Photoelastic Evaluation of Load Transfer to an Implant Connected to a Natural Tooth under Varying Types of Periodontal Support

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Clinical significance
The use of either segmented or non-segmented implant abutments may be considered for satisfactory implant integration and support in tooth restoration under a sound periodontal condition. The connection of implants to the teeth is not recommended under the condition of decreased periodontal support or stability.

Abstract
Purpose: The purpose of this study was to compare the stress transfer from a fixed restoration, supported by an implant restored with either a segmented or non-segmented implant abutment, connected to a simulated tooth with decreased foundational support by photoelastic evaluation.
Methods: A photoelastic model of a human left mandible, edentulous posterior to the first premolar, was fabricated, with a 3.75×13 mm screw-type implant embedded within the edentulous area. The edentulous areas were restored with a three-unit fixed prosthetic restoration with the distal implant abutment connected to the simulated tooth abutment. The implant abutments consisted of either a segmented conical abutment or a non-segmented UCLA abutment. A hemiseptal periodontal defect was created by the removal of buccal and disto-buccal tissues to simulate decreased support caused by a 4 mm infrabony defect. Vertical occlusal loads were applied at fixed locations on the restorations for the simulated periodontal condition. The stresses which developed in the mandible were monitored photoelastically and recorded photographically.
Results: Decrease of the foundational support of the tooth resulted in higher stresses transferred to the mesial and apical aspects of the implant as compared with those in the non-defect control condition. Similar results were obtained for both segmented and non-segmented abutment restorations.

Conclusion: Within the limitations of this study, application of load to the simulated abutment teeth with decreased periodontal support resulted in higher stresses around the supporting implant structure for both abutment designs. The distribution and intensity of the stresses were similar for segmented and non-segmented abutments.

Key words: photoelastic study, implant design, natural tooth, periodontal support

Introduction
A variety of techniques and designs have been established for dental implant restoration and treatment of the partially edentulous state. The most controversial aspect of the treatments pertains to the restorative connection of the teeth to the implants. The stability of the teeth connected to implants and the effect of the restoration on the implant require investigation and review.

Clinical reports of unstable connection of teeth to implants have been presented. While few case of implant failure was found, the connected teeth demonstrated destabilized (continued tooth drift or intrusive) tooth movements. Some of the methods to stabilize the restored teeth include the use of rigid attachments and connectors. Photoelastic testing has been used to evaluate the stress transfer between the simulated teeth and supporting implants with a three unit fixed partial denture with the use of rigid restorative connections.

There are numerous reports of clinical success with the use of rigid-type connectors. A comparative analysis of a semi-rigid versus rigid at-
tachment between the restorative teeth and implants revealed an increased incidence of complications with the use of the semi-rigid attachment. Clinical findings around teeth and implants, connected or free standing, have shown similar implant-marginal bone outcomes.

Basic comparisons and mechanisms underlying foundational differences in mobility and support have been presented. An early implant design to accommodate for foundational differences between the tooth and the implant rigidity involved the use of a resilient plastic insert within the implant to adjust for the support difference between the natural teeth and the implants. Rangert et al. discussed the machined interplay of a conventional two-piece segmented machined titanium implant design that could potentially adjust for any differences in the tooth-implant connection and rigidity. Clinical analyses of success reports of teeth with rigid connections to implants have evaluated the bases for periodontally stable and healthy dentitions. Previous in vitro studies with rigid connections between teeth and implants have also reported a favorable stress distribution for the teeth under the condition of sound periodontal support.

Few recent studies have raised concerns regarding the prognosis of implants and teeth in periodontally compromised patients. Periodontally compromised patients were shown to have a greater implant success rate with the use of the conventional two-stage surgical placement protocol. Differences in implant surface configuration did not influence the success rates, that is, no differences in the success rates have been reported between the use of machined or rough titanium surface preparations in periodontitis-susceptible patients. A correlation has been shown between susceptibility to periodontitis and peri-implant bone loss. A slight increase in the implant failure rate was also shown in these patients (3.3% in non-periodontitis-susceptible patients vs. 8.0% in periodontitis-susceptible patients) over a ten-year period. No studies have reviewed the effects of the connection used between the implant and restoration under the periodontally compromised condition.

Recommendations for sufficient implant support to render the success of an implant restoration independent of the connection in natural teeth have been made. In the restorative situation where an increase in implant support is not tenable, the option of using rigid restorative connection between implants and teeth can be exercised. However, the effect of a periodontally compromised dentition connected to an implant has not been shown.

The effect of simulated bone loss around supporting abutments for conventional fixed or removable prosthetic restorations has been evaluated. Decreased periodontal support led to changes and increased stresses in the soft tissues or load transfer to connected tooth abutments. These effects of changes in the tooth support on connected dental implants have not been demonstrated previously. A previous study evaluated the effects of abutment design for teeth connected with a rigid attachment to simulated teeth using either segmented or non-segmented implant abutments. These abutment designs demonstrated similar load transfer results. The purpose of this study was to photoelastically compare the stress transfer among the fixed restorations supported by an implant restored with either a segmented or non-segmented implant abutment, and the implant connected tooth with decreased foundational support.

**Materials and methods**

A life-sized photoelastic model of an adult human left mandible was fabricated for quasi-three-dimensional testing and analysis (Fig. 1). The partially dentate model was edentulous posterior to the first premolar. Individual photoelastic simulators were used for the teeth (PLM-1, Measurements Group, Raleigh, North Carolina, USA), periodontal ligament (Solithane, Uniroyal Chem-
ical Co. Inc., Middlebury, Connecticut, USA), and body of the mandible (PL-2, Measurements Group) (Table 1). The photoelastic model was prepared using the master mold-and-pour resin technique which has been utilized previously. The model was made with a socket space for a tooth, which was subsequently placed and fixed with simulated periodontal ligament material.

The premolar abutment tooth was prepared with a standard metal ceramic shoulder bevel tooth preparation. A screw-type implant, 3.75 mm diameter and 13 mm length (3i; Palm Beach Gardens, Florida, USA) was directly embedded into the model at the position of the second molar. The distance between the premolar tooth and the second molar implant was 16 mm. Complete integration was obtained by pouring the plastic simulant of the mandibular body directly around the implants and allowing the resin to polymerize.

Conventional restorative techniques were used to fabricate the fixed prostheses. Gold-palladium alloy (550 SL, Leach and Dillon; N. Attleboro, Massachusetts, USA) cast to the machined gold abutment components (3i, Palm Beach Gardens, Florida, USA) of either one of two specified designs was used. The restorations were fabricated using either the segmented two-piece conical abutments (3i, Palm Beach Gardens, Florida, USA) or the non-segmented direct abutments (3i, Palm Beach Gardens, Florida, USA) (Fig. 2).

The restorative procedure was accomplished using transfer-type impression copings with polyvinyl siloxane impression material (Reprosil, Caulk/Dentsply, York, Pennsylvania, USA) and a custom tray. All restorations were fabricated upon stone casts. A silicone putty matrix (Coltene Laboratory Putty, Coltene/Whaledent, Mahwah, New Jersey, USA) was used to confirm the wax pattern dimensions of both restorations prior to the casting. The restorative solder joint connections were accomplished using conventional restorative techniques with resin indices (GC Pattern Resin, GC Dental, Tokyo, Japan).

The indices were made directly upon the photoelastic model. After soldering, the restorations were evaluated for passivity of fit on the model by placing the restorations on the photoelastic model and examining for stress in the field of a circular polariscope (Measurements Group); the polariscope reveals the presence of any stress within the model. No stress was observed, confirming passivity. All restorative dimensions were consistent with the base parameters of occlusal plane, arch form and arch relation.

The 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 (Measurements Group) by means of a calibrated load cell (100 pound low range transducing cell; GM2 Universal Transducing Cells, Camarillo, CA) mounted on the movable head of a loading frame (Fig. 3). Loads were monitored by a digital read-out after signal treatment with a strain gauge conditioner (Model 2130 and 2120A, Measurements Group). Vertical point loads were applied at fixed locations on the occlusal surfaces of the restorations. The loading points were identified as follows: point T - over natural abutment tooth; point 1 - midway between tooth and implant; point 2 - over implant; point 3 - distal to implant (Fig. 4). These loading points were marked with a round bur (No. 1; Dentsply International, York, PA) to ensure reproducibility and facilitate point load placement. The magnitude of the loads applied over the implant areas was 133 N. The magnitude of the load over the simulated tooth was reduced to 89
N to reflect anterior tooth location. These loads were selected because they are realistic functional load levels and also provide a satisfactory optical response within the model. The resulting stresses in all areas of the model were monitored and recorded photographically in the field of a circular polariscope. Each loading and observation sequence was repeated at least twice to ensure reproducibility of the results.

After loading the model with normal support, the loss of periodontal support on the tooth abutment was simulated by the removal of 4 mm of the material from the facial and distal aspects of the tooth to create a 4 mm bony defect in the buccal and distal-buccal regions (Fig. 5).

The fringe pattern findings were collected for the loading conditions with full and simulated reduced periodontal support. Observations of fringe patterns caused by the various loading conditions were made on scanned data photographs, which were subsequently viewed with a computer graphic program (Photoshop 4.0, Adobe Systems, Inc., San Jose, CA). Fringe observations were accomplished after monochromatic mode changes that facilitated fringe observation in regions of closely spaced fringes.

**Results**

In the presentation of the stress data below, the following terminology has been adopted: a) low stress - 1 fringe or less; b) moderate stress - between 1 and 3 fringes; and c) high stress - more than 3 fringes.

**Normal support** (Fig. 6 and 7)

The load applied to the tooth concentrated the stress within the tooth and apically, for both segmented and non-segmented abutment situations. A lower level of stress was transferred to the implant in both abutment situations. Stresses were distributed to the mesial crest, mesio-apical area and distal crest. The magnitude of stress on the mesial crest was higher than that on the distal crest.

As the loading points were moved to the pontic region (point 1), a larger proportion of the load was transferred from the tooth to the implant, for both abutment types. Load towards the implant gradually decreased the stress around the
tooth and proportionally increased it in the implant. Loading directed upon the implant transferred a very low level of stress to the tooth. Loading above the implant and distal edge of the implant showed highest peri-implant stresses for both abutment types.

In comparing the two abutment types, slightly higher stress was transferred at the mesial crest of the implant for the segmented abutment under all loading conditions. However, the overall stress distribution was quite similar for both non-segmented and segmented abutments.

**Buccal and distal defect (Fig. 8 and 9)**

Loading on the tooth produced stress of a similar magnitude and distribution around the tooth in both the segmented and non-segmented abutment situations. With loading at the tooth and at point 1, the stresses were greater in the presence of a distal buccal defect than in the non-defect condition. Loading over the implant and the distal load point yielded similar results in both the defect and non-defect models. The stress distributions were similar for both segmented and non-segmented abutment load points.

Loading between the tooth and the implant generated more stress around the apical and distal aspect of the implant. As the load point was moved towards the distal implant abutment, the effects of any changes of the supporting structure or implant abutment design was reduced. The magnitude and distribution of the stresses were similar when loads were applied on the implant loading points for comparison with the smaller buccal defect load-testing condition. Loading at point 3 directed on the distal edge of the implant resulted the highest observed stresses around the implant.
Discussion

The suitability of connection of implants to natural teeth has been controversial. The basis for this controversy is the dissimilar mobility between the teeth and the osseointegrated implants. Although clinical reports have documented successful usage successes, the potential limitations of the tooth/implant restorative option have not been evaluated.

It has been suggested that fixed splinting redistributes forces to supporting structures. However, most of the clinical studies have been conducted on periodontically sound teeth. There always exists the possibility of a change in the periodontal support of any fixed prosthetic tooth supporting abutment. The placement and restoration of dental implants for the distal extension edentulous ridge requires provision of sufficient implant support to render the restoration independent of the restorative tooth connection. Non-connection options include single tooth implant restorations, and the use or incorporation of various types of overdenture-type implant abutments and attachments.

This study investigated the effect of change of the periodontal support of a tooth-implant restoration on the distribution of stresses with a photoelastic model. The loads transferred to the supporting bone simulator varied depending on the loading points. Loading on the tooth generated stresses around the tooth and the stresses were transferred to the implant. Loading on the implant transferred the least stress to the tooth. In this study, the stress was concentrated at the mesial crest around the implant connected to the simulated periodontal tooth. The loss of the supporting structure of the tooth increased the magnitude of the stress around the distal implant. These results were similar to those obtained in the condition where a tooth was connected to an implant via a non-rigid attachment. The observations suggest that the stress around the implant exhibited a mesial cantilever effect.

The prosthetic consideration of a rigid soldered connection between the tooth and implant abutments was used in this study. Although advantages of non-rigid connections have been reported, clinical success with avoidance of the risk of tooth intrusion requires utilization of the rigid connection design. Abutment selection is also considered for tooth restoration. Two different abutment designs were compared for their possible effects on the stress transfer between a simulated tooth and implant. A standard two-piece segmented abutment has been postulated to allow some mechanical flexibility or interplay based on the fit and design tolerance of the abutment components. In this study, the comparable stress distribution obtained with both types of abutment in this model demonstrate relative interchangeability of these two abutment designs, which are consistent with our previous results. There may be an economic and cost benefit related to the use of a non-segmented abutment. However, slightly greater stress fringes were observed in the distal-buccal defect with the use of the segmented abutment. Any decrease in periodontal support increases the potential movements and the transfer of load through the abutment.

The clinical selection and design of any tooth-implant restoration must be based on several parameters. These parameters include the implant length, width, position and angulations, occlusion, and prognosis of periodontal tissues. Based on the findings of this study, connection of a single implant to teeth with varying support cannot be recommended. Consideration of either the segmented or the non-segmented abutment may yield similar results in terms of the expected transfer of stresses to the abutment-implant connection. Should a combined restoration be required, the restorative design should include consideration of the complications of the use of abutments, including tooth intrusion, screw loosening and fracture. Design and restoration retrievability for any tooth-implant combined restoration is highly recommended.

Conclusion

This investigation used photoelastic techniques on a model of a mandible to study the effect of decreased fundamental support of simulated natural teeth on the stress distribution. The merits of segmented and non-segmented implant abutments were also considered. Simulated vertical mastication forces were applied and the resulting stresses were documented.

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

1. Decrease of fundamental support of the tooth
resulted in stress concentration around apex of the tooth and mesial crest of the implant.

2. The magnitude and distribution of the stresses observed using segmented and non-segmented abutment designs were similar for the tooth-implant supported situation.

3. The magnitude of stresses was slightly greater with the use of the segmented abutment as compared with that of the non-segmented abutment design.

4. Connection of a single implant to the respective tooth should be carefully executed based on the clinical criteria.

References


