

# Effects of overdenture retention designs and implant orientations on load transfer characteristics

David R. Federick, DMD, MScD,<sup>a</sup> and Angelo A. Caputo, PhD<sup>b</sup>

University of Texas Dental Branch, Houston, Tex., and University of California at Los Angeles, School of Dentistry, Los Angeles, Calif.

Various approaches have been used for the retention and stabilization of implant-supported overdentures. This study examined photoelastically the simulated load transfer characteristics of a resilient cap attachment with moderately atrophied mandibular plastic models with two implant orientations. Comparison was made with overdentures supported by a splinting bar and a bar with distal resilient cap attachments. Stress patterns developed by simulated occlusal loading demonstrated little cross-arch load sharing and more uniform stress distribution with noninclined implants for all retention designs. The most equitable simulated occlusal force transfer was provided by the resilient cap attachments direct to the implants. (*J Prosthet Dent* 1996;76:624-32.)

Removable prosthesis designs that incorporate osseointegrated implants provide the edentulous patient with alternatives to mucosa-supported complete dentures.<sup>1</sup> An effective approach is the implant-supported overdenture, which offers improved retention, stability, function, proprioception, and comfort.<sup>2,3</sup>

Implant receptor site options in the resorbed edentulous mandible are often limited to the anterior sector, particularly in the region of canine and first premolar teeth. Various alternatives have been advocated for retaining overdentures to implants,<sup>4</sup> including splinting bars, attachments,<sup>5</sup> and combinations of bars and attachments.<sup>6-8</sup> Difficulties encountered with some systems include fabrication complexity, multiple intraoral steps, and postinsertion maintenance.<sup>9,10</sup> A recently developed attachment includes a resilient cap design that purports to alleviate some of these difficulties.<sup>11,12</sup>

All the retention approaches distribute occlusal forces through the overdenture to the implants and the posterior edentulous ridges.<sup>13</sup> The degree of load sharing that occurs depends on the specific system used.<sup>13,14</sup> An ideal condition would exist if the load were shared so that no area would be overloaded. Because this ideal condition is probably unattainable, designs that tend to provide the most equitable load transfer would be preferred.<sup>15</sup>

The purpose of this study was to determine photoelastically the load transfer characteristics of implant-supported overdentures with resilient cap attachments, resilient cap attachments on a bar splinting the two implants, and a bar alone. Two implant angulations were studied.

## MATERIAL AND METHODS

Two photoelastic models of a moderately atrophied edentulous mandible were fabricated. The configura-

<sup>a</sup>Clinical Associate Professor, Department of Fixed Prosthodontics, University of Texas Dental Branch.

<sup>b</sup>Professor and Chairman, Biomaterials Science Section, University of California at Los Angeles, School of Dentistry.

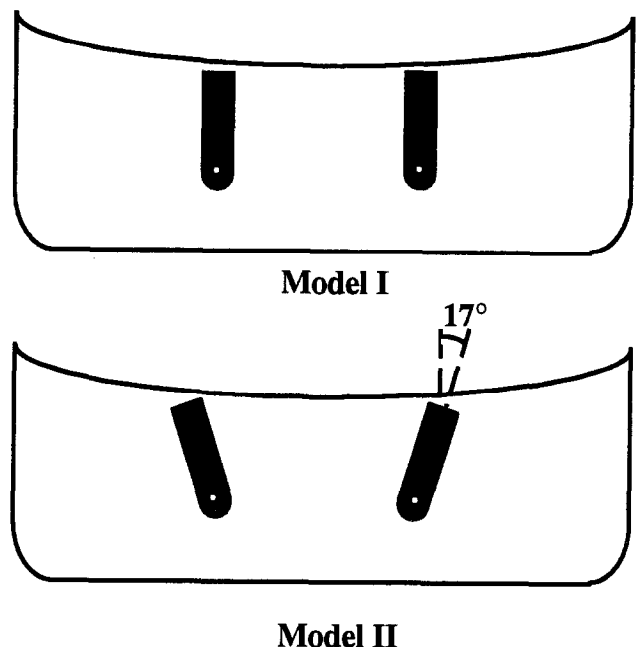
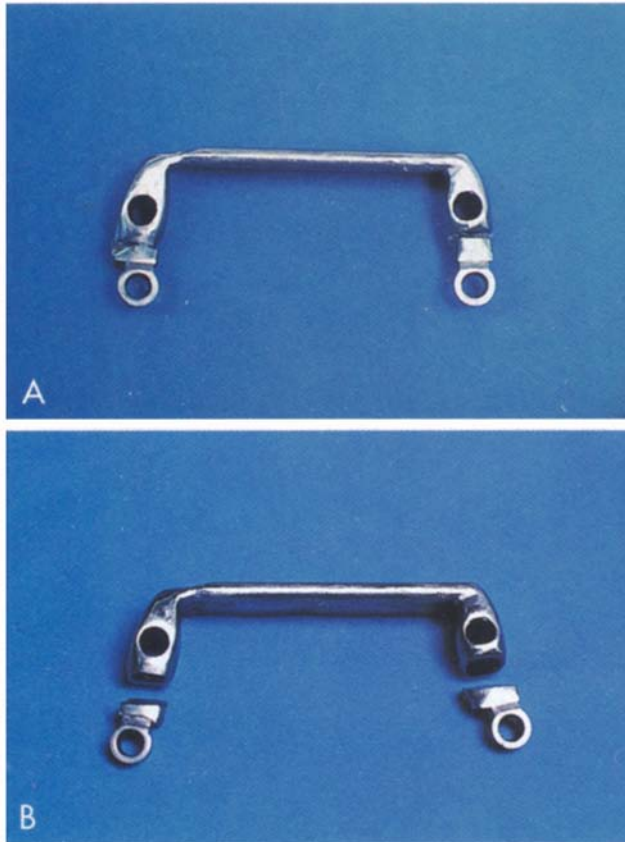


Fig. 1. Diagrammatic representation of implant orientations in photoelastic models I and II.

tion of the arch was adapted from a mandibular impression of an edentulous patient. With the aid of the accompanying patient radiographs, the cast was modified to simulate only the osseous structure. A silicone mold of this modified cast was made from which the photoelastic models were constructed. Each model incorporated two Calcitek implants (Calcitek Inc., Carlsbad, Calif.), 4 mm diameter and 13 mm long, located in the canine–first premolar region. In one model the implants were vertical (parallel to the midline); in the second model the implants were 17 degrees divergent from the midline (Fig. 1). The crestal exit locations of the implants were the same for both models. The bone simulant plastic (PL-2, Photolastic Division, Measurements Group, Inc., Raleigh, N.C.) was cast di-



**Fig. 2.** Hader bar retention configurations. **A**, Bar casting with distal ERA-RPD attachments. **B**, Bar casting with attachments removed.

rectly around the implants to represent the condition of complete “integration.”

Three overdenture retention designs were studied for each implant orientation. For each model the first design included a Hader bar (Centraux-Metalex, Bienne, Switzerland). The Hader bar connected the two implants in combination with distally placed ERA (resilient cap) removable partial denture (RPD) attachments (ERA-RPD, Sterngold-ImplaMed, Attleboro, Mass.) (Fig. 2, A). The second design was the Hader bar alone, which was obtained by removing the ERA attachments (Fig. 2, B). The final design used ERA direct overdenture implant abutments (ERA-OD). For the model with the divergent implants, alignment correction ERA abutments were used (Fig. 3). The designs are summarized in Table I.

Baseplate wax, approximately 2 mm thick, was adapted to the posterior edentulous areas of both models to represent the thickness of the soft tissue. Transfer copings were attached to the implant abutments and impressions of the models with the wax spacer were made with a combined light- and heavy-bodied impression technique (Reprosil, Caulk/Dentsply, Milford, Del.). Abutment analogs were attached to the transfer copings and resealed into the impression before pouring in improved dental stone. The overdentures were fabricated to these



**Fig. 3.** Inclined implants with 17-degree ERA overdenture abutments.

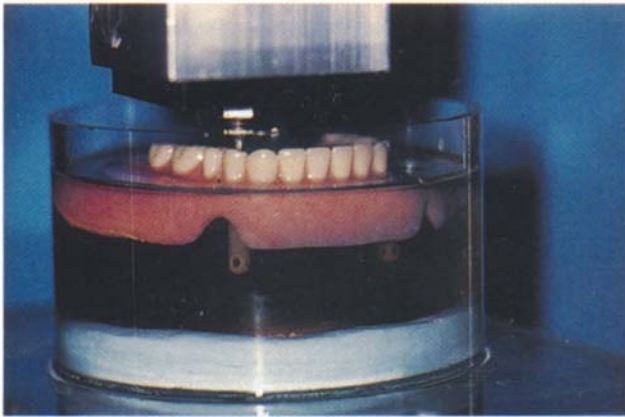
**Table I.** Model configurations

Model	Implant orientation	Hader bar	ERA attachments
IA	Vertical	Yes	RPD
IB	Vertical	Yes	None
IC	Vertical	No	OD
IIA	17-Degree divergent	Yes	RPD
IIB	17-Degree divergent	Yes	None
IIC	17-Degree divergent	No	OD

stone casts by use of conventional dental laboratory techniques. For the retention designs with the Hader bar, a single metal clip was located in the overdenture midway between the two implants. The relationship of the clip to the Hader bar was not altered between the two designs (Table I). The space beneath the dentures, provided by the baseplate wax, was filled with a light body silicone impression material to simulate the resiliency of soft tissue.

The overdentures were fitted sequentially with each of the attachment conditions listed above. The denture with each of the attachments (white, least-retentive nylon keys) was placed on the photoelastic model and subjected to simulated occlusal loads. Loads were applied in a straining frame by means of a calibrated load cell mounted on the movable head of the frame. Loads were monitored by a digital readout after signal treatment with a strain gauge conditioner (models 2130 and 2120A, Instruments Division, Measurements Group Inc.). Unilateral vertical loads up to 30 pounds were applied to each side of the arch at the following locations: directly over the implant (at the first premolar), at the second premolar, and at the second molars. A bur was used to make small indentations in the center of the denture teeth at these locations to facilitate reproducible load application.

The model was immersed in a tank of mineral oil to minimize surface refraction and thereby facilitate



**Fig. 4.** Test setup: photoelastic model with overdenture immersed in mineral oil. Load being applied to denture over implant.

photoelastic observation (Fig. 4). The resulting stresses in all areas of the supporting "bone" were monitored and recorded photographically in the field of a circular polariscope arrangement.

## RESULTS

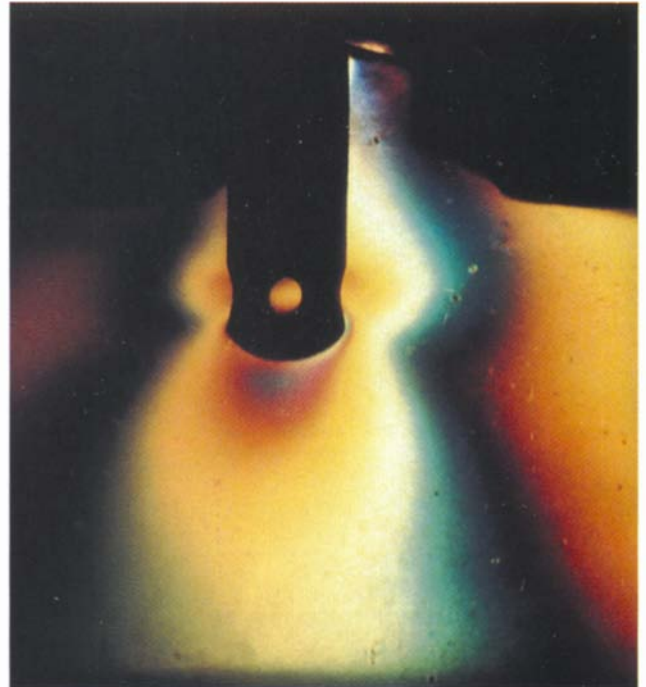
Examination of the two models after curing of the photoelastic bone simulant revealed an essentially stress-free condition. The Hader bar castings with distal ERA-RPD keyway components were secured to the implants in the photoelastic models with gold retention screws. The models were again examined and no induced stress was revealed. Placement of the dentures on the models did not impose stresses within the simulated supporting bone.

For each implant orientation and abutment condition, unilateral loading of one side of the arch produced stresses in the supporting structure beneath the load and contralaterally. These stresses were similar to those generated in comparable locations with the loads applied to the other side. Consequently, results will be described for loads applied to the right side only.

Under certain loading conditions instability was observed in the form of lifting of the contralateral side of the denture. For each implant orientation and abutment condition, this instability was observed when the load was applied over and just distal to the implant. The instability occurred at approximately 2 to 7 pounds. As the point of load application was moved distally, the load at which instability became evident increased until no denture lift was noted at a 30 pound test load applied at the first molar. In all cases anterior loads produced instability almost immediately (1 to 2 pounds). Consequently, no stress observations on the contralateral side were noted.

### Load above implant

**Vertical implants.** The transfer of stress to the supporting structure for the situation of bar and ERA at-



**Fig. 5.** Load applied above right implant for model IA (view of loaded side).

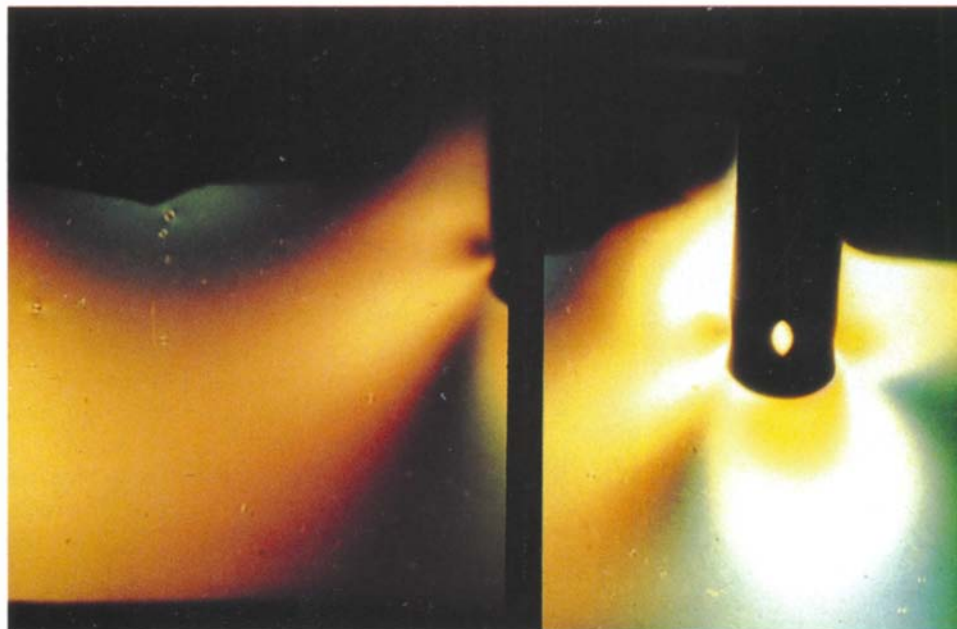
tachments (model IA) was primarily along the implant axis, with stress localized at the apex (Fig. 5). The stress along the mesial surface of the implant was somewhat more intense. Little transfer of stress to the edentulous ridge was noted.

Removal of the ERA attachments (model IB), leaving only the bar, resulted in a fairly symmetric stress distribution about the implant apex (Fig. 6), although there was some concentration of stress along the mesial aspect of the implant. Increased rotation of the denture around the bar occurred, as evidenced by the greater stress generated beneath the denture base.

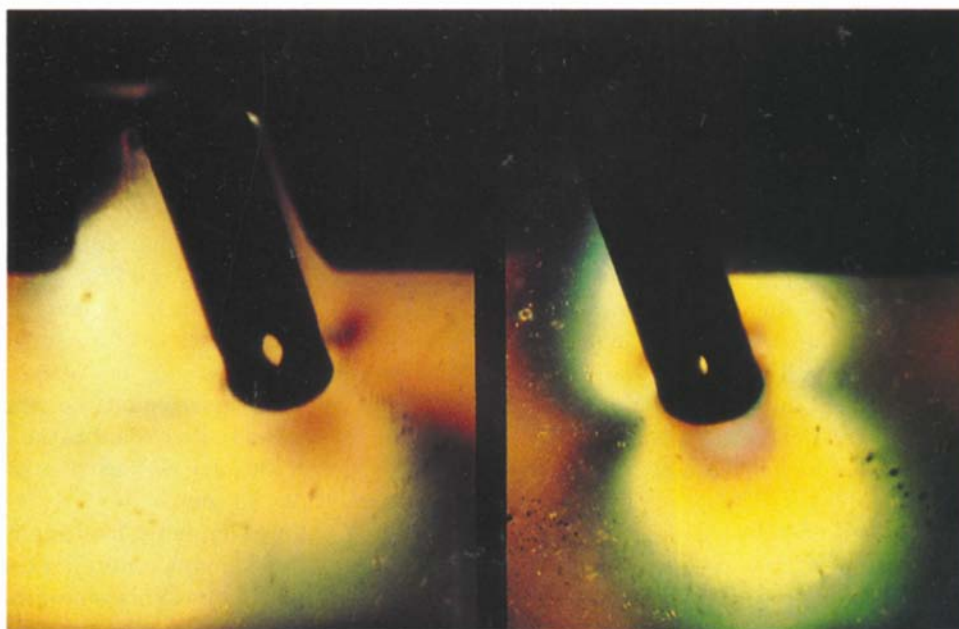
With the ERA-OD attachments alone (model IC), the primary transfer of stress to the supporting structure on the loaded side occurred apically and at a lower level than for model IA. Some low-level stress was noted along the mesial aspect of the implant. Transfer of the load to the posterior region was limited and uniformly distributed.

**Inclined implants.** With a 30 pound load applied above the inclined implants of models IIA and IIB, the stresses developed in the supporting bone were similar. The stresses were localized near the implant, with the distal aspect of the implant under the load being more heavily stressed than the mesial surface (Fig. 7, left). Little posterior stress activity was noted in both models.

With the ERA-OD attachments (model IIC), the stress field was almost symmetrically distributed about the implant, with somewhat higher stress localized apically than for models IIA and IIB (Fig. 7, right). Again, little posterior activity was noted.



**Fig. 6.** Load applied above right implant for model IB. *Left*, Posterior view of loaded side; *right*, view of implant on loaded side.



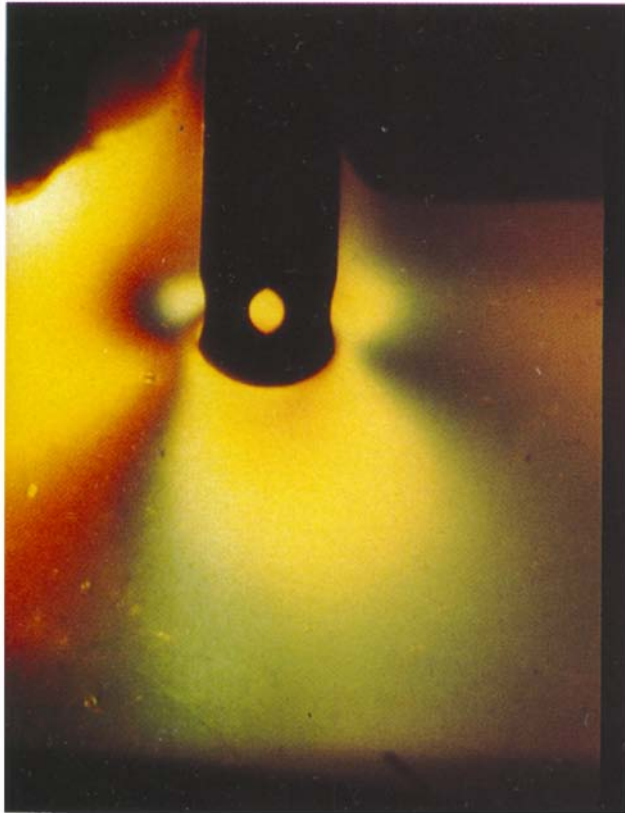
**Fig. 7.** Load applied above right implant for models IIA and IIB, *left*, and IIC, *right*. View of loaded side.

### Load at second premolar

**Vertical implants.** The load applied at the second premolar with the bar and ERA-RPD attachments (model IA) produced stresses that were almost symmetric about the implant axis (Fig. 8). However, the stress along the mesial surface of the implant was slightly higher than on the distal side and extended more toward the crest.

The greatest stress developed at the implant apex. Low-level stresses were observed posteriorly beneath the denture base.

For model IB the load applied at the second premolar generated stresses located primarily along the mesial aspect of the implant and apically (Fig. 9, *right*). Additionally, stress was localized at the mesial surface of the



**Fig. 8.** Load at second premolar for model IA. View of loaded side.

implant close to the apex. Posterior rotation of the denture around the bar caused transfer of load to the posterior ridge (Fig. 9, left).

The load applied at the second premolar for model IC produced apical stress that was almost symmetric about the implant axis. However, the stress along the mesial surface of the implant was somewhat higher than along the distal side and extended more toward the crest. Stresses observed posteriorly beneath the denture base were uniform and somewhat higher than for loading at the implant site.

**Inclined implants.** For model IIA the implant on the loaded side was more heavily stressed along the distal aspect than on the mesial (Fig. 10). The greatest stress was seen apically. Low-level stress activity was observed below the denture base. Loading model IIB produced stress within the supporting structure similar to that observed with model IIA.

For model IIC there was rotation of the denture, which induced stresses beneath the denture base and a symmetric stress distribution around the implant axis (Fig. 11). The greatest stress occurred at the apex of the implant.

### Load at second molar

**Vertical implants.** With the load applied at the second molar, no significant differences were evidenced be-

tween the three retention configurations. The representative load transfer pattern is illustrated in Figure 12 for model IA. It can be seen that low-level stresses developed at the implant, with mesial-apical stress localized at the implant. The stresses at the implant were reduced compared with more anteriorly placed loads. The major transfer of the force to the supporting bone was accomplished through the posterior denture base.

**Inclined implants.** For all three models the major transfer of the force to the supporting bone occurred through the denture base (Fig. 13). The stresses at the implant were reduced compared with more anteriorly placed loads. This latter effect was somewhat more pronounced with the ERA-OD attachments.

For each implant orientation the differences in the load transfer characteristics of the three retention configurations diminished when the load was applied more posteriorly.

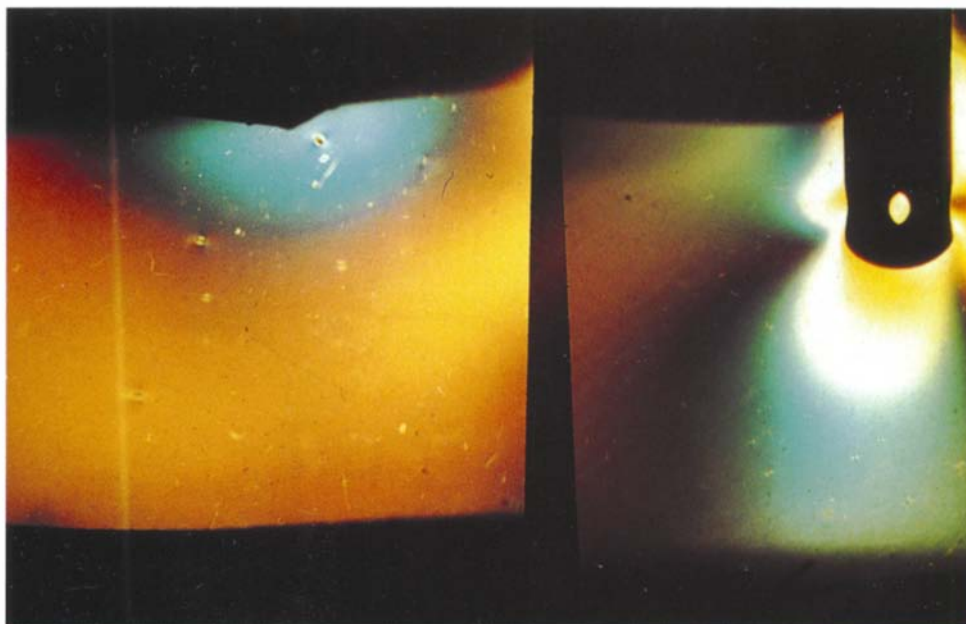
## DISCUSSION

Implant-retained overdentures provide edentulous patients with an option to conventional complete dentures. Various retentive devices are available to attach the overdenture to the implants. The load transfer mechanisms of these devices are critical to the success and longevity of this treatment modality. This study investigated various combinations of bar and clip and resilient cap retentive devices.

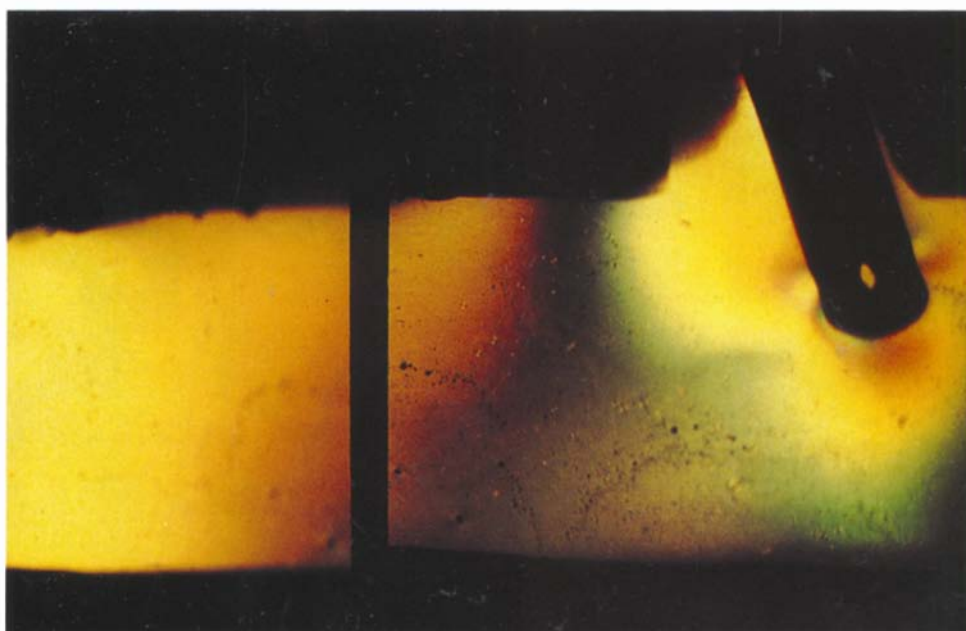
For vertical orientation of the implants, load applied directly over one of the implants produced the most stress in the supporting structure in the vicinity of the loaded implant. With the Hader bar and ERA-RPD combination the distal location of the ERA attachment relative to the axis of the implant led to increased stress localized along the distal surface of the implant. This effect was reduced with the Hader bar alone. However, with the direct ERA-OD attachment the force transfer was primarily symmetric with respect to the implant. Only a small portion of the force was distributed to the denture base for all three designs.

With the inclined implants, load applied directly over one of the implants again produced the most stress distal to the loaded implant. This concentrated stress distal to the loaded implant was pronounced with the combination of the Hader bar and ERA-RPD attachment and with the Hader bar alone. When the ERA-OD attachment was used, this distal stress was reduced, with the stress distributed in an almost symmetric manner around the implant. Minimal posterior sharing of the load was observed with all three retention configurations.

With vertical implants, more posterior load application led to an increased proportion of the load distributed to the denture base and a concomitant reduction of the stresses at the implant. There was some distal stress observed at the implant with all three retention configura-



**Fig. 9.** Load at second premolar for model IB. *Right*, View of loaded side implant; *left*, view of loaded side posterior ridge.



**Fig. 10.** Load at second premolar for model IIA (view of loaded side).

rations, but this effect was smallest for the ERA-OD configuration.

Similarly, for inclined implants more posteriorly applied loads resulted in increased stress transfer to the edentulous ridge by the denture base while simultaneously reducing the load taken by the implant. For both vertical and inclined implant orientations, the differences between the load transfer characteristics of the three attachment configurations diminished when the applied load was at more posterior locations.

Some instability of the dentures was observed when

loads were applied anterior to the implants. As the point of load application was placed more distally, a marked increase of stability occurred for both implant orientations. Further, there was no pattern of instability behavior as a function of overdenture retention design. Clinically, such potential instabilities may be minimized by developing bilateral occlusal contacts posterior to the implants. In this way, the magnitude of instability that might occur intraorally would be reduced by interarch interactions.

The observed load transfer characteristics for the three retention configurations tested in conjunction with the



**Fig. 11.** Load at second premolar for model IIC (view of loaded side).



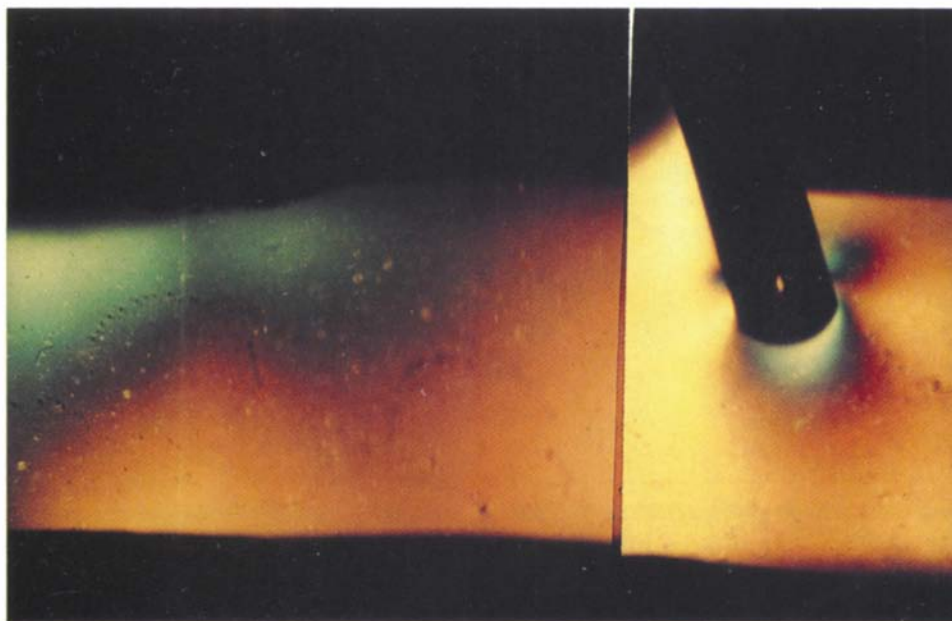
**Fig. 12.** Load at second molar for model IA (view of loaded side). Models IB and IC exhibited similar characteristics.

two implant orientations led to some considerations for clinical use of the Hader bar and ERA attachments. Regardless of retention design, higher stresses were concentrated along the distal surfaces of the inclined implants. Therefore, within anatomic limitations, vertical implant orientation is preferred. It was demonstrated that the design with the ERA-OD attachments tended to generate stresses that were lower and more symmetrically distributed around the implants. This type of distribution is a more favorable condition for the supporting bone.

In addition, the direct ERA-OD attachment has other advantages, such as ease of application, lower laboratory costs, and simplified hygiene. Further, the overdenture is easier to fabricate and repair, and periodic replacement of ERA key components is simpler than replacing tissue bar clips.

#### **CLINICAL SIGNIFICANCE**

Various designs for implant retained overdentures have been used. Clinically, the systems that provide



**Fig. 13.** Load at second molar for model IIA (view of loaded side). Models IIB and IIC exhibited similar characteristics.

the most equitable transfer of occlusal forces are to be preferred from the standpoint of bone preservation. This study examined the simulated stresses generated by overdentures with resilient cap and Hader bar retentive systems. It was found that placement of implants as close to perpendicular to the occlusal plane as possible would reduce stress intensity and concentration around the implants. Also, regardless of implant orientation, the resilient cap attachments placed directly to implants would provide the most equitable load transfer to the bone. These observations, in conjunction with technique and fabrication simplicity, suggest that the resilient cap attachment design for implant-retained overdentures could provide an excellent clinical result.

## CONCLUSIONS

Simulated occlusal load transfer by implant-supported overdentures to photoelastic models was investigated. Three overdenture retention designs were studied: resilient cap attachments, resilient cap attachments with a Hader bar, and a Hader bar alone. Photoelastic models had either vertical or inclined implant orientations.

Within the limits of this study, the following conclusions were drawn.

1. The three retention designs produced different load distribution characteristics.
2. Unilateral loads applied distal to the implants were more uniformly distributed to the supporting structures, which provided a greater degree of denture stability.
3. Regardless of retention design, higher concentrated

distal stress was observed with the inclined implants. Therefore vertical implant orientation is preferred.

4. The resilient cap direct attachment tended to provide the most equitable force distribution, as evidenced by more uniform transfer of stress by the implants to the supporting structures.

## REFERENCES

1. Brånemark PI, Zarb GA, Albrektsson T. Tissue integrated prostheses: osseointegration in clinical dentistry. Chicago: Quintessence, 1987.
2. Boerrigter EM, Stegenga B, Raghoebar GM, Boering G. Patient satisfaction and chewing ability with implant-retained mandibular overdentures: a comparison with new complete dentures with or without preprosthetic surgery. *J Oral Maxillofac Surg* 1995;53:1167-73.
3. Zarb GA, Schmitt A. The edentulous predicament, II: the longitudinal effectiveness of implant-supported overdentures. *J Am Dent Assoc* 1996;127:66-72.
4. Judy KD, Richter RS. Implant-supported overdenture prostheses. *Pract Periodont Aesth Dent* 1991;3:51-6.
5. Preiskel HW. Precision attachments in dentistry. St. Louis: Mosby-Year Book, 1992.
6. Shifman A, Marshak B. Implant-retained mandibular overdentures: a simplified, cost-effective treatment approach. *Quintessence Int* 1994;25:825-8.
7. Davis DM, Watson RM. The use of two implant systems for providing implant supported overdentures in the mandible—a clinical appraisal. *Eur J Prosthodont Rest Dent* 1993;2:67-71.
8. Maltz D, Rosenberg E. Implant overdentures—a simple solution. *Compend Contin Educ Dent* 1991;12:820-6.
9. Misch CE. Treatment options for mandibular implant overdenture: an organized approach. In: CE Misch, editor. *Contemporary implant dentistry*. St. Louis: Mosby-Year Book, 1993:223-40.
10. White GE. Overdentures. In: *Osseointegrated dental technology*. London: Quintessence, 1993:153-68.
11. Davidoff SR, Davis RD. The ERA implant supported overdenture. *Compend Contin Educ Dent* 1995;16:516-22.
12. McPherson D. ERA attachment simple, predictable. *Modern Dentalab* 1991;12:11-24.

13. Schwartzman B, Mito RS, Caputo AA, Beumer J. Load transfer by multiple implants under various prosthetic devices [abstract]. *J Dent Res* 1991;70:460.
14. Jemt T, Carlsson L, Boss A, Jörnérus L. In vivo load measurements on osseointegrated implants supporting fixed or removable prostheses: a comparative pilot study. *Int J Oral Maxillofac Implants* 1991;6:413-7.
15. Davidoff SR, Steinberg MA, Halperin A. The implant supported overdenture: a practical implant-prosthetic approach. *Compend Contin Educ Dent* 1993;14:722-30.

Reprint requests to:  
 DR. DAVID FEDERICK  
 13233 D FIJI WAY  
 MARINA DEL REY, CA 90292

Copyright © 1996 by The Editorial Council of *The Journal of Prosthetic Dentistry*.  
 0022-3913/96/\$5.00 + 0. 10/1/76996

### Noteworthy Abstracts of the Current Literature

#### Variability in microleakage observed in a total-etch wet-bonding technique under different handling conditions.

Tay FR, Gwinnett AJ, Pang KM, Wei SH. *J Dent Res* 1995;74:1168-78.

**Purpose.** The purpose of this study was to determine the amount and patterns of microleakage in a total-etch wet-bonding technique with one dentin adhesive under different handling conditions.

**Material and Methods.** Forty-five extracted, caries-free human third molars were used and a 4 mm diameter × 2 mm deep cavity preparation was completed in the buccal surface of each tooth. One half of each preparation was above and one half was below the cemento-enamel junction. The specimens were randomly divided into three groups ( $n = 15$ ): control group, inadequate light group, and incomplete evaporation of primer solvent group. The specimens in the control group were etched, five applications of mixed All Bond 2 system (Bisco Dental Prod., Itasca, Ill.) primer A and B were completed, and the preparations were air dried for 10 seconds. The preparations were then light polymerized with an adequate light (420 mW/cm<sup>2</sup>) for 20 seconds. Dentin-enamel resin was applied and light polymerized for 20 seconds. Finally, resin composite (Z100, 3M Co., St. Paul, Minn.) was incrementally placed within the preparations, light polymerized, finished, and polished. The inadequate-light group specimens were treated the same as the control group specimens; however, the light-polymerizing unit was different. The inadequate-light source used registered 68 mW/cm<sup>2</sup> output. The incomplete evaporation group specimens were also treated the same as the control group except that the mixed primers were not dried before light polymerization. All specimens were thermocycled and stored in 37° C water for 7 days before silver staining. Ten specimens from each group were then demineralized, dehydrated, and cleared in methyl salicylate. The extent of microleakage on these specimens was evaluated. The path of microleakage was determined with scanning electron microscopy on the remaining specimens from each group.

**Results.** A Kruskal-Wallis test (significance level 0.0001) revealed a significant difference in microleakage extent among the three groups. A Dunn test (significance level 0.05) revealed significant differences in microleakage extent by pairwise comparison of groups: the incomplete evaporation group was significantly different from the control group and the inadequate-light group was significantly different from the control group. Microleakage at the etched enamel margin was essentially absent in the control group. Some microleakage was present in all groups when the margins were placed in cementum or dentin. Silver staining was also observed along the incrementally placed resin composite sites in the inadequate-light group.

**Conclusions.** The total-etch technique in combination with acetone-containing adhesives can generate a gap-free resin composite restoration. An inadequate light source and incomplete evaporation of the primer solvent can cause the presence of gaps along the tooth-restoration junction. 55 References.—DL Dixon