The effects of splinting periodontally compromised removable partial denture abutments on bone stresses: a three-dimensional finite element study

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Background/purpose: Periodontally compromised abutments complicate the treatment plan of distal extension removable partial dentures. The objectives of this study were: (1) to determine if splinting a tooth with reduced bone height to a healthy one is beneficial to the weak one; (2) to investigate fixed splinting of two teeth (the first and second premolars) with various alveolar support levels on bone stress around the periodontal construction according to different crown to root ratios of the periodontally compromised abutment; and (3) to assess the efficiency of splinting in the presence of non-axial loads.

Materials and methods: Thirteen three-dimensional finite element models were designed that included the mandibular first and second premolars and the surrounding bone. Ten models were similar except for the alveolar bone height around the second premolar that had different amounts of bone resorption of 0−9 mm with splinted teeth. The last three were the same except for the teeth which were not splinted. A vertical force of 25 N was applied to each occlusal surface of the premolars. Finally, von Mises stress was evaluated at three points for all models. In the first stage, the efficiency of splinting was assessed. In the last stage, the effects of non-axial loads were evaluated in the splinted teeth models.

Results: In stage 1, it was shown that splinting could redirect the stresses to apical areas and prevented crestal bone from increased stress. In stage 2, the findings of von Mises stress in the apical area of the first premolar were almost the same in all models. In the apical area of the second premolar and the alveolar crest area, the bone stress increased when the height of the alveolar bone of the second premolar decreased. Stage 3 revealed that splinted teeth are efficient in carrying non-axial loads.

Conclusion: Splinting a very weak abutment to an adjacent healthy tooth might not be beneficial. The acceptable crown to root ratio for fixed splinting a weak abutment to an adjacent normal tooth was around 1.65−2.
Introduction

The usual treatment choices for patients with posterior edentulous ridges are cantilever fixed partial dentures (FPDs), removable partial dentures (RPDs), and implant-supported prostheses. However, anatomic considerations or financial constraints may result in considering the FPD or RPD options. Although both of these treatment modalities can provide the patient with chewing function, patients often prefer a fixed prosthesis because of perceived comfort and ease of maintenance. However, an FPD might not provide a suitable biomechanical solution because of its limited capacity to transfer occlusal forces to distant portions of the arch. This limitation is especially prominent in situations of teeth with reduced periodontal support.1−5

The mobility of natural teeth may increase when the supporting periodontium is lost. It is, therefore, important to reduce the deteriorating effects of the poor supporting tissues under physiologic loads in rehabilitating periodontally compromised dentition.6 Tooth mobility in natural dentition may be eliminated or controlled by proper diagnosis and management, such as occlusal adjustments and tooth splinting in an inflammation-free environment.6,7 For conventional FPDs, joining teeth together in a splint system is an important method used to decrease mobility in cases of reduced periodontal support.8 Several biomechanical studies investigated the influence of bone levels and splinting on teeth with reduced periodontal support height.9−12 The reduced bone support and unfavorable crown to root (C/R) ratio of an abutment not only reduce the area of the periodontal ligament (PDL), but also increase the leverage when a non-axial load is applied. Biomechanical factors, such as overload, leverage, torque and flexing, induce abnormal stress concentrations in the prosthesis and periodontium. Those studies demonstrated that teeth splinting can decrease both the displacement and stress concentrations.

Berg and Caputo13 studied some aspects of stress distributions of RPDs in bilateral maxillary distal extension situations with progressive diminution of periodontal support. Itoh et al.3 investigated the effects of periodontal support and fixed splinting on load transfer by RPDs in mandibular bilateral distal extension situations. They concluded that fixed splinting of simulated periodontally compromised abutments effectively redistributes forces to supporting structures.

Considering Ante’s law14 for FPDs, which was questioned in several studies,15,16 specific clinical guidelines for splinting are lacking. In all of those studies, the definition of a weak abutment varied among clinicians. Yang et al.11 considered a C/R ratio of 1:0.7 for periodontally compromised abutments.

In other studies,3,9 distal abutments had mesial and distal osseous craters that were 4 mm deep. In a study by Wang et al.,12 severely compromised periodontal involvement of the terminal abutment was defined as only one-third of the normal bone height remaining. Finally, Aydin and Tekkaya17 assumed a C/R ratio of 1 for periodontally weak abutments. Therefore, it seems that the literature lacks criteria for periodontal involvement.

The finite element method (FEM), which was introduced to solve structural mechanical problems, has long been applied in dentistry to determine stresses and strains in dental structures caused by occlusal forces.18 Three-dimensional (3D) FEM is a powerful tool for examining complex mechanical behaviors of prostheses and surrounding structures. Their usefulness in designing and analyzing dental restorations is well established.19-24

The objectives of this study were: (1) to assess the usefulness of splinting a tooth with reduced alveolar bone height to a healthy one from a stress point of view; (2) to evaluate the effects of gradual alveolar bone loss of one tooth (the second premolar) in a splinted segment of two teeth (premolars); (3) to find the greatest C/R ratio to splint a weakened tooth to a healthy one beyond which the splinting is useless; and (4) to evaluate splinted teeth when non-axial loads are applied from a stress point of view.

Material and methods

Thirteen 3D FEM models were created with a posterior mandibular segment, first and second premolars based on the average dimensions,25 spongy, cortical bone, and PDL (Fig. 1). The normal alveolar bone model was the control, and bone loss was measured vertically from the crest of the second premolar bone level in millimeters. Each model consisted of a cancellous core surrounded by a 0.75-mm thick cortical layer. A 0.25-mm thick simplified PDL layer was modeled based on the root-form geometry of the premolar. Ten models were similar except for the alveolar bone height of the second premolar. In the first model, the alveolar bone height was normal around the second premolar (C/R ratio, 0.55). Gradual loss of alveolar bone in the second premolar increased to 9 mm in the last model (C/R ratio, 3.09). In all models, the alveolar bone height around the first premolar was kept normal. Two teeth were splinted in the crown so that they could be considered as one part with no deformation in the splint area. In the last three models, the splint was deleted from the model with 1 mm, 4 mm, and 8 mm of alveolar bone loss.

SolidWorks 2006 (Solidworks Corp., Concord, MA, USA) was selected to create the solid models. The
models were designed in a top-to-bottom manner starting with a definition of volumes. The next step was to import the solid models into ANSYS Workbench version 11.0 (ANSYS Inc., Canonsburg, PA, USA) to construct the FEMs. All vital tissues were presumed to be elastic, homogeneous, and isotropic. The corresponding elastic properties such as Young’s modulus and Poisson’s ratio were determined according to recent research (Table 1).19−24 Models were meshed with between 21,407 and 29,568 nodes, between 11,206 and 15,658 10-node-quadratic tetrahedron body elements, and between 5129 and 7371 contact elements in the model with the highest and the lowest amounts of bone loss, respectively (Fig. 2). As to boundary conditions, all nodes at the bottom of the model were restrained so that rigid body motion was prevented.

The study was divided into three parts. In part 1, three models without splinted crowns (with normal, and 4 mm and 8 mm of bone loss) were loaded with a 25-N force vector on each premolar to assess the stress situation of the alveolar crest compared to apical stress to show that the crestal stress was greater than apical ones in loading separate (non-splint) crowns.

In part 2, 10 models with splinted crowns and gradual bone loss were loaded with a vertical force

<table>
<thead>
<tr>
<th>Material</th>
<th>Young’s modulus (kg/cm²)</th>
<th>Poisson’s ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enamel</td>
<td>8.26 × 10⁵</td>
<td>0.33</td>
</tr>
<tr>
<td>Dentin</td>
<td>2.14 × 10⁵</td>
<td>0.31</td>
</tr>
<tr>
<td>Periodontal ligament</td>
<td>70.3</td>
<td>0.49</td>
</tr>
<tr>
<td>Spongy bone</td>
<td>2.15 × 10³</td>
<td>0.38</td>
</tr>
<tr>
<td>Cortical bone</td>
<td>1.45 × 10⁵</td>
<td>0.26</td>
</tr>
</tbody>
</table>

Fig. 1 Finite element models: (A) with 1 mm of bone loss in the second premolar; (B) with 3 mm of bone loss in the second premolar; (C) with 7 mm of bone loss in the second premolar; and (D) with 9 mm of bone loss in the second premolar.

Fig. 2 Meshed model with 1 mm of alveolar bone loss in the second premolar.
vector of 25 N onto each premolar crown. This stage was intended to determine the desired C/R ratio beyond which splinting was of little use.

In part 3, three splinted crown models with 1 mm, 4 mm, and 8 mm of bone loss were loaded with a non-axial load of 25 N directed 15º towards the mesial to evaluate the effects of non-axial loads.

Application of a vertical force of 25 N at each occlusal surface of the premolars was based on previous studies.10,11 von Mises stresses were evaluated in three locations in the bone for all models: the apical area of the first premolar, the apical area of the second premolar, and the alveolar crest between premolars midway buccolingually reached through slicing the models.

Results

Results are divided according to the stages of this study. Loading non-splinted crowns revealed a higher stress in the alveolar crest area than in the apical area of the premolar (Table 2). In the apical area of the first premolar, the von Mises stresses in this area were in a range of 1.4–2.2 MPa in different alveolar bone loss models with no predictable pattern in gradual bone loss. In the apical area of the second premolar, the findings in this area were 1.477 MPa for the healthy model, which increased to 2.099 MPa in the model with 8 mm of bone loss. In the alveolar crest area, the findings began at 0.141 MPa for the healthy model and increased to 3.405 MPa in the model with 8 mm of bone loss. These findings showed a predictable increase with the progression of bone loss.

In the loaded splinted crown models with gradual bone loss, some stress modifications at the three points of assessment were revealed (Fig. 3), and numeric data of von Mises stresses in the different models are given in Table 3. In the apical area of the

\[
\begin{array}{|c|c|c|c|}
\hline
\text{Stress (MPa)} & \text{AP5} & \text{Crest} & \text{AP4} \\
\hline
\text{Normal} & 1.477 & 0.141 & 1.990 \\
\hline
\text{With 4 mm of bone loss} & 1.559 & 2.129 & 1.405 \\
\hline
\text{With 8 mm of bone loss} & 2.099 & 3.405 & 2.253 \\
\hline
\end{array}
\]

AP5 = apical area of the second premolar; Crest = intercrestal area between the premolars; AP4 = apical area of the first premolar.

\[\text{Fig. 3 von Mises stress distributions in splinted models: (A) with 1 mm of alveolar bone loss, (B) with 3 mm of alveolar bone loss, (C) with 7 mm of alveolar bone loss, and (D) with 9 mm of alveolar bone loss.}\]
the first premolar, the findings of the von Mises stresses in this area were around 2 MPa in all phases of alveolar bone loss. These findings did not show a clear pattern of changes in different bone loss models. It could be considered to be the same in the various models. In the apical area of the second premolar, the findings were 1.495 MPa for the model with 1 mm of bone loss, which increased to 3.170 MPa in the model with a C/R ratio of 3.09. The pattern clearly showed an increase in stress with gradual loss of alveolar bone. In the alveolar crest area, findings began at 0.297 MPa for the 1-mm bone loss model and increased to 0.922 MPa in the last phase of the study in the model with 4 mm of bone loss.

**Discussion**

Favorable masticatory forces within a healthy periodontium, which thereby avoid occlusal trauma, are a primary concern in partially edentulous restorations. Ante’s law, Ewing’s requirements, and cross-arch stabilization are all clinical guidelines used to address this fundamental problem. Teeth may have a less-than-ideal prognosis as abutments for an RPD when there is slight mobility or an unfavorable C/R ratio, perhaps combined with a conical root.

The present study, as well as previous investigation, demonstrated the preferential development of stresses within osseous defects and their variations with the amount of periodontal support. These stress concentrations suggest that occlusal forces can exacerbate the situation in the defect region and possibly cause further bone resorption, depending on their magnitude and frequency. Loss of bone support increases the maximum stresses generated in the supporting structures, especially in the alveolar bone crest. After horizontal bone loss from periodontal disease, the PDL-supported root surface area can be dramatically reduced. In addition, bending moments affecting the supporting bone may be magnified because of the greater leverage associated with a lengthened clinical crown. That may explain the increased deflection and stress generated in models with low bone support.

Asplint, according to the *Glossary of Periodontic Terms* is “an appliance designed to stabilize mobile teeth”. There is general agreement to splint bilateral distal extension cases to their healthy adjacent teeth when the terminal abutments have reduced support or unfavorable root forms.

The improvement in stress distribution to the supporting structures with fixed splinting was demonstrated for both mandibular and maxillary RPDs with various attachment retainers. The results of our study with respect to the effect of fixed splinting are in agreement with previous articles. However, there were some differences in the maximum stresses and their distributions observed within the periodontal structures after fixed splinting.
The findings of the present investigation indicated that fixed splinting of periodontally compromised teeth can reduce the stress in the interdental crest area compared to the loading of non-splinted crown models, which can protect this weak area against destructive stresses. Indeed, fixed splinting improves the stress distribution in the surrounding bone and transfers stress from the interdental crest to the apical area of teeth where there is better resistance. Another point worth mentioning in this part of the study was the von Mises stress findings of the crestal bone in the healthy tooth structure model. This stress was lower than the apical stress of both premolars. This prevents us from splinting healthy teeth for retention after orthodontic treatment.

The efficiency of splinting in non-axial loading was also shown in this study (Table 4). Although fixed splinting is a time-honored method of improving the status of weak abutments, there are certain precautions that should not be overlooked. It is seldom beneficial to splint an extremely weak abutting tooth to a strong one. The result is generally to weaken the strong abutment rather than strengthening the weak abutment. Phoenix et al. believed that sometimes it is advantageous to sacrifice a periodontally compromised tooth if an adjacent tooth can serve as a better abutment.

Previous studies reported that the lifespan of RPD abutments greatly depends on the quality of periodontal support rather than its quantity. It was demonstrated that teeth with bone loss may successfully be used as RPD abutments if splinted properly, and their long-term maintenance is ensured.

Kratochvil and Caputo showed that physiologic adjustment has a great influence on the direction of force exerted on the abutments, PDL, and bone supporting a distal-extension RPD. An unadjusted casting exerts a tipping and torque action on the teeth and periodontium. Previous photoelastic and finite element stress analyses showed that an adjusted RPD has a favorably altered stress distribution in the periodontium with severe supporting bone loss.

Nyman and Lindhe showed that under normal circumstances, a C/R ratio of 1:1 is considered the minimum ratio that is acceptable for a FPD abutment. Itoh et al. believed that positive effects of fixed splinting of RPD abutments are more pronounced as the severity of the periodontal defect increases. A review of RPD therapy by Phoenix et al. pointed out that a tooth that has lost more than 50% of its bone support is a poor candidate for fixed splinting. In contrast, the findings of our study suggest that by fixed splinting of a weak abutment even with a C/R ratio of 1.65–2 to its adjacent tooth, the stress distribution is improved to produce a lower stress in the crestal bone compared to the apical regions (Fig. 4). But with higher C/R ratios, stresses in the supporting structures significantly increase, and this periodontally questionable tooth should be condemned in favor of using an adjacent healthy tooth as the abutment, even though the span is increased by one tooth by doing so.

To construct a finite element model, it is usually necessary to simplify the system by making some assumptions. The final model represents an average clinical situation, and generalization of its results should be done with care. Therefore, because the finite element models used in this study do not identically reproduce all clinical situations, the application of the results should be tempered with sound clinical judgment. However, this study suggests that when an abutment displays decreased periodontal support, fixed splinting may provide adequate support and stabilization for an RPD, but it is not a method of salvaging a tooth with an otherwise hopeless prognosis.

Within the limitations of this 3D finite element stress analysis study, the following conclusions were drawn: (1) splinting a tooth with reduced bone height to an adjacent healthy tooth redirects stress from the bone crest to the apical areas of both teeth; (2) even after fixed splinting of two abutments, gradual loss of bone support increases the stress in the alveolar crest area; (3) fixed splinting of a very weak abutment to an adjacent healthy tooth might not be beneficial (the maximum acceptable C/R ratio for fixed splinting of a weak abutment to adjacent normal tooth was shown to be 1.65–2); and (4) splinted teeth can tolerate non-axial loads.

References


