Effect of Offset Implant Placement on the Stress Distribution Around a Dental Implant: A Three-Dimensional Finite Element Analysis

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There are some anatomical restrictions in which implants are not possible to be inserted in their conventional configuration. Offset placement of implants in relation to the prosthetic unit could be a treatment solution. The aim of this study was to evaluate the effect of the offset placement of implant-supported prosthesis on the stress distribution around a dental implant using 3D finite element analysis. 3D finite element models of implant placement in the position of a mandibular molar with 4 configurations (0, 0.5, 1, 1.5 mm offset) were created in order to investigate resultant stress/strain distribution. A vertical load of 100 N was applied on the center of the crown of the models. The least stress in peri-implant tissue was found in in-line configuration (0 mm offset). Stress concentration in the peri-implant tissue increased by increasing the amount of offset placement. Maximum stress concentration in all models was detected at the neck of the implant. It can be concluded that the offset placement of a single dental implant does not offer biomechanical advantages regarding reducing stress concentration over the in-line implant configuration. It is suggested that the amount of offset should be as minimum as possible.

Key Words: biomechanics, bone stress, dental implants, finite element analysis, occlusal load, stress distribution

INTRODUCTION

Currently, the replacement of a single missing tooth using implant-supported fixed prosthesis is a widely accepted treatment modality. Although success and survival rates of single-implant restorations are considered to be high, there are still cases of failure.1–3 The clinical success and longevity of restoration with an implant-supported prosthesis are highly influenced by biomechanics of oral implants, load distribution at the implant-bone interface, and transfer of mechanical stresses to the surrounding bone.4–5

Conventional placement of dental implants is not indicated in some anatomical restrictions such as proximity of the maxillary sinus or mandibular canal to the implant in molar region. However, in some cases, mild anatomical restriction could be managed with inserting the implant in an offset configuration in relation to the prosthetic unit. In addition, the offset placement of dental implants can lead to an optimal aesthetic restoration by reduction of emergence profile and to facilitate the dental hygiene in the posterior mandible region.6 However, there are some concerns regarding the biomechanics of offset implants and stress distribution in their surrounding tissue due to the nonaxial forces applied to these implants.7–11 Thus, it is important to ensure whether stress distribution occurs in a safe manner around the offset implants.

Stress distribution around dental implants has been assessed using a wide variety of methods. Three-dimensional finite element analysis (3D-FEA) has been frequently used in the dental implant field to predict stress distribution patterns in the implant components and the surrounding bone.12–15 FEA model enables researchers to simulate various clinical scenarios and to determine the best option from a biomechanical perspective. The latter is of paramount importance since stress distribution in peri-implant bone is considered a key factor for the success of dental implants.12

Offset implant placement has been widely reported in the case of prosthesis supported by 3 implants.16–22 Although it has suggested that an offset implant placement in the case of prosthesis supported by 3 implants due to its tripod effect would offer biomechanical advantageous,16,17 studies investi-
gating biomechanical effects of this offset configuration using finite element analysis have demonstrated contradictory results. However, the biomechanics of a restoration supported by a single implant is quite different with those of fixed partial dentures supported by 3 or more implants. In the case of 3 or more implants, a single load applying at the splinted restoration can induce varying degrees of stresses or strains in all implants and adjacent bone. Accordingly, the outcomes of the studies evaluating biomechanical properties of fixed partial dentures supported by 3 or more implants might not necessarily be extrapolated to the situations that a restoration is supported by a single implant. Unlike the cases of the offset implant placement in 3-unit fixed implant-supported partial dentures, very little information is available regarding the biomechanical effects of an offset implant placement when treating a single implant. Therefore, the aim of this study was to assess the effect of the offset implant placement on the stress distribution around a dental implant using 3D finite element analysis.

**MATERIALS AND METHODS**

Four 3-dimensional (3D) finite element models were designed of a segment of mandible. Each model contained a 1-piece implant, cortical and spongy bone, and a metal-ceramic crown on the implant. The models were the same except for the exact location of the crown in relation to the implant long axis. The center of the crown coincided with the implant long axis in model A and shifted mesially 0.5 mm, 1.0 mm, and 1.5 mm in models B, C, and D, respectively (Figure 1). A symmetrical crown to the implant long axis was simulated in model A. Asymmetrical crowns were simulated in models B through D where the implant was not exactly at the mid span between the 2 remaining teeth. The implant dimension was 4 × 10 mm. SolidWorks 2010 software package (SolidWorks Corp, Concord, Mass) was selected for the modeling phase. The models were then transferred to the ANSYS Workbench version 11.0 (ANSYS Inc, Canonsburg, Pa) for analysis. Mechanical properties of the materials used were applied (Table 1). Models were meshed with 85,551 to 86,663 nodes; 52,304 to 52,913 elements. All nodes at the base of the model were restrained so that all rigid body motions were prevented. A vertical force of 100 N was applied on the center of the crown. Contact elements were defined between parts. The von Mises stress of the bone in the distal side of the implant from the crestal down to the apical was recorded in both cortical and spongy bone.

**RESULTS**

The stress concentration in the peri-implant tissue was in proportion to the amount of offset placement. As the amount of offset placement increased, stress concentration increased
By increasing the amount of offset placement from model A to model B, C, and D, stress concentration around the implant neck increased 28.88%, 59.23%, and 211.60%, respectively.

During loading, maximum stress concentration in each model was detected around the neck of the implant, which was minimum in model A (8.67 MPa) and maximum in model D (18.9 MPa). In all models, stress concentration in peri-implant tissue decreased slightly from the neck to the apex of implant (Table 2). Additionally, as the distance from the implant increased, stress distribution in bone decreased.

By descending in implants from neck to apex, the stress concentration discrepancy between 4 models decreased (Figures 2 and 3). After the fourth thread, the stress distribution in all 4 groups was very close to each other (<1 MPa), and the difference was not considerable.

### DISCUSSION

The present study aimed to investigate the stress distribution around a single dental implant placed offset in relation to the axis of the prosthetic unit in the mandibular posterior region. Three dimensional finite element analysis, simulating a vertical force of 100 N applied on the center of the crown of the models, was used to achieve this purpose. The key finding of the present study was that stress concentration in the peri-implant tissue increased by increasing the amount of offset placement.

A main factor influencing the final success or failure of implant-supported restorations is the manner in which stresses are transferred to the implant and surrounding bone.\(^{12,23}\) The present results showed that stress concentration in peri-implant tissue in different configurations of offset placement was more than that of in-line configuration. It can be attributable to the increased length of the prosthetic beam leading to inappropriate stress distribution in the fixture and surrounding bone, which is not directed to the long axis of the fixture.

The present findings are in disagreement with those of Weinberg and Kruger who investigated mathematically the biomechanical advantages of an offset placement of a single implant using a 2-dimensional model.\(^{24}\) They reported that the lingual offset of the mandibular implant decreased the torque at the gold screw. However, they investigated the effect of buccal or lingual offset placement configuration, but not the mesial or distal offset. The present results are also partially in disagreement with those of Anitua and Orive who compared the effect of the distal offset configuration of a single implant-supported prosthesis on bone stress distribution with that of straight alignment using Finite Element Analysis.\(^{6}\) They indicated that the offset implant placement produced less stress compared to the straight configuration. This disagreement can be explained by the fact that conditions they evaluated were quite different from those of the present study. In Anitua and Orive study, static loads of 200 N and 230 N were applied on the mesial and distal borders of the prosthetic unit, respectively. On the other hand, in the present study, a vertical force of 100 N was applied on the center of the prosthesis. Since the load transfer from implants to surrounding bone largely depends on the type and direction of loading,\(^{12}\) the difference in the direction of the loads between the 2 studies could be partially responsible for the disagreement. Moreover, it should be noted that material properties of mandible are other key factors that could greatly affect the predictive accuracy of the FEA studies.\(^{12,25,26}\)

The results of the present study revealed that the maximum stress concentration in all groups was located around the neck of the implant, and it decreased slightly from the neck to the apex. The present finding is in line with the results of other studies that have reported overloading occurred in the superior region of the cortical bone around the contact area with the implant.\(^{6,19,21,27–29}\) This finding could explain why bone loss initiates mostly from the alveolar crest. Failure to achieve appropriate stress distribution would lead to increased stress concentration around the implant neck. This stress could

<table>
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<th>Bone Type</th>
<th>Thread Number</th>
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<th>1 mm</th>
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<td>13.819</td>
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<tr>
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<tr>
<td>Spongy</td>
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<td>0.442</td>
<td>0.421</td>
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<tr>
<td>Spongy</td>
<td>12</td>
<td>0.396</td>
<td>0.419</td>
<td>0.427</td>
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</tr>
</tbody>
</table>
surpass the elastic limit of the bone and cause microfracture and bone loss at the neck of the implant.\textsuperscript{22,30} The present finding also highlights the importance of the presence of good quality cortical bone around the implant neck that can tolerate the maximum stress concentration. Moreover, it was found that the stress values after the third thread were quite similar in all four groups, indicating that most of the stress in bone is located in the first 3 threads of the dental implants independently of the offset or in-line configuration of the implant.

In another way, the offset placement of the implant could be considered as a kind of implant-supported cantilevered fixed partial dentures (ICFPD). Accordingly, the present findings might be comparable with those of studies reporting stress concentration around implants with cantilever extension is more than implants without cantilever extension.\textsuperscript{8–11,31} This stress is shown to be proportional to the length of cantilever,\textsuperscript{23} and it might lead to problems such as screw loosening,\textsuperscript{32} bone resorption, and compromised longevity of implant-supported prosthesis.\textsuperscript{33,34} The present results also showed that the stress concentration in peri-implant tissue increased as the amount of offset placement increased. Accordingly, this study is in accordance with studies which investigated cantilevers and reported that the amount of stress concentration in bone surrounding the implant increases as the length of cantilever extension increases.\textsuperscript{35,36}

Although bone loss and stress concentration in implant and supporting bone increase in ICFPDs,\textsuperscript{8–11,31} the 5- and 10-year ICFDP cumulative survival rates are reported to be 94.3% and 88.9%, respectively; therefore, ICFDPs are considered as a reliable treatment option.\textsuperscript{31} These high survival rates could be attributable to several rules and guidelines such as splinting implants and using anterior-posterior spread, which are followed by clinicians for the safe length of cantilever.\textsuperscript{15,35–37} Following these guidelines would reduce the harmful biomechanical effects and result in acceptable outcomes. However, small hidden cantilevers in the prosthetic reconstructions such as offset implant configurations could produce similar high stress as the long cantilevers since no guideline are followed to manage them. In a study evaluating the influence of cantilever

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure2.png}
\caption{The von Mises stress distribution of models. In-line (a), 0.5 mm (b), 1 mm (c), and 1.5 mm (d) offset placement.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure3.png}
\caption{The von Mises stress along the implant (from crest to the apex) of different groups.}
\end{figure}
length on the stress distribution, increasing the cantilever length from 10 mm to 15 mm led to 30% increase in the stress concentrated at the implant-abutment surface. This amount of increase in the stress at the neck of the implant was found in the current study (32.8%) when the amount of offset placement increased only half a millimeter (from 1 mm to 1.5 mm). Based on these results, it is suggested that the amount of offset should be as minimum as possible.

It should be noted that there are some limitations associated with the present study. As in previous studies, it was assumed that implants were completely osseointegrated; however, 100% ratio of osseointegration between the implant and bone does not occur in the clinical setting. Nevertheless, since this assumption was applied to all models, it most probably would not influence the final conclusion. In addition, in the present study, a vertical load was applied on the center of the crown in all models. However, in the clinical setting, complex patterns of force vectors such as oblique and horizontal forces are applied on a dental implant. Therefore, although finite element analysis closely simulates the clinical condition, these limitations should be taken into account when a clinical application is envisaged.

CONCLUSION

Within the limitations of the present study, it can be concluded that the offset placement of a single dental implant does not offer biomechanical advantages regarding reducing stress concentration over the in-line implant configuration. The stress concentration in peri-implant tissue in different configurations of offset placement was more than that of in-line configuration.

In the offset configuration, the amount of stress concentration in the peri-implant tissue increased by increasing the amount of offset placement. Therefore, it is suggested that the amount of offset should be as minimum as possible.

ABBREVIATIONS

3D: three-dimensional
3D-FEA: three-dimensional finite element analysis
ICFPD: implant-supported cantilevered fixed partial dentures

REFERENCES


