Stress transfer of four mandibular implant overdenture cantilever designs

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Statement of problem. The influence of implant number and cantilever design on stress distribution on bone has not been sufficiently assessed for the mandibular overdenture.

Purpose. The purpose of this simulation study was to measure, photoelastically, the biologic behavior of 2 or 3 implants retaining different designs of cantilevered bar mandibular overdentures and to compare load characteristics.

Materials and methods. Two photoelastic models of a human edentulous mandible were fabricated having 2 or 3 screw-type implants (Nobel Biocare, 3.75 × 10 mm) embedded in the parasymphyseal area. Bar frameworks using a 7-mm cantilever were fabricated for both models. A clip-retained and a plunger-retained (SwissLoc) prosthesis were fabricated as superstructures for each framework. Vertical loads of 15 and 30 pounds were applied unilaterally to the first molar and 15 pounds to the first premolar on each of the 4 standardized overdenture prostheses. The cantilever was removed from the 2-implant framework and the clip-retained prosthesis was loaded similarly on the first molar with 25 pounds. Stresses that developed in the supporting structure were monitored photoelastically and recorded photographically.

Results. While all 4 prostheses demonstrated low stress transfer to the implants, the plunger-retained prosthesis caused more uniform stress distribution to the ipsilateral terminal abutment compared to the clip-retained prosthesis and provided retention security under tested loads. The plunger-retained prosthesis retained by 2 implants provided better load sharing from the ipsilateral edentulous ridge than the clip-retained prosthesis retained by 3 implants, and lower resultant stresses were seen on the implants.

Conclusions. Under load, all prosthetic designs demonstrated a low stress transfer to the ipsilateral abutment and to the contralateral side of the arch. The plunger-retained prosthesis retained by 2 implants demonstrated a more uniform stress transfer to the ipsilateral terminal abutment than the clip-retained prosthesis retained by 3 implants and provided more retention, given the implant configuration, prosthetic design and arch form. (J Prosthet Dent 2004;92:328-36.)

CLINICAL IMPLICATIONS

A plunger-retained mandibular implant overdenture designed with 2 implants and a cantilever bar may offer patients more retention and less surgical and financial exposure than a clip-retained cantilever design with 3 implants, while transferring less stress to the ipsilateral terminal abutment.

The high success rate of interforaminal implants used to support mandibular overdentures is well documented with longitudinal studies up to 12 years.1-7 These data include splinted or unsplinted implant designs retained by 2 implants. In fact, studies have shown no significant differences in periimplant health,8 patient satisfac-

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Presented at the Academy of Prosthodontics annual meeting, Niagara Falls, Ontario, Canada, May 2004.

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position and retention mechanism of mandibular implants supporting an overdenture have little impact on the long-term stability of the clinical parameters. In spite of these studies, cantilever designs supported by 2 implants may not be adopted for routine use for a number of reasons.

First, reluctance to implement the 2-implant mandibular overdenture cantilever design may have been galvanized by Dolder’s original overdenture work, which purported that diagonal placement of bar joints using 2 or more retained roots may lead to fracture or mobility of the roots. Other authors have emphasized the importance of designing a single bar parallel with the hinge axis to encourage torsion-free load transmission to implants. However, a review of mandibular overdenture treatment concepts proposed that this premise was based on empirical experiences or were opinions of members of individual centers.

Secondly, a number of authors have noted that bilateral distal extension prostheses supported by 2 or more implant abutments may cause higher bending moments which may lead to mechanical failure. However, no data was included in these studies on the length of the cantilever. El-Sheikh and Hobkirk used 13-mm-long cantilevers in an in vitro study comparing a single bar with distal extensions having clips or no clips. The authors found an increase in compressive forces compared to implants without the clips. This may favor a retentive unit under the cantilever. Moreover, Mericske-Stern et al have offered a guideline of 15-25 mm for the central bar length and 7 mm for the cantilever length.

Finally, the use of more than 2 implants has been recommended to support a mandibular overdenture in clinical scenarios that will require increased retention such as high muscle attachments, prominent mylohyoid ridges, or extreme gaggers. Protection of knife-edged residual ridges, superficial mental foramina or sensitive mucosa have also been indicated for multiple implants and cantilever bars. However, a 2-implant supported overdenture cantilever design may satisfy the increased demand for retention and tissue protection providing a more conservative surgical and economic treatment approach. Furthermore, if this design incorporated a locking device under the cantilever bars, retention security could be maximized. The biomechanical ramifications of these designs have yet to be established. In fact, there is a paucity of studies on stress transfer of the mandibular implant overdenture cantilever design.

MATERIAL AND METHODS

Two photoelastic models of a moderately resorbed edentulous human mandible were fabricated with a photoelastic resin (PL-2; Photoelastic Division, Measurement Group, Raleigh, NC). A supporting photoelastic resin “foot” was incorporated at the lower border of the mandible to provide horizontal orientation of the occlusal plane. Two 3.75 mm diameter, 10 mm long, solid screw-type implants (28885; Nobel Biocare, Yorba Linda, Calif) were included in the parasympyseal region of the mandible representing complete integration on the first model. The implants were placed, approximately, in the canine region with an interimplant distance of 22 mm and aligned perpendicular to the eventual occlusal plane. Standard abutments (4.0, 29455; Nobel Biocare) were placed and tightened to 20 N-cm with a manual calibrated torque wrench (Implant Innovations, West Palm Beach, Fla). The second photoelastic model was prepared from the same mold, with the addition of a third 3.75 mm diameter, 10 mm long, solid screw implant and standard abutment placed in the symphysis region, with an interimplant distance of 13 mm. The same manufacturer and torquing regimen used in the 2-implant model were used for the implants and standard abutments in the 3-implant model. A stress-free condition was determined by the absence of significant stress fringes in a circular polariscope for both photoelastic models.

A definitive cast with abutment analogs (29108; Nobel Biocare) was generated from each of the photoelastic models according to procedures previously described. To spatially standardize all tested prostheses, an articulated mounting of an opposing denture tooth arrangement was completed, using the remaining mandibular bony landmarks as guides for occlusal plane and arch form. The substructure frameworks and final superstructure prostheses were constructed using this mounting. Cantilever lengths were established at 7 mm from the distal aspect of the cylinder and selected to allow only the length of a clip attachment (Hader; Attachments International, San Mateo, Calif) and minimize the transfer of forces to the implant supporting structure.
A cantilever bar overdenture framework waxing was fabricated to the 4.0 gold cylinders (29049; Nobel Biocare) on each definitive cast using 1.8 mm diameter plastic patterns (Attachments International). The patterns were subsequently cast using a 51.5% Au, 38.5% Pd alloy (Olympia; JF Jelenko, Armonk, NY). The frameworks were cut and soldered to achieve a visual passive fit using the 1-screw Sheffield test. The cantilever bar frameworks were secured to the respective photoelastic models with gold screws (DCA 075; Nobel Biocare) and tightened to 10 N·cm with the same torque wrench used in the models (Figs. 1 and 2). The photoelastic models were photographed to ensure a relatively stress-free condition after the frameworks were attached.

A clip-retained cantilever bar overdenture prosthesis and a plunger-retained cantilever overdenture design were fabricated for the 2- and 3-implant photoelastic models, for a total of 4 prostheses. The clip-retained cantilever bar overdenture for the 2-implant model (CRP-2) was designed to incorporate 2 retentive devices on the central single bar and 1 on each cantilever extension. The clip-retained overdenture for the 3-implant model (CRP-3) was designed to incorporate 1 retentive device on each of the double bars and on the cantilever extensions. The plunger-retained cantilever overdenture for the 2-implant array was designed with 2 retentive clips (OSV; Cendres et Metaux, Biel-Bienne, Switzerland) on the center bar and only an attachment (SwissLoc; Attachments International) under each of the cantilevers (PRP-2). The plunger-retained overdenture design for the 3-implant array (PRP-3) was designed with 1 clip on each of the double bars, and again only the locking device under the cantilever for retention. Appropriate lengths of high-strength 1.8-mm hardened precious metal bar stock (OSV; Cendres et Metaux) were cut and fit accurately over the spacers between the gold copings as well as over the distal extension bars. For the plunger-retained prosthesis, the same precious metal bar stock was cut and fit similarly but only for the noncantilevered bar segments. The horizontal locking device (SwissLoc NG 6mm; Attachments International) was incorporated in the waxing bilaterally, to engage a midpoint concavity on the underside of the cantilever bar (Fig. 3). Hardened acrylic resin denture teeth (OrthositPE; Ivoclar of North America, Amherst, NY) were arranged on PMMA record bases on the definitive cast and were set on a flat plane parallel to the ridge with the central fossa centered over the ridge crest. The attachments were incorporated in the record base after orienting them to their respective bar frameworks. Using a 3-mm tissue spacer on the posterior edentulous ridge on the definitive cast, all 4 overdenture prostheses were processed according to a procedure previously described.

Both the single bar and double bar cantilever bar frameworks were reattached to the respective photoelastic models with gold screws (DCA 075; Nobel Biocare) and tightened to 10 N·cm with the same
torque wrench used previously. The CRP-2 and CRP-3 were attached to the respective frameworks on each photoelastic model by means of the clips. To eliminate potential contact of the acrylic resin on the implant abutments and bars, disclosing wax (Kerr, Romulus, Mich) was used to ensure that at least 1 mm of space was maintained. A vinyl polysiloxane impression material (Star VPS; Danville Engineering, Danville, Calif.) was then applied to the intaglio surface of the extension base of the prostheses to mimic the soft tissues37 and placed on the photoelastic models and trimmed after polymerization (Fig. 4). This allowed for simulated tissue support distal to the cantilevers when the prostheses were loaded.

The PRP-2 and PRP-3 were then attached to the respective frameworks on each photoelastic model by engaging the clips and locking devices. The same disclosing medium was used to verify sufficient clearance between the cantilever bar and locking devices as well as abutments and bars with the acrylic. Reline procedures were duplicated for the extension base. All 4 prosthesis frameworks were sequentially secured to their respective frameworks on the photoelastic model, with the attachments engaged, and examined photoelastically to assure that each unloaded prosthesis was relatively stress-free.

Each model was immersed in a tank of mineral oil to minimize surface refraction and, thereby, facilitate photoelastic observation. Loads were applied in a straining frame by means of a calibrated load cell (100-pound low range transducing cell; GM2 Universal Transducing Cells, Camarillo, Calif) mounted on a movable head of a loading frame (Fig. 5). Loads were monitored by a digital read-out after signal treatment using a strain gauge conditioner (models 2130 and 2120A; Instruments Division, Measurements Group). Vertical forces of 15 and 30 pounds were applied unilaterally to the central fossa of the first molar.

A vertical force of 15 pounds was applied to the distal occlusal fossa of the first premolar. These load levels were selected because they are within a range of normal occlusal mastication and near maximal loads for implant overdenture patients, depending on the opposing jaw status.38 The first molar was chosen for loading because maximum occlusal forces are often exerted in this region where there is maximum contraction of the elevator muscles.39,40 The first premolar was chosen for a more anterior load application because food is predominantly masticated between the premolars and molars.41 A progressive load was also applied to the left first premolar distal fossa to assess the load required to lift off the prosthesis from the photoelastic model on the unloaded side. Loading was performed on the CRP-3 and the resultant stresses in all areas of the supporting structures were monitored and recorded photographically in the field of a circular polariscope. Three separate views of the model were recorded for each loading configuration: right posterior, central, and left posterior. Each loading was repeated at least twice to ensure reproducibility. The photoelastic model was removed from the tank of mineral oil, and the superstructure and substructure frameworks were removed from the photoelastic model to eliminate any residual stresses for the subsequent test. Photoelastic observations were recorded for each prosthesis on each model. In addition to the 4 cantilevered prostheses, a clip-retained noncantilevered prosthesis was tested on 2 implants (NCP-2) with a 25-pound load on the central fossa of the first molar.

RESULTS

Loading on the right and left side produced similar fringe patterns; therefore, only the results from the left side are presented.
Clip-retained, 3-implant model

For the CRP-3, loading in the central fossa of the left first molar with 15 pounds generated 1 fringe order of stress in the distal apical region of the left (simulated patient’s) implant, radiating obliquely to the edentulous crest. On the mesial (facing towards the left implant) apical region of the center implant, 1 fringe was observed, radiating to the neck of the implant. Less than 1 fringe was evident on the distal aspect of the right implant, radiating to the edentulous crest, up to the first molar area. Overall, low stress was discernible on the edentulous ridges. For loading with 30 pounds on the left first molar central fossa, a similar distribution was observed with an increase of approximately a half fringe (Fig. 6).

Loading in the distal fossa of the left first premolar of the CRP-3 with 15 pounds, a 1+ fringe order of stress was observed on the distal apical region of the left, radiating to the crest. Less than 1 fringe was seen on the mesial aspect of the left implant. One fringe was observed on the distal neck of the center implant, radiating distal-apically. One fringe of stress was seen also along the distal apical aspect of the right implant, radiating towards the crest. The CRP-3 lifted off on the unloaded edentulous ridge at the 26-pound force level.

Plunger-retained, 3-implant model

For the PRP-3, loading in the central fossa of the left first molar with 15 pounds generated low level stress (less than 1 fringe) to the center and left implant. One fringe order of stress is seen at the distal apical region of the right implant, radiating distally towards the crest of the ridge. No discernible stress was observed on the edentulous ridge on the loaded side.

Loading the PRP-3 with 30 pounds in the central fossa of the left first molar generated a similar distribution as the 15-pound load, with the approximate increase of a half fringe. There was, however, a distinction, with 1 fringe generated on the edentulous ridge of the loaded side (Fig. 7).

Loading the PRP-3 on the left first premolar in the distal fossa with 15 pounds, 1+ fringe order of stress was seen along the distal body of the left implant. One fringe was seen at the mesial midsection of the center implant, with less than 1 fringe on the distal aspect. One fringe was observed at the apex of the right implant, radiating both mesially and distally. Almost no discernible stress was evident on the edentulous ridge on the loaded side.

Clip-retained, 2-implant model

For the CRP-2, loading in the central fossa of the left first molar with a 15-pound load generated less than 1 fringe order of stress on the distal apical region of the left, radiating along the mesial surface and slightly distally. Low-order stress (less than 1 fringe) was seen also on the loaded edentulous ridge and mesial apical aspect of the right implant. No discernible stress was observed on the nonloaded edentulous ridge. A 30-pound load in the central fossa of the left first molar generated a similar stress pattern as the 15-pound loading condition, with the addition of approximately a half fringe on the loaded side (Fig. 8).
For the CRP-2, loading in the distal fossa of the left first premolar with 15 pounds generated 1 fringe order of stress fairly symmetrically around the body of the left implant. Less than 1 fringe of stress was observed on the loaded edentulous ridge near the applied load. No more than 1 fringe was seen on the mesial apical portion of the right implant. The prosthesis lifted off the residual ridge when a load of 22.5 pounds was applied in the distal fossa of the left first premolar.

For the PRP-2, loading the central fossa of the left first molar with 15 pounds generated less than 1 fringe order of stress fairly symmetrically around the body of the left implant. Less than 1 fringe of stress was observed on the loaded edentulous ridge near the applied load. No more than 1 fringe was seen on the mesial apical portion of the right implant. The prosthesis lifted off the residual ridge when a load of 22.5 pounds was applied in the distal fossa of the left first molar.

Loading the PRP-2 with 15 pounds in the distal fossa of the left first premolar generated 2 fringe orders of stress on the mesial aspect of the left implant, and 1 fringe order of stress on the distal body. One fringe was observed on the loaded edentulous ridge near the applied load. Little if any stress was recorded on the right implant.

**Plunger-retained, 2-implant model**

For the PRP-2, loading the central fossa of the left first molar with 15 pounds generated less than 1 fringe order of stress fairly symmetrically around the body of the left implant. Little if any stress was seen on the right implant. Less than 1 fringe was seen on the loaded edentulous ridge near the applied load. A 30-pound load on the central fossa of the left first molar generated an increase of approximately a half fringe order of stress with a similar distribution (Fig. 9).

Loading the PRP-2 with 15 pounds in the distal fossa of the left first premolar generated 2 fringe orders of stress on the mesial aspect of the left implant, and 1 fringe order of stress on the distal body. One fringe was observed on the loaded edentulous ridge near the applied load. Little if any stress was recorded on the right implant.

**Noncantilevered, 2-implant model**

For the noncantilevered prosthesis supported by 2 implants, a 25-pound load on the central fossa of the left first molar generated 1 + fringe order of stress on the distal apical aspect of the left implant radiating obliquely from mesial apical aspect to crest (Fig. 10). On the loaded side, a 3 fringe order of stress was recorded broadly on the edentulous ridge. Little if any stress
was seen on the contralateral implant or edentulous ridge. The prosthesis lifted off the photoelastic model with a greater than 25-pound load on the first molar.

DISCUSSION

Although the photoelastic model consisted of a single resin to represent the periodontium and the condition of the implants, with no differentiation between cortical and medullary bone, the magnitude of stress concentrations might be modified, but not, substantially, the locations. However, stress distribution is a function of implant length, geometry, and diameter, so different stress patterns might be found if these variables are dissimilar, even with the same model and prostheses.

This investigation was in agreement with other studies which found that despite the prosthetic design, resultant stresses were greater on the side of the load application. The variation in stress intensity and distribution among the 4 loaded prostheses was altered by the retention device, as well as number and location of implants along the anterior arch, consistent with the work of Tashkandi et al. Compared to the CRP-3, the PRP-3 showed a reduction of stress on the ipsilateral implant to the first molar applied force. The edentulous ridge on the loaded side of the PRP-3 shared the applied load more than in the CRP-3. There is evidence of uneven force distribution on the midline implant with both prosthetic designs. Only slightly more stress was seen on the contralateral distal implant with the PRP-3 owing to tension from engagement of the locking device. The loading of the left premolar concentrated the stresses over the ipsilateral implant in all 4 designs consistent with another study. Both the CRP designs demonstrated lift-off under applied loads of less than 27 pounds on the first premolar. The NCP-2 also lifted off under 27 pounds. Kayacan et al noted that if the clips become too loose, the overdenture will rotate under small tensile forces and the prosthesis will come in contact with 1 point on the cantilever bar and increase maximum bending moment on the implants. In comparing the CRP-2 to the PRP-2 with a first molar load, the edentulous ridge on the loaded side shared the load with both prosthetic designs. Similar low stress intensity and distribution appeared on the ipsilateral implant. Slightly more tension was noted on the PRP-2 contralateral implant as compared to the CRP-2.

When comparing the PRP-2 to the CRP-3, the PRP-2 provided a load sharing from the ipsilateral edentulous ridge unlike the CRP-3. The position of the PRP-2 locking device on the underside of the cantilever bar, coupled with the space above the bar allowed more rotation of the distal extension base than in the CRP-3.

El-Sheikh and Hobkirk also found that removing the retention clips on the cantilever bar segment resulted.
in a decrease in compressive force to the ipsilateral terminal abutment compared to clip retention. Overall, lower resultant stresses were seen on the implants of PRP-2 in contrast to CRP-3, which may provide an alternative treatment for patients with similar arch form and framework design that are in need of retention security and mental nerve protection and have economic or surgical limitations.

The use of implants less than 8.5 mm in length has been cautioned in mandibular 2-implant retained overdentures. Moreover, with a cantilevered bar design, higher bending moments have been reported on the terminal abutment under function. Therefore, unless a wide-bodied implant is used for the 8.5-mm implant, which may improve stress distribution, it may be judicious to use at least a 10-mm implant when only 2 implants are planned. Patients with high occlusal forces may require additional implants.

It appears that patient mediated factors such as retention, jaw morphology, dexterity, and financial considerations should dictate the number of implants and design of the mandibular implant overdenture cantilever prosthesis. However, it is conceivable that decreased stress transfer with the plunger-retained prosthesis may lead to more stress in the attachment apparatus and higher burden of maintenance. Future clinical studies will be helpful in evaluating the peri-implant health and prosthetodontic maintenance of the mandibular cantilevered prosthesis using these designs supported by 2 implants.

CONCLUSIONS

Within the limitations of this study the following conclusions were drawn:

1. Under load, all 4 prosthetic designs demonstrated a low stress transfer to the ipsilateral abutment.
2. For all prosthetic designs, low stress was transferred to the contralateral side of the arch.
3. The plunger-retained prosthesis supported by 2 implants demonstrated a more uniform stress transfer to the ipsilateral terminal implant than the clip-retained prosthesis supported by 3 implants and provided more retention, given the implant configuration and arch form.

The authors thank Dr. Peter Staubli for his design and laboratory assistance with the SwissLoc prosthesis. The authors also thank Al Burleson for his laboratory assistance.

REFERENCES


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