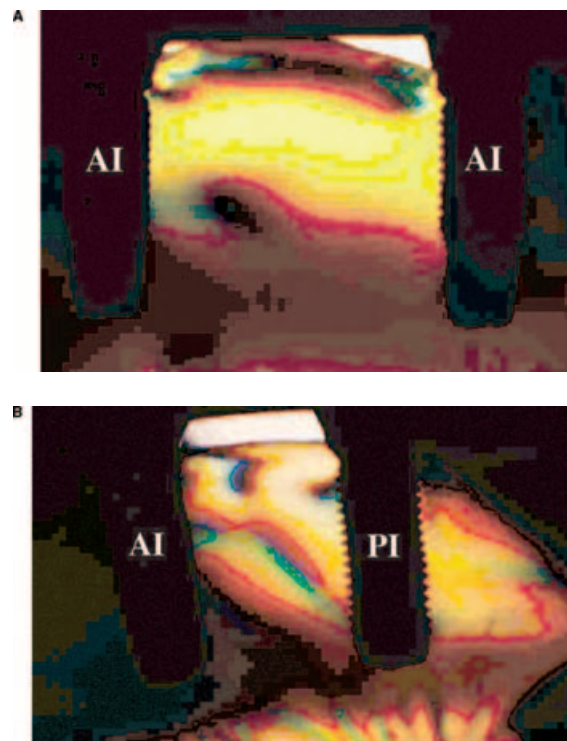


Figure 6. Bar-ERA system under 14 kg protrusive loading: (A) Low-level stresses were produced at the crestal supporting areas of anterior implants (AI); (B) Increased stress along with intrusion and bending occurred at the posterior implant (PI).

bar-ERA system, higher intensity of stresses was noted at the posterior implants (Figs 6B and 7B). Both attachment systems transferred comparable low-level stresses to the distal edentulous ridges.

Laterotrusive Load with Balancing Contact

Stress levels and locations varied with each attachment system when loads were transferred from the buccal incline of premolars to the supporting structure. Low-level stress around the non-working side posterior implant was noted with the bar-ERA overdenture, indicating limited cross-arch interaction. With the O-ring overdenture, stresses indicating mesial-palatal bending were evident on the non-working side posterior implant. Low stress was transferred to the anterior implants with the bar-ERA retained overdenture. The stress on the non-working side anterior implant experienced a palatal and distal bending (Fig 8A). In the case of the O-ring mechanism, elevated stress and stress interaction between

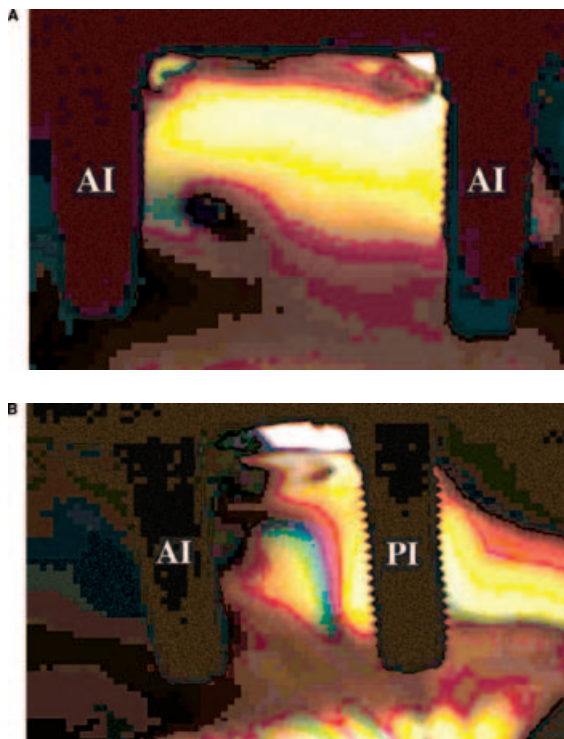


Figure 7. O-ring under 14 kg protrusive loading: (A) Low level stresses were produced at the crestal supporting areas of anterior implants (AI); (B) Intrusive high-level stresses occurred at the posterior implant (PI).

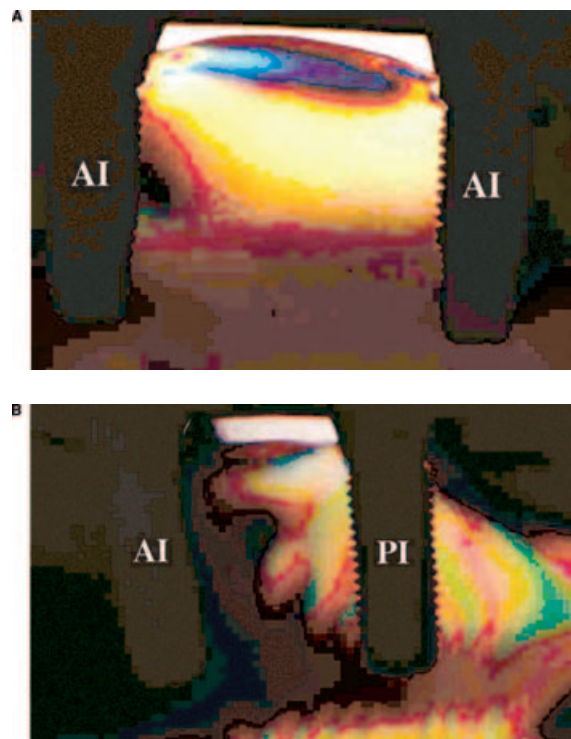


Figure 8. Bar-ERA system under 14 kg laterotrusive loading: (A) Mild stresses were produced at the anterior implants (AI); (B) High-intensity intrusive stresses occurred at the working side posterior implant (PI).

anterior implants were noteworthy (Fig 9A). Highest stresses occurred at the posterior implants of the loaded side (working) with both systems. With the bar-ERA design, the working side posterior implant developed stresses along the long axis indicating intrusion (Fig 8B); however, the working side posterior implant with the O-ring design underwent intrusion and mesial bending, with somewhat lower maximum stress levels (Fig 9B). Stresses at the non-working side distal edentulous ridges were very low in either retention situation; however, stresses at the working side distal edentulous ridges were mild and somewhat higher with O-ring than those seen with bar-ERA.

Discussion

There are a variety of retentive mechanisms available for attaching an overdenture to implants. The complication-free survival of this treatment modality in maxilla may depend on load transfer from attachment to implant, and its effect on the underlying bone to implant interface. This study

investigated the stress within the bone associated with the splinting of implants, and compared these stress patterns when implants were not splinted.

Protrusive and laterotrusive loads under 4.6 kg caused instability of the overdenture, while low level stresses were observed around the implants. Removing part of the buccal flange for viewing purposes might have negatively impacted the stability of the overdenture. The findings of this study are similar to those of Federick and Caputo;¹⁰ in that study, similar retentive mechanisms were assessed with similar results. It may be suggested that balanced occlusion might be necessary when these systems are used.

When protrusive loads with balancing contacts were applied, both retentive devices transferred loads in a similar way. All the implants shared the load in each case; however, posterior implants exhibited distal bending, which might be due to the balancing contacts. When the low frequency and magnitude of the incisive loads are considered, implants may not be subject to detrimental loads with either attachment

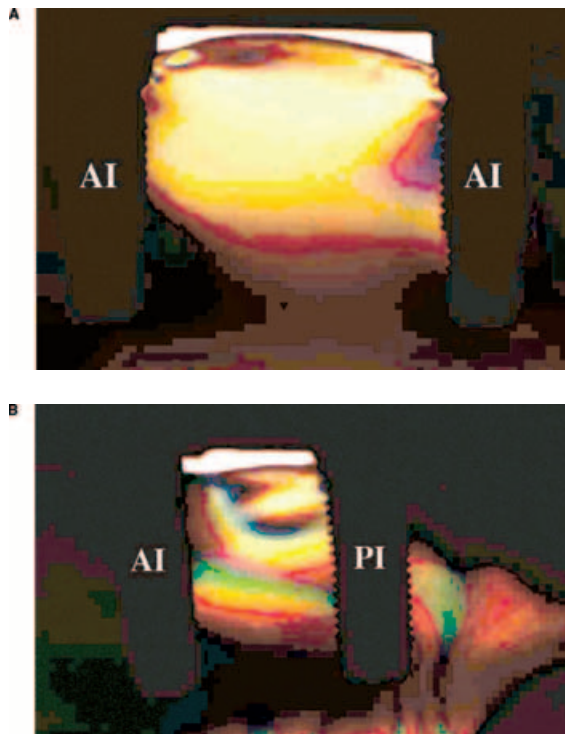


Figure 9. O-ring under 14 kg laterotrusive loading: (A) Low level stresses with some bending were produced at the anterior implants (AI); (B) Working side posterior implant (PI) was subjected to elevated intrusive stresses along with bending.

system during protrusive loads, but if high forces are anticipated, the situation must be carefully considered.

Laterotrusive loads with balancing contacts were used in simulated chewing motion throughout this study. Transferred loads differed for each system. O-ring design caused stresses around all the implants with some level of bending, and the magnitude of stress and bending was higher at the loaded posterior implant. Bar-ERA design produced a considerably lower level of stress at the non-working side posterior and anterior implants, compared to working side posterior implant. The bar-ERA also transferred considerably less stress to the loaded side distal edentulous ridge, compared to O-ring.

Even though O-ring involved all the implants in load sharing, the observed localization of stresses accompanying bending might be a concern. Clinical reports suggest that solitary attachments like O-ring are associated with a tendency for continuing bone loss.^{11,12} This may be explained by the

bending stress observed in this study. In contrast, Palmqvist et al¹³ could find no predictive value for implant failure for a variety of superstructures that included both bars and non-splinted attachments. In the case of bar-ERA, overloading the posterior implants might occur, and longevity may be jeopardized with high frequency and magnitude of chewing loads in the posterior. Clinical data suggests that implant-assisted maxillary overdentures have the highest late failure rate (10.5%);¹⁴ however, the location of implant failures in relation to retention mechanism was not stated. The present study suggest that all the implants attached through the O-ring system might be vulnerable for loss, where failure might more likely occur at the posterior implants in the bar-ERA system.

The photoelastic modeling system used in this study—as with all modeling systems, including finite element analysis, mathematic models, or strain-gauge studies—has limitations when predicting the response of biologic systems to applied loads. However, all these systems can indicate, under carefully controlled conditions, where potential stress-related difficulties may arise. The results of the photoelastic information obtained in the present investigation can help the clinician by providing guidelines for the use of attachment systems in implant overdentures. As always, this information should be used in conjunction with sound clinical judgment.

Conclusions

This in vitro study compared the load transfer characteristics of 2 retention mechanisms in an implant-assisted overdenture in maxilla. The results lead to the following conclusions:

1. Instability of the overdenture occurred in both retention cases when protrusive and laterotrusive loads under 4.6 kg were applied, and simulated balancing contacts had to be established to apply loads at clinically acceptable levels.
2. The protrusive loads were better distributed among the implants than the laterotrusive loads with both retention mechanisms.
3. The O-ring system transferred bending forces to the implants under laterotrusive loads, especially to the loaded posterior implant.

4. The bar-ERA system transferred high level stresses to the loaded posterior implant during laterotrusive loading.
5. Higher stresses were observed with the O-ring system under laterotrusive loads at the distal edentulous ridge.

Acknowledgment

This study was partially supported by Implant Innovations Inc., Palm Beach Gardens, FL.

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