Bicortically Stabilized Implant Load Transfer

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Purpose: *Questions exist as to the potential advantages of bicortical stabilization of implants in the mandible through engagement of the lingual cortical plate. The purpose of this investigation was to determine photoelastically the effect of lingual cortical plate engagement on implant load transfer.* ***Materials and Methods:*** *Composite photoelastic models of an edentulous posterior segment of a mandible were fabricated using plastics of different modulus to simulate cortical and trabecular bone. One model included a 3.75×15-mm threaded implant that engaged the simulated lingual cortical plate, while in the other model the implant was centrally located within the simulated trabecular bone. A metal superstructure was cast using an abutment cylinder. Simulated vertical occlusal loads were applied to the superstructure over the implant and at fixed buccal cantilever lengths. Stresses that developed within the model were monitored photoelastically and recorded photographically. Peri-implant defects were then formed in the models and the loading and recording procedures were repeated.* ***Results:*** *Lingual cortical plate engagement generated the highest stresses at the lingual cortical plate and the buccal crestal cortical layer at the implant neck. Stress intensity within the buccal plate at the implant neck was lower than that in the centrally placed implant. In the presence of a peri-implant defect, for all load conditions, more load was borne by the trabecular bone. Increasing cantilever lengths caused asymmetric load transfer with higher maximum stresses.* ***Discussion:*** *For both implant placements, a large portion of the applied load was taken by the crestal cortical bone simulant. Engagement of the lingual cortical plate reduced maximum stress in the crestal cortical bone by approximately 25%. With peri-implant defects, the simulated trabecular bone provided the main support of the applied load. Longer buccal cantilever lengths increased maximum stresses for all placement and crestal bone conditions.* ***Conclusions:*** *The results of this investigation do not indicate a clear load transfer advantage to apical engagement of the lingual cortical plate in this model.* (INT J ORAL MAXILLOFAC IMPLANTS 2003;18:59–65)

Key words: *dental implant, bicortical stabilization, implant load transfer*

Posterior regions of the mandible frequently present problems for implant placement and restoration.[1,2] Restrictions on implant selection and placement often occur because of the anatomic features of the posterior mandible, as well as bone quality. A major determinant of implant length is the height of alveolar bone coronal to the inferior alveolar nerve. Implant diameter and orientation are determined by the shape and degree of resorption of the alveolar ridges, as well as prosthetic considerations. Previous biomechanical studies have shown that more equitable stress transfer to supporting structures is obtained with longer implants that are loaded along their axes.[3–5] In situations of moderate to severe alveolar ridge resorption, maximum implant length and orientation favorable to masticatory forces often are difficult to attain. The longevity of implant restorations is greatly influenced by the outcome of surgical placement and the attainment and maintenance of implant stability. Further, osseointegration longevity may be compromised by undesirable implant selection, location, and orientation.

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Table 1 Photoelastic Modeling Materials

Tissue	Modulus of elasticity (MPa)
Cortical bone[11]	14,700
Cancellous bone[11]	490
PLM-1 simulant*	2931
PL-2 simulant*	207

*Measurements Group, Raleigh, NC.

In addition to the aforementioned factors, enhanced implant stability and improved load transfer characteristics may be achieved through bicortical stabilization with apical engagement of the lingual cortical plate.[2] Support for this hypothesis was provided in a study using rabbit tibiae, which demonstrated that removal torques for bicortically stabilized implants were twice the values for implants with monocortical engagement.[6] However, the mechanisms by which bicortical stabilization affect load transfer have not been elucidated. Photoelastic analysis has been widely used to study the biomechanics of implant load transfer in dentistry.[7–10] This method was shown to be suitable for the determination of stress distributions throughout the model. The information obtained was useful in providing guidelines for the implementation of various implant procedures. The purpose of this investigation was to determine photoelastically the load transfer characteristics of bicortically stabilized implants.

MATERIALS AND METHODS

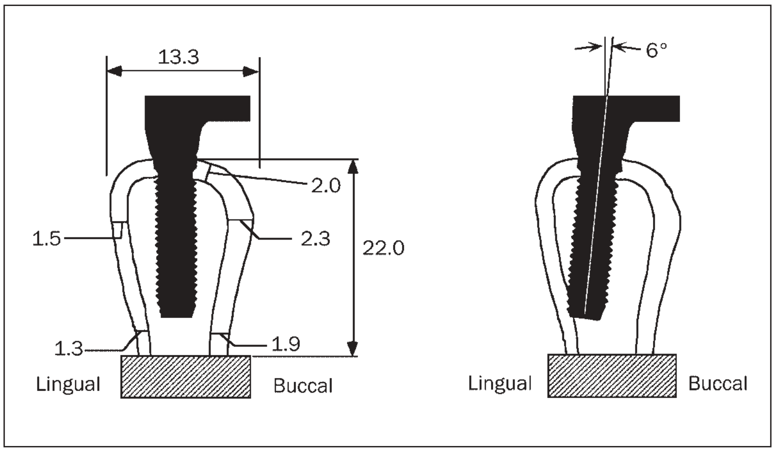
A photoelastic approach was selected to determine the load transfer effects of cortical engagement by implants, since this technique of stress analysis has been shown to be predictive of clinical responses to various types of treatment modalities.[4] Composite photoelastic models of an edentulous posterior segment of a mandible were fabricated using plastics of different modulus to simulate cortical and trabecular bone (Table 1). These simulants provided a modulus ratio representative of the diverse values of cortical and cancellous bone. The configuration of the segment was based on reported dimensions of a mandible at the second molar.[12] This condition is representative of a mandible that has undergone a small degree of resorption (Figs 1a and 1b). A sequential molding technique with a silicone mold material (3110 RTV Rubber, Dow Corning, Midland, MI) was used. The cortical plate simulant (PLM1, Photolastic Division, Measurements Group, Raleigh, NC) was cast around the implant to the level of the implant platform. After the cortical plate plastic had set, the trabecular bone simulant (PL-2, Photolastic/Measurements Group) was cast into the inner space around the implant.

Two models were made. In the first model, a 15-mm-long threaded implant of 3.75 mm diameter (Nobel Biocare, Yorba Linda, CA) was oriented so that the neck portion contacted the crestal cortical layer and the entire implant was centrally located within the trabecular bone (Fig 1a, *left*). In the other model, 3 apical threads of the implant engaged the lingual cortical plate (Fig 1a, *right*). An index was used to assure that orientation of the implants led to the same screw access hole position for both models. A metal superstructure was cast using an abutment cylinder (CeraOne, Nobel Biocare) and a gold coping (Nobel Biocare). A buccal cantilever was included to allow simulation of buccal cusp loading.

Prior to load application, the composite photoelastic models were subjected to a stress-relieving regimen of 37ºC for a period of 24 hours. The models were examined in the field of a circular polariscope and only very low stresses were noted. Consequently, the stress patterns that developed under subsequent loading were attributable to the applied load. The models were subjected to simulated occlusal loading in a straining frame by means of a load cell calibrated with standard weights (100-lb [45.45-kg] low-range transducing cell, Model GM2, Universal Transducer Cells, Camarillo, CA) mounted on the movable head of the loading frame (Fig 1b). Loads were monitored by a digital readout using a strain gauge conditioner (Models 2130 and 2120A, Instruments Division, Measurements Group). The models were supported at their inferior borders by a resin base lined with a thin layer of silicone impression material. It subsequently was demonstrated that this mode of support was appropriate, since there were no interactions between the clamp and the stress field at the apex of the implant. The resin base containing the model was clamped in a vise to prevent motion of the model under load. Vertical loads of 15 lbs (6.8 kg) were applied to the metal superstructure over the access hole position and at 3- and 5-mm buccal cantilever locations. Loads over the access holes were along the implant axis for the centrally placed implant and at 6 degrees to the axis of the implant engaging the lingual plate (Fig 1a). These loads were selected because they are realistic functional load levels and also provided a satisfactory optical response within the model.

The load-induced stresses within the supporting bone simulants were monitored quasi–3-dimensionally in the field of a circular polariscope.[6] Each loading and observation sequence was repeated at

Fig 1a Schematic of photoelastic models. *(Left)* Centrally placed implant; *(right)* implant engaging lingual cortical plate simulant.



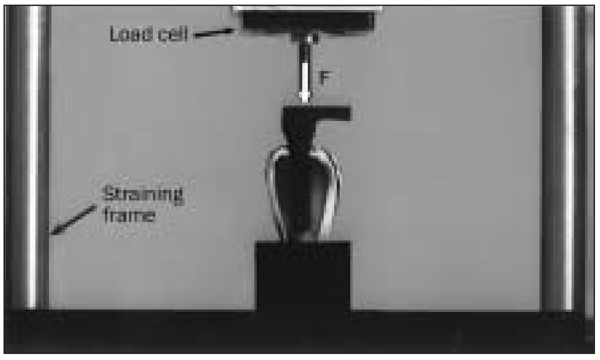


Fig 1b Model under load in straining frame.

Fig 2 *(Right)* Stress produced in model with centrally placed implant and no peri-implant defect under a 15-lb vertical load along implant axis.

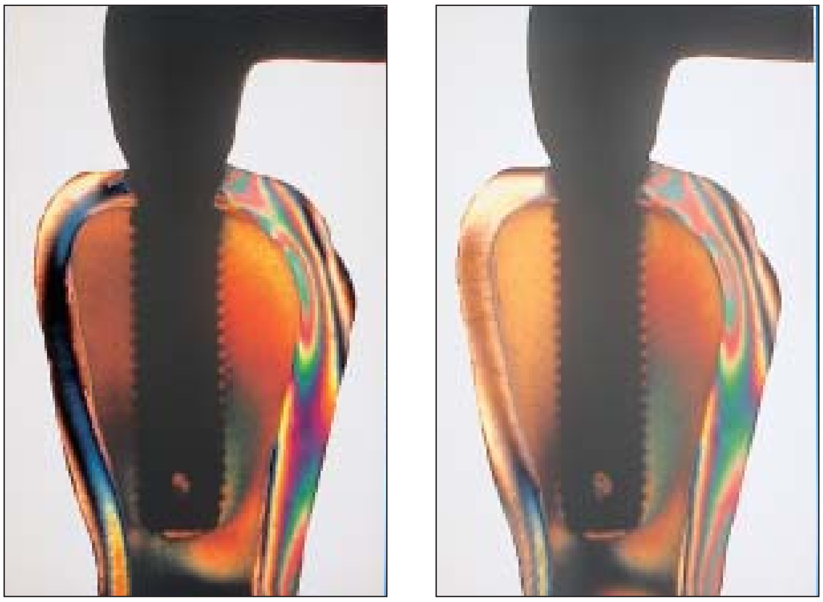
least 2 times to ensure reproducibility of results. The fringe pattern findings and data were collected for the loading subjected to each situation of restorative connection and loading position. Observations of fringe order number resulting from the various loading conditions were made on scanned data photographs, which were subsequently viewed with a computer graphics program (Photoshop 4.0, Adobe Systems, San Jose, CA). Quantification of stress intensity by fringe number counting was accomplished by means of monochromatic mode changes, which facilitated fringe observation in regions of closely spaced fringes.

After completion of the occlusal loading tests, both models were modified using a tapered diamond bur to produce saucer-like, symmetric peri-implant defects around the implant necks. The defects so made extended through the entire thickness of the simulated cortical bone. The modified models were subjected to the same loading regimen as described above.

RESULTS

Prior to application of loads to the models, the models were examined in the circular polariscope. Since only very low stresses were noted, the stress patterns that developed under load were attributable to the applied load. While under the specified loads, additional manual loading was superimposed to ascertain whether compressive or tensile stresses were present at points of interest.

When a vertical load was applied at the center of the centrally placed implant, the highest stress concentration was located within the crestal cortical layer (Fig 2). Slightly higher stress was seen at the buccal neck portion and in the external oblique



Figs 3a *(Left)* **and 3b** *(Right)* Stress produced in model with centrally placed implant and no peri-implant defect under a 15-lb vertical load. *(Left)* Three-millimeter buccal cantilever; *(right)* 5-mm buccal cantilever.

Fig 4 Stress produced in model with implant engaging lingual cortical plate simulant and no peri-implant defect under a 15-lb vertical load.

ridge area. The stress within the trabecular bone simulant was uniformly distributed and at a low level, with the exception of the buccal aspect of the apex of the implant.

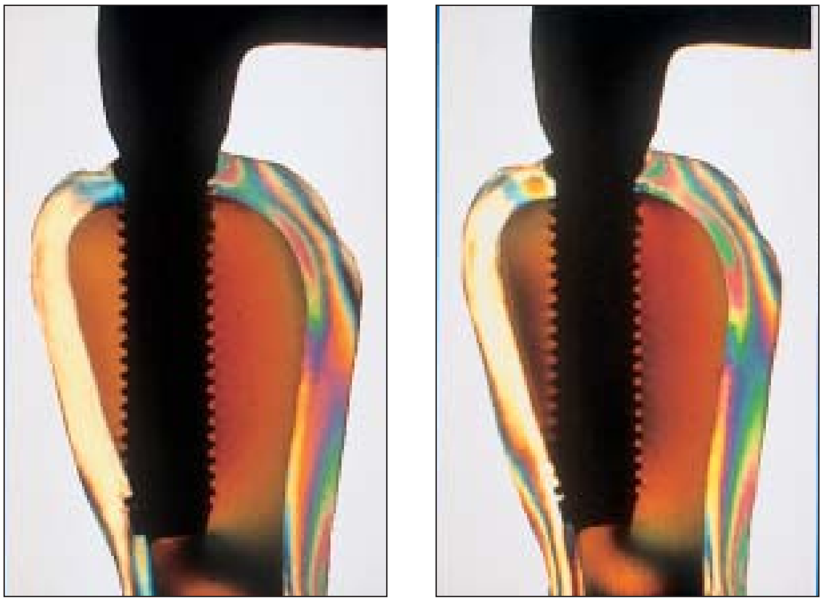
The effects of 3- and 5-mm buccal cantilever lengths for the centrally placed implant are compared in Figs 3a and 3b. For both cantilever lengths, stresses were concentrated primarily within the buccal cortical layer at the implant neck and in the external oblique ridge area. The distribution of stresses was similar for the 2 cantilever lengths, with the main differences being in magnitude. The higher stresses occurred for the 5-mm length. No substantial differences occurred within the trabecular bone simulant.

The effects of the vertical load applied to the implant engaging the lingual cortical plate are shown in Fig 4. When the implant engaged the lingual cortical plate, the highest stresses were generated at the lingual cortical plate and the buccal crestal cortical layer at the implant neck. The stress intensity within the buccal plate at the implant neck was lower than for the similarly loaded centrally placed implant.

The effects of 3- and 5-mm buccal cantilever lengths for the implant engaging the lingual cortical plate are compared in Figs 5a and 5b. As was seen with the centrally placed implant, increased stress at the implant neck and in the external oblique ridge area was noted with increasing cantilever length. A comparison of the maximum fringe orders revealed that the stresses in the buccal cortical plate were approximately 20% higher for the centrally placed implant. At the implant apex, compressive support by the lingual plate was transformed into bending of the cortical plate, with tension at the outer lingual surface. Little difference was seen within the trabecular bone simulant.

The presence of a peri-implant defect (complete removal of cortical simulant around implant) for the centrally placed implant caused pronounced redistribution of stresses. For all load conditions, a larger proportion of the load was borne by the trabecular bone, with cantilever loads producing non-symmetric load transfer. These observations are illustrated in Figs 6a and 6b for 5-mm buccal cantilever loads. The highest stresses were concentrated near the implant neck and at the buccal aspect of the apex. The stresses in the lingual cortical layer for the centrally placed implant were developed more indirectly by transfer from the trabecular bone and were higher than for the non-defect situation. With a load applied at the implant center, the stresses were distributed more symmetrically around the implant (Fig 6b).

When the implant engaged the lingual cortical plate, a peri-implant defect also caused redistribution of the load to the trabecular bone. This redistribution is illustrated in Fig 7 for a 5-mm cantilever length. The stresses formerly localized in the crestal cortical layer at the implant neck were then taken by the trabecular bone in this region. The support provided at the implant apex by the lingual cortical plate reduced trabecular stress at the buccal aspect of the apex by approximately one third (by



Figs 5a *(Left)* **and 5b** *(Right)* Stress produced in model with implant engaging lingual cortical plate simulant and no peri-implant defect under a 15-lb vertical load. *(Left)* Three-millimeter buccal cantilever; *(right)* 5-mm buccal cantilever.

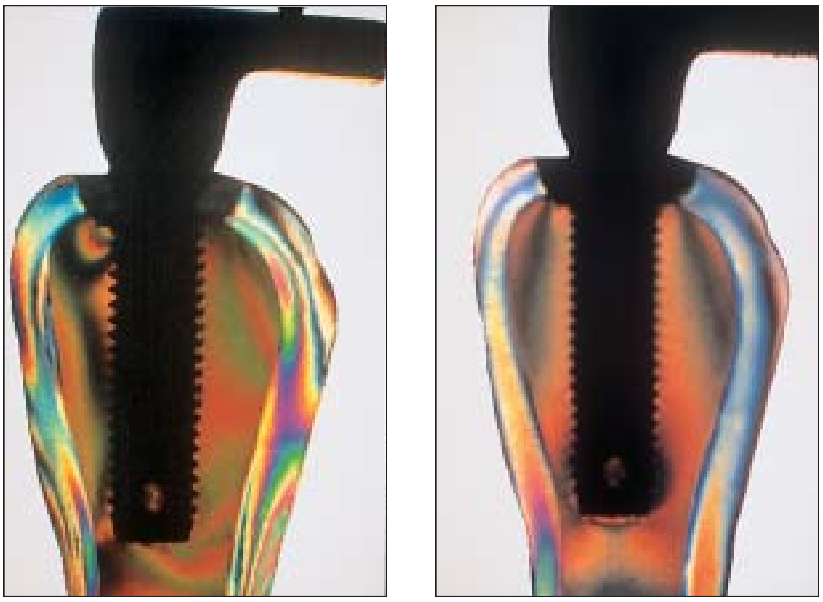


Fig 6a *(Left)* Stress produced in model with centrally placed implant having peri-implant defect under 15-lb vertical load and 5-mm buccal cantilever.

Fig 6b *(Right)* Stress produced in model with centrally placed implant having peri-implant defect under a 15-lb vertical load along implant axis.

fringe order comparison) and at the neck by one quarter, relative to the centrally placed implant (Fig 6a). However, stress within the lingual plate at the implant apex increased compared to the non-defect situation (Figs 5a and 5b). As was noted for the non-engaged implant, a load applied at the implant center caused stresses to be distributed more symmetrically around the implant (Fig 8). Further, stress within the lingual cortical plate at the implant apex was increased compared to the non-defect situation (Fig 4).

DISCUSSION

This investigation has demonstrated that some load-distributing advantages may be achieved through bicortical stabilization of implants in the mandible by engagement of the lingual cortical plate. These effects represented a maximum 20% stress reduction for any of the loading conditions. If functional or parafunctional loads are not excessive, this reduction may not be clinically significant.

Fig 7 *(Left)* Stress produced in model with implant engaging lingual cortical plate simulant having peri-implant defect under a 15-lb vertical load and 5-mm buccal cantilever.

Fig 8 *(RIght)* Stress produced in model with implant engaging lingual cortical plate simulant having peri-implant defect under a 15-lb vertical load.

For both implant orientations, the most severe stresses occurred with a long cantilever length. This cantilever length is related to occlusion. To keep the cantilever effect to a minimum, special consideration should be given to the following factors: *(1)* reduction of the occlusal table, *(2)* limiting of occlusal contact to the area over the implant, and *(3)* avoidance of interferences during excursive movement.

It was shown that for both implant orientations and all load conditions on models with peri-implant defects, considerable redistribution of force occurred from the crestal cortical layer to the trabecular bone. This observation has some implications for situations in which the crestal cortical layer is very thin, which is often the case in the posterior regions of both the maxilla and mandible, even in the absence of a peri-implant defect.[13] Becker and associates stated that "implants placed in sites with thin cortical bone increased the chance for a patient to lose at least one implant by 130% when compared to implants placed in a thick cortical layer or compact bone."[14] Such overloading has been seen clinically where implants were placed in thin cortical bone (types 3 or 4 bone).[15]

The models employed in this investigation simulated complete integration of the implants. However, studies have shown that implants that are considered to be integrated clinically have less than complete bone-implant contact.[16] Photoelastic investigations using models with varying degrees of contact between implants and simulated bone have shown that less bone-implant contact generally increases the stresses within the supporting structure.[17,18] Furthermore, there are localizations of stress at regions where the simulated integration is incomplete. These results suggest that partially integrated bicortically stabilized implants might cause exacerbation of stress levels observed in the present study.

The results of the current investigation demonstrated that the stress advantages to engagement of the lingual plate may be questionable. In addition, placement of implants too far lingually can lead to substantial bone loss once the implants are restored.[19] Therefore, should engagement of the lingual cortical plate be attempted? The response to this question lies in a balancing of the potential risks associated with safely achieving surgical engagement of the cortical plate, as well as other considerations. Alternatives to bicortical stabilization may include placement of a wide-body implant and elimination of any interference during excursive movements. A case for engagement of the lingual cortical plate could be made if the crestal cortical layer is almost absent and the trabecular bone is of poor quality (type 3 or 4). On the other hand, if a reasonably thick crestal cortical layer is present, it was shown that the main stress bearing would occur at this location. Consequently, it is questionable whether the potential surgical risks associated with attaining engagement in all cases are warranted.

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 of 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 bicortical stabilization. As always, this information should be used in conjunction with sound clinical judgment.

CONCLUSIONS

The load transfer characteristics of an implant using the lingual cortical plate for bicortical stabilization were photoelastically compared with a centrally placed implant. The results indicate the following:

1. For both implant placement configurations, a large portion of the applied load was taken by the simulated crestal cortical bone. Engagement of the lingual cortical plate produced a reduction in maximum stress in the crestal cortical bone of approximately 20%.
2. In the presence of a peri-implant defect extending through the cortical bone, the trabecular bone provided the main support of the applied load.
3. Increased buccal cantilever length caused considerable increases in maximum stresses for all placement configurations and crestal bone conditions.

The results of this investigation indicate that potential load transfer advantages to bicortical stabilization through apical engagement of the lingual cortical plate need to be considered with respect to potential risks.

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