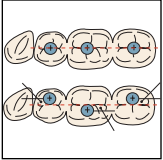


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## Biomechanical Comparison of Straight and Staggered Implant Placement Configurations



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*The effect of buccolingual staggered implant placement on stress distribution within the supporting structure was examined photoelastically. Two photoelastic models of a human mandible, edentulous distal to the canine, were fabricated. Three screw-type implants were embedded into the edentulous region of each model. The implants were placed in a straight line in one model and in a buccolingual staggered configuration in the other. Vertical and lateral loads were applied to a fixed partial denture superstructure. No clear biomechanical advantage to a staggered 1.5 mm buccal and lingual offset placement configuration was observed. (Int J Periodontics Restorative Dent 2004;24:47–55.)*

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Overloading is considered to be one of the main causes of implant failures.<sup>1–4</sup> Clinical and experimental studies have concluded that overloading can lead to loss of osseointegration.<sup>5–9</sup> Also, it has been suggested that risk for overload is higher in partially edentulous cases compared with completely edentulous cases.<sup>4</sup> Application of osseointegrated implants for partially edentulous patients is increasing.<sup>9–14</sup> However, observation periods are relatively short in general,<sup>15</sup> and stress transfer characteristics of partial implant-supported prostheses have not been documented well compared with completely edentulous or single-tooth replacement cases. Among partially edentulous patients, distal extension cases are challenging because bone quality is often poor in the posterior region.<sup>1,16</sup> In addition, there are anatomic limitations, such as the inferior alveolar nerve or maxillary sinus,<sup>1,17</sup> and occlusal forces are higher compared to the anterior section.<sup>1</sup>

Treatment considerations, such as use of wide-diameter implants, to reduce the potential for generation



**Fig 1** Three-dimensional photoelastic model with three implants in the posterior region.

of high stresses in the supporting bone have been recommended clinically.<sup>18–20</sup> Another possible approach to reduce a risk for overload is the placement of implants in a buccal and lingual offset configuration, rather than the more usual straight-line placement scheme.<sup>3,4</sup> While the effectiveness of this approach in reducing implant overload has yet not been proven clinically, some mathematic analyses have been performed for individual, nonsplinted implant-supported restorations.<sup>21</sup> It was shown for these conditions that the moment on the prosthetic components could be reduced depending upon the occlusal force pattern.<sup>21</sup> Those authors suggest that the favorable effects are more likely to occur in the mandible than the maxilla.

Neither that study nor others have considered the effects of a staggered buccolingual implant placement scheme on the stresses generated within the supporting bone. Therefore, the purpose of this study was to compare photoelastically the stresses generated by a

**Table 1** Photoelastic modeling materials

Tissue	Simulant	Elastic modulus (MPa)	Poisson's ratio
Mandibular bone	PL-2 (Measurements Group)	207	0.42
Canine	PLM-1 (Measurements Group)	2,931	0.36
Periodontal ligament	Solithane (Uniroyal Chemical)	7	0.45

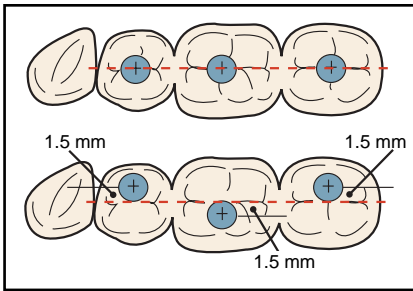
staggered implant configuration with those generated by implants placed in a straight line.

### Method and materials

Two life-size photoelastic models of an adult human left mandible were fabricated for quasi-three dimensional testing and analysis (Fig 1).<sup>22</sup> The partially dentate models were edentulous distal to the canine. Individual simulant materials were used for the body of the mandible, canine, and periodontal membrane (Table 1). Three screw-type 13-mm implants (3i) of 3.75 mm diameter were included into the edentulous region of each model. The condition representing complete integration was obtained by pouring the plastic simulant of the mandibular body directly around the implants and allowing the resin to cure. The implants were placed in a straight configuration line in one model and in a buccolingual staggered (offset) configuration in the other. For the staggered configuration scheme,

the anterior and posterior implants were located 1.5 mm lingually compared to the straight-line configuration; the middle implant was 1.5 mm buccally (Fig 2). The amount of offset was selected in accordance with a previous investigation.<sup>21</sup> The mesiodistal location of each implant was the same in the two implant placement schemes.

Standard 3.0-mm abutments (3i) were screwed on the implants with titanium abutment screws for all specimens. Restorations were fabricated using a dental casting alloy (Castwell MC, GC) cast to the machined gold abutment components (3i). The dimensions of the two restorations were kept constant with use of a silicone putty matrix. Therefore, all variables except for buccolingual location of the implants were the same between the two models. Restorations were screwed on the abutments with gold retaining screws (3i), and the abutment and retaining screws were tightened with screwdrivers (3i) as tightly as possible by hand.



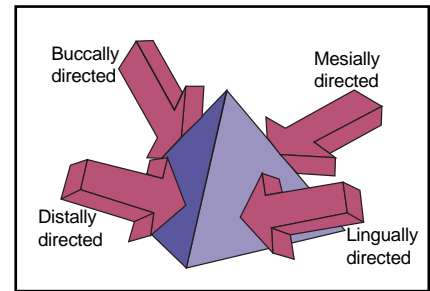
**Fig 2a** (left) Location of implants: straight placement configuration, top; staggered placement configuration, bottom.

**Fig 2b** (right) Occlusal view of models (straight configuration, top; staggered configuration, bottom) illustrates implant locations relative to mandibular bone model morphology. Note that bone around implants becomes thinner on one side for staggered configuration.



**Fig 3a** (left) Locations of load point applications: Vertical load is applied separately to each location.

**Fig 3b** (right) Loading pyramid used for lateral loading. Load is applied separately on each surface.

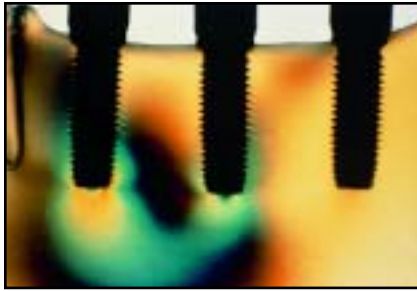


Simulated vertical and lateral functional loads were applied to the prostheses at fixed locations. Vertical loads were applied at the locations of the central fossa of each artificial crown (Fig 3a). The magnitude of vertical load was 89 N for the premolar region and 134 N for the molar regions to reflect the higher bite force in the posterior region. Lateral loads toward the buccal, lingual, posterior, and anterior directions were applied by means of a metal loading pyramid attached on the prostheses with cold-cure resin (Fig 3b). The pyramid was placed sequentially over the anterior and middle implants. The location of the pyramid was such that its apex was just above the buccolingual and mesiodistal center of the occlusal surface of each crown. The magnitude of lateral load

<b>Table 2</b>		<b>Applied loads (N)</b>		
<b>Load direction</b>	<b>Anterior implant</b>	<b>Middle implant</b>	<b>Posterior implant</b>	
Vertical	89	134	134	
Anterior	67	89	—	
Posterior	67	89	—	
Lingual	67	89	—	
Buccal	67	89	—	

was 67 N for loading on the anterior implant and 89 N for the middle implant. These load levels (Table 2) were selected because they are realistic functional load levels and provided a satisfactory optical response within the model.

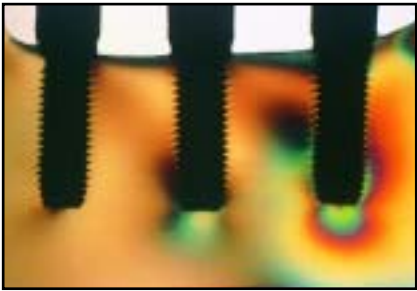
The models were immersed in a tank of mineral oil to minimize surface refraction and thereby facilitate photoelastic observation within the field of a circular polariscope arrangement. After the curing process and prior to load application, the



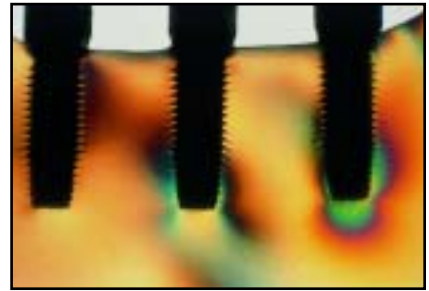
**Fig 4a** (left) Stresses produced by 89-N vertical load upon anterior implant: straight configuration model.



**Fig 4b** (right) Stresses produced by 89-N vertical load upon anterior implant: staggered configuration model.



**Fig 5a** (left) Stresses produced by 134-N vertical load upon posterior implant: straight configuration model.



**Fig 5b** (right) Stresses produced by 134-N vertical load upon posterior implant: staggered configuration model.

models were confirmed to be essentially stress free. Passivity of the restorations was also demonstrated following restoration placement and screw tightening. Consequently, the stress patterns that developed under subsequent load were attributable to the applied load and were recorded photographically. Isochromatic fringes represent stress distribution within the photoelastic models, and fringe order, which is proportional to principal stress difference, indicates stress intensity. For each loading condition, load-induced photoelastic effects were photographed. Photographic results were scanned and analyzed in detail on a computer monitor.

## Results

### *Vertical loading on central fossae*

In both straight and staggered configurations, loading directed upon the anterior implant was borne almost entirely by the anterior and middle implants (Fig 4); there was very little transfer to the distal implants. The straight placement configuration tended to transfer load more axially and developed higher stress at the apical region of the anterior implant (straight configuration, almost 2.0 fringe orders; staggered configuration, slightly lower than 1.5 fringe orders). The staggered configuration

developed higher and more asymmetric stress around the apex of the middle implant, being highest at the distal aspect.

When the load point was moved to the middle implant, the location of the highest stress transfer shifted posteriorly for both implant placement configurations. The straight configuration tended to transmit load more axially, with stresses localized at the apical quarter of the middle and posterior implants. The staggered configuration produced somewhat higher stress, approximately 0.5 fringe order higher, localized at the distal aspect of the apex of the middle implant.

Loading directed upon the posterior implant produced the highest stresses of all three vertical fossa loadings (Fig 5). These high stresses were localized at the apical region and the crest distal to the neck of the posterior implant for both placement configurations. Stresses around the posterior implant apex were higher at the distal aspect (2.5 fringe orders). This distribution indicated a distal tipping of the posterior implants. Some differences between the straight and staggered configurations were seen at the apex of the middle implant and the posterior implant crestal stress. At the middle implant, the staggered configuration developed higher stress compared with the straight configuration. Around the posterior implant, higher stress developed at the apex and mesial aspect of the neck of the posterior implant with the straight configuration. As was seen for the other two vertical fossa loadings, there was no large difference in the maximum stress intensity or distribution between the straight and staggered placement configurations.

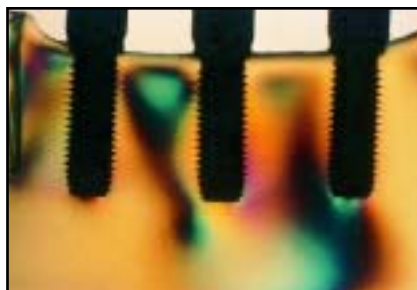
#### *Lateral loading*

Under lateral loading, the pattern of stress distribution varied greatly depending upon the direction of loading. When a buccally directed load was applied over the middle implant, the stress was localized around the middle implant and near the mesial crest of the anterior implant for both models (Fig 6). The staggered configuration localized

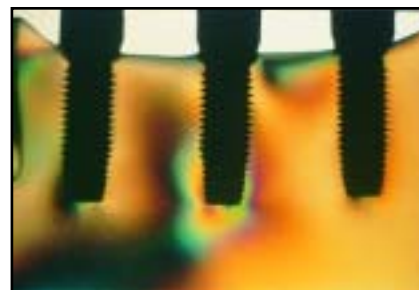
higher stress at the apical region of the middle implant (2.0 fringe orders for straight configuration and 1.5 fringe orders for the staggered configuration), while the straight configuration transferred more load to the mesial crest of the anterior implant and crestal region between the anterior and middle implants.

When lingually directed load was applied on the middle implant, clearer differences in stress distribution were noted between the two configurations (Fig 7). However, the location of the highest stress was at the mesial crest of the anterior implant for both placement configurations. Crestal stress between the anterior and middle implants was higher and more extensive for the staggered configuration, but higher stress developed along the distal aspect of the posterior implant for the straight configuration. The differences were approximately 0.5 fringe order. The staggered configuration tended to show more axial stress distribution compared with the straight configuration.

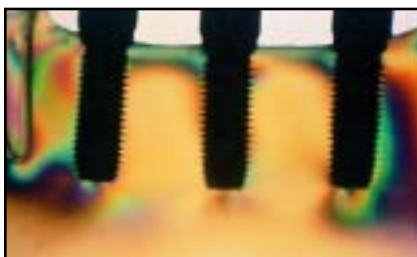
For both placement configurations, anteriorly directed loads applied over the middle implant produced higher stress at the mesial aspect of the anterior implant than for the other two implants. The stresses between the anterior and middle implants and at the apex of the anterior implant were higher for the staggered configuration, within 0.5 fringe order difference. Only very low stress, no more than 1.0 fringe order, was generated around the posterior implant for both implant placement configurations.



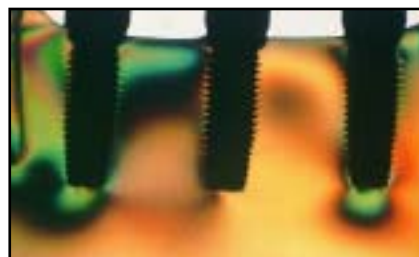
**Fig 6a** (left) Stresses produced by 89-N buccally directed load upon middle implant: straight configuration model.



**Fig 6b** (right) Stresses produced by 89-N buccally directed load upon middle implant: staggered configuration model.



**Fig 7a** (left) Stresses produced by 89-N lingually directed load upon middle implant: straight configuration model.



**Fig 7b** (right) Stresses produced by 89-N lingually directed load upon middle implant: staggered configuration model.



**Fig 8a** (left) Stresses produced by 89-N posteriorly directed load upon middle implant: straight configuration model.



**Fig 8b** (right) Stresses produced by 89-N posteriorly directed load upon middle implant: staggered configuration model.

Similar stress distributions were generated by both placement configurations under posteriorly directed loading on the middle implant (Fig 8). The load was transferred primarily to the posterior implant and was manifested by higher stresses around the distal apex and implant neck compared with the two other implants. The stress observed around the anterior and middle implants was no greater than 1.0 fringe order.

Lateral loads applied at the anterior implant produced stresses of lower intensity compared with the results of loading to the middle location, reflecting a smaller load level. In general, the distribution and intensity of stresses were similar for both implant placement configurations. Under anterior loading, higher stresses developed along the mesial length and crest of the anterior implant. Load transfer to the middle implant was seen at the crest

between the anterior and middle implants and at the distal crest and apex. The posterior implant exhibited stress at the distal crest and along its length. The staggered placement demonstrated slightly higher stresses (less than 0.5 fringe order).

For buccally directed loads on the anterior implant, the highest stress was observed around the apical half of the anterior implant and localized at the apex with the

straight configuration. Only low-level stresses, just the beginning of 1.0 fringe order, were transferred to the other implants. Compared to straight placement, the staggered configuration produced lower-level stresses around the apical half of the anterior implant. Increased sharing of the load was seen near the apex of the middle implant and uniformly around the posterior implant for the staggered configuration.

For both placement schemes, lingual loading on the anterior implant produced responses along the mesial length of the anterior implant and localized stresses at the mesial and distal crests. Higher stresses (1.0 fringe order) were noted with the staggered configuration. There was some transfer to the middle and distal implants for both configurations. Posterior loading on the anterior implant was distributed to all three implants, mainly along their distal apical aspects. Somewhat higher stresses (less than 0.5 fringe order) developed at the middle and posterior implants for the straight configuration.

## Discussion

The present study considered the effect of staggered implant placement on load transfer in a three-unit fixed posterior implant-supported prosthesis. The concept of staggered placement of implants in posterior edentulous cases originated from complete bone-anchored bridge, where implants are placed in a nonlinear arch configuration.<sup>4</sup>

Based on the long-term clinical success of such nonlinear implant placement for completely edentulous patients,<sup>23-25</sup> buccal and lingual offset was proposed to be an effective way to reduce potential risk of overload for posterior partial implant-supported prostheses.<sup>3,4</sup>

From the results of the present study, some differences in stress production in the supporting structure did exist between the two implant placement configurations, but no clear stress-reduction effect of staggered placement was observed. For example, for vertical loading, higher stress was developed around the middle implant in the staggered placement configuration, regardless of location of load application. Also, buccally directed load developed higher stress around the middle implant for the staggered configuration. On the other hand, higher stresses were developed around the anterior and posterior implants with the straight configuration under some loading conditions (eg, lingually directed loading). The superiority in terms of stress distribution between the straight and staggered configurations was not consistent and was highly influenced by loading conditions. Staggered placement can increase or decrease stresses depending upon occlusion or the location of the implants. However, the differences between these two implant placement schemes were not large, within 0.5 fringe order in most cases. Therefore, the differences observed may not be great enough to cause significant differences in biologic

response between the two implant placement schemes.

Since the width of the edentulous ridge is usually limited because of bone resorption, it is very difficult, maybe impossible, to place implants in large offset positions aiming at a greater stress-reduction effect in the majority of cases. Thus, the amount of offset would be necessarily much smaller for posterior partially edentulous situations than for completely edentulous cases. Therefore, offsets that can be made in the posterior region may not be sufficient to achieve a substantial stress-reduction effect against the straight placement configuration. This is most likely why substantial differences in stress distribution and intensity between the two placement configurations were not observed in the present study. Even if the edentulous ridge was wide enough to place implants in larger offset positions, extreme offsets result in longer buccolingual cantilevers, which may increase bending moment and lead to overloading.<sup>4,26,27</sup>

Since the buccolingual width of the alveolar ridge is limited, offset placement of implants will lead to thinner remaining bone on one side. However, sufficient bone thickness is necessary around implants to withstand occlusal load. In this study, there was a general tendency for high stresses to be concentrated at the buccally placed middle implant in the staggered placement configuration. Taking this tendency into account, staggered placement may increase risk for overload and consequent bone resorption at the

middle implant where the remaining buccal bone is thin. Also, offset placement may increase the risk of lateral perforation during implant osteotomy. Perforation of the mandibular lingual cortex in the canine and first premolar region could injure the lingual artery or its branches.<sup>28</sup> Therefore, risk and benefit should be assessed not just from restorative standpoints when the location of implant placement is planned.

Offset placement of implants under some occlusal loading conditions caused improvement of the torque on the restoration-implant components when calculating torque on each individual unsplinted implant.<sup>21</sup> No direct reconciliation of those results with the present study is possible, since the current analysis deals with the stresses in the supporting structure of a splinted situation. However, a common conclusion of these studies is the importance of occlusion for the load-induced stresses in the supporting structure and for the torque at the individual restoration-implant components.

It has been suggested that posterior implant-supported prostheses should disclude in eccentric positions, when healthy anterior teeth are available, to prevent overloading from laterally directed loads.<sup>27,29,30</sup>

The results from this investigation support this clinical recommendation, since laterally directed loads tended to produce higher, nonuniform stresses within the supporting structure than did vertical forces. Stresses caused by lateral loading

were not always highest at the loaded implant, as was observed for vertical loading, regardless of the implant placement configuration. Therefore, if the lateral component of occlusal force is strong, bone resorption caused by overload may take place not only just below the high occlusal contact, but also at distant locations, depending upon the direction of loads.

In general, load applied at a particular location from opposing directions generated somewhat different stress distributions. The explanation for this observation lies in the shape of the model. Since the shape of the experimental models was made similar to that of a real mandible, the long axes of the implants were not perpendicular to the horizontal plane, but slightly inclined lingually. Also, the width of the alveolar ridge was narrower at the premolar region than the posterior region. These factors may be why the results of load from opposite directions, even for the straight configuration models, were different, especially for buccal and lingual directions. This finding suggests that volume and shape of available bone may also influence the stress distribution within the supporting structure.

## Conclusions

The staggered placement changed stress distribution, but did not provide overall improved stress conditions in the supporting structure as has been advocated. No clear advantage for one placement

configuration over the other could be found, consistent with a recent finite element study.<sup>31</sup> Therefore, both the straight and staggered placement configurations can be employed clinically, provided sufficient bone is present. Since the results were highly dependent upon the location and direction of loading, consideration of the patient's occlusion will be very important. Occlusion should be designed carefully so that a more favorable stress transfer can be obtained by not generating lateral forces.

Within the limits of the model system used in this study, the following conclusions were drawn:

1. Location and direction of loading had a great influence on the stress-transfer characteristics of both placement configurations.
2. For vertical and buccally directed loads, the staggered configuration tended to reduce stresses around the anterior and posterior implants, but increased stresses around the middle implant. However, differences between the two placement configurations were not large.
3. The staggered placement configuration changed the stress distribution, but did not reduce overall stress substantially.

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