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Stresses Around The Abutment Teeth And Implants Supporting An Implant Supported Removable Partial Denture.

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ABSTRACT

The effect of using clip bar attachment on the splinted implants in the anterior modification area. Abutment teeth were evaluated by finite element analysis. The principle stresses obtained from this study were calculated and compared between the two RPD designs. Three types of stresses were studied (Tensile stresses S1, Compression stresses S3, and Von MisesSeqv). The results revealed no difference between the stress distribution patterns of the two studied designs.

Key words: Dental implant, Anterior modification, Finite element analysis.

Introduction

Removable partial dentures (RPD) have to be in a state of equilibrium, i.e., a state in which opposing forces or influences are balanced. Keeping in mind Devan's statement ‘to preserve what remains,’’ forces should be given major consideration while designing a partial denture, to ensure the dynamics of these appliances without deleterious effects to the supporting structures (Singla, S.G. and Jagmohan, L, 2006). Bilateral distal extension partial dentures can be challenging, as support is needed from the teeth, mucosa, and residual alveolar ridges. Various destructive forces can act on the abutment teeth and the posterior mandibular residual alveolar ridges (Kuzamanovic, D.V. et al, 2004). In tooth tissue supported RPD attention must be given to both abutment and edentulous ridge. For the abutment teeth these consideration are periodontal health, crown and root morphology, C/R ratio, bone index area, location of abutment in the ridge, and opposing dentition. For edematous ridge these consideration are the quality of the ridge, the extent of the ridge covered by denture base, the type and accuracy of impression technique, and the partial denture design (McGivney, 1994).

The greatest difficulty occur in transion area where tooth support ends and mucosa support begins, when functional occlusal load is applied to denture base, an axis of rotation is created, the denture tend to rotate about its most distal abutment inducing heavy torsional stresses on the abutment teeth and possible traumatization of the ridge (Carr, A.B, 2005). The degree and direction of the denture base movement are greatly influenced by the quality of the supporting residual ridge, the design of RPD and the extent of the forces exerted on the denture during function (Ben-Ur, 1996). When RPD with both anterior and posterior denture bases present a stress problems, since the length of the ridge area extends anterior and posterior to the fulcrum clasping areas produces a double acting lever problem for the abutment teeth (Augsburger, R.H, 1969). Some situations necessitate the replacement of the missing anterior teeth with RPD rather than fixed restoration. This is because the length of the edentulous span, loss of large amount of residual ridge by resorption, accident or surgery result into much vertical space prevents the use of fixed denture or in which esthetics requirements can be better met through the use of labial flange and teeth added to the denture framework (Vig, R.G, 1963).

Anterior splint bar may be attached to adjacent abutments in such a manner that fixed splint results with smooth contoured bar resting lightly on the gingival tissues to support the RPD. The use of internal clip attachment with connecting bar will provide support, retention and stability for the anterior modification area and serves to eliminate both occlusal rests and retentive clasp on the adjacent abutment teeth (Appligate, O.C, 1966).

Implant dentistry is often the treatment of choice to replace missing teeth in partially and completely edentulous patients. A dental implant system consists of a structure connecting prosthesis to the mandible such that a force due to biting or chewing is distributed over the bone (Misch C.E, 2008). Recent studies with
posterior fixed partial dentures supported by implants or combination of implant and natural teeth report implant success rate of 98% and 94% respectively as a mean for both jaws after 5 years (Quirynen, M., 1992).

Dental implant was used to reduce problems associated with tooth–tissue supported RPD exhibiting an anterior modification space. This implant provides support to the anterior saddle part of the distal extension RPD, which converts the anterior modification area from tooth–tissue support to tooth implant support (Giffin, K.M, 1996).

(Mericke-Stern, 1998) showed that for unsplinted implants with ball attachment, chewing and grinding resulted in lower forces compared to maximum biting, particularly in the vertical direction. The transverse force component in backward–forward direction, however, reached magnitudes that exceeded the vertical component by 100–300% during chewing function. This chewing pattern had not been observed in previous investigations with bars and telescopes. The stress values in bone tissue are lower around splinted than around uncoupled implants, implant stability and healing are better with splinted than uncoupled implants (Mericke-Stern, R, et al, 1996).

(Payne and Solomons, 2002) observed that the bar-clip attachment system can decrease the stress concentration at the implant since this type of attachment system allows vertical and rotational overdenture movement toward the oral mucosa around the long axis of the bar. A certain amount of overdenture movement during mastication is necessary to protect the abutment and to allow for tissue resiliency. (Hadad, 2009) investigated stresses induced by splinted and non-splinted implant supported overdenture by FEA and found that stresses induced around two separate implants were more than that developed around splinted implants under unilateral loading.

Finite element stress analysis (FEA) is the method of choice for theoretical analysis of the mechanical behavior of biological tissues and restorative material with complex shape which are subjected to complex loading force.

The FEA offers many advantages over other methods in considering the complexities that characterize actual clinical situations. This technique appeared to overcome most of the problems associated with earlier experimental methods in that the dimensions and properties of all composite materials could be easily simulated and varied, and stress and displacement could also be easily calculated (Simsek, B, et al, 2006).

Finite element analysis can simulate stress dynamics using a computer created model to calculate stress, strain and displacement. Such analysis has the advantage of allowing several conditions to be changed easily and also allows measurement of stress distribution around implants at optimal points that are difficult to examine clinically (Geng, J.P et al, 2001).

The effect of using clip bar attachment on splinted implant restoring the anterior modification area of implant supported removable partial denture restoring lower Kennedy class I with anterior modification was evaluated by finite element analysis for three types of stresses are tensile, compression and Von Mises with two designs of splinted implants with and without clip attachment during tissueward and tissueaway in both working and balanced sides.

Materials and Methods

Removable partial denture was constructed by the conventional technique on a modified stone cast has anterior and posterior edentulous space with the remaining natural teeth were canine, first and second premolars bilaterally.

Numerical model was obtained by C.T scanning and MIMICS software (Materialized Interactive Medical Image Control System). The goal of this software is to generate a 3D model and optimize the model for other analysis software such as ANSYS for finite element analysis (FEA).

Fig. 1: C.T scanning
The implant, bar and attachment were drawn in (ANSYS 11) program. The implant length and diameter were 11mm and 4mm respectively, the bar length and width were 6mm and 4mm respectively and the clip attachment was 3mm in length and 5mm in width.

SOLID 72 element was used in this study as it is well suited to model irregular meshes (such as produced from various CAD/CAM systems), which is the element of choice to generate the finite element model mesh pattern, in accordance with geometry characteristics of the model used in this study.

![Image of clip bar attachment on splinted implants and splinted implants](image)

**Fig. 2:** Clip bar attachment on splinted implants and splinted implants

Mechanical properties were given for each material, which were considered as isotropic, linear elastic, and homogenous. The elastic constant E (Young’s modulus of elasticity) and the Poisson’s ratio (ν) of each material was given. The outer surface of the cast was assumed to be the mucosa, while the inner 2mm was compact bone, and the center of the cast was the cancellous bone. The implant was assumed to be osseointegrated with the adjacent bone. The material properties of the layer that surround the abutment roots were assumed to be periodontal ligament (P.D.L). The models were loaded on the distal extension base and central fossa of lower second molar with static load 30kg (300N) in unilateral axial direction (tissueward and tissueaway). In ANSYS program the model was duplicated into two models, which were identical except in the clip bar attachment on the splinted implants in the anterior modification area. Every model was loaded in a tissueward and tissueaway direction, resulting in four models. The models were prevented from movement at the base in all directions. The boundary conditions were not affecting the stress results at the Peri-implant region. After geometry amendment was preformed, finite element types were selected and material property data was entered, the software solved the problem using the equation: \( \{P\} = [K] \{U\} \) Where \( P=\)Load vector, \( K=\)Overall stiffness matrix and \( U=\)Displacement vector.

ANSYS produced stresses results for the following regions: Implants and abutment teeth. The principal stresses were used at the bone-implant and bone-root interface to define local risk indicators of physiological bone failure and of the activation of bone resorption.

**Results**

In each case stresses were measured around the left abutment tooth (second premolar, working side), the right abutment tooth (second premolar, balancing side), the left implant, and the right implant. Stress contours were colour-coded and explained for each figure where the stress values were indicated in Mega Pascal (MPa). Stress values were represented in the form of Tensile stresses (S1), Compression stresses (S3), and Von Mises (Seqv) and these stresses were measured in Mega Pascal (MPa).

**A-Stresses induced on the working side.:**

1-Stresses induced around second premolar on the working side in splinted implant with and without clip attachment during tissueward and tissueaway loading.:**

<table>
<thead>
<tr>
<th>Design</th>
<th>Stresses</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max tensile</td>
<td></td>
<td>2.03MPa</td>
<td>2.03MPa</td>
<td>1.6MPa</td>
<td>1.6MPa</td>
</tr>
<tr>
<td>Max compression</td>
<td></td>
<td>1.7MPa</td>
<td>1.7MPa</td>
<td>2.2MPa</td>
<td>2.2MPa</td>
</tr>
<tr>
<td>Von Mises</td>
<td></td>
<td>1.7MPa</td>
<td>1.7MPa</td>
<td>2MPa</td>
<td>2MPa</td>
</tr>
</tbody>
</table>

Model 1: RPD with clip bar attachment between the two splinted implants during tissueward loading.
Model 2: RPD with bar splinting the two implants during tissueward loading.
Model 3: RPD with bar splinting the two implants during tissueaway loading.
Model 4: RPD: with clip bar attachment between the two splinted implants during tissueaway loading.

Fig. 3: Principle stresses during tissueward and tissueaway loading.

The highest tensile stresses were concentrated around the mesial placed occlusal rest and measured 2.03 for both model 1 and 2, while the highest tensile stresses were concentrated in the cervical one third of buccal surface of the root for both model 3 and 4 and measured 1.6 MPa.

The maximum compressive stresses were found on the occlusal surface of the abutment tooth in model 1 and on the occlusal one third of the distal surface of abutment tooth in model 2. The stress values were 1.7 MPa for the two models, while the maximum compressive stresses were found around the mesial placed occlusal rest of both model 3 and 4. The stress values were 2.2 MPa for the two models.

The von Mises stresses summarize the overall stress state. The average values of the von Mises of the abutment tooth were 1.7 MPa for both model 1 and 2, while the average values of the von Mises of the abutment tooth were 1.7 Mpa for both model 3 and 4, and concentrated around the distal one third of the buccal surface.

Fig. 4: Stresses in working abutment tooth during tissueward and tissueaway loading

2-Stresses induced around the splinted left implant with and without clip attachment during tissueward and tissueaway loading:

<table>
<thead>
<tr>
<th>Design</th>
<th>Stresses</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Max tensile</td>
<td>18MPa</td>
<td>17.9MPa</td>
<td>22.3MPa</td>
<td>22.3MPa</td>
</tr>
<tr>
<td></td>
<td>Max compression</td>
<td>26.9MPa</td>
<td>26.8MPa</td>
<td>18.5MPa</td>
<td>18.5MPa</td>
</tr>
<tr>
<td></td>
<td>Von Mises</td>
<td>34.4MPa</td>
<td>34.3MPa</td>
<td>32.3MPa</td>
<td>32.3MPa</td>
</tr>
</tbody>
</table>
Model 1: RPD with clip bar attachment between the two splinted implants during tissueward loading.
Model 2: RPD with bar splinting the two implants during tissueward loading.
Model 3: RPD with bar splinting the two implants during tissueaway loading.
Model 4: RPD with clip bar attachment between the two splinted implants during tissueaway loading.

Fig. 5: Principle stresses during tissueward and tissueaway loading.

The highest tensile stresses were concentrated around the implant collar at the upper border of implant threads and measured 18 and 17.9 MPa for model 1 and 2 respectively, and measured 22.3 Mpa for both models 3 and 4.

The maximum compressive stress was concentrated around the cervical one third of the implant and measured 26.9 and 26.8 Mpa for model 1 and 2 respectively, and measured 18.5 Mpa for both model 3 and 4.

The average values of the von Mises of the left implant were 34.4 and 34.3 Mpa for model 1 and 2 respectively and concentrated around the cervical one third of the left implant, while the average values of the von Mises for model 3 and 4 were 32.3 Mpa.

Fig. 6: Stresses in left implant during tissueward and tissueaway loading

B-Stresses induced on balancing side:
1-Stresses induced around second premolar in splinted implant with and without clip attachment during tissueward and tissueaway loading in balancing side:

Table 3: Stresses around the root of second premolar abutment tooth.

<table>
<thead>
<tr>
<th>Design Stresses</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max tensile</td>
<td>0.6MPa</td>
<td>0.6MPa</td>
<td>1.7MPa</td>
<td>1.7MPa</td>
</tr>
<tr>
<td>Max compression</td>
<td>1.6MPa</td>
<td>1.6MPa</td>
<td>0.7MPa</td>
<td>0.7MPa</td>
</tr>
<tr>
<td>Von Mises</td>
<td>1.4MPa</td>
<td>1.4MPa</td>
<td>1.4MPa</td>
<td>1.4MPa</td>
</tr>
</tbody>
</table>
Model 1: RPD with clip bar attachment between the two splinted implants during tissueward loading.
Model 2: RPD with bar splinting the two implants during tissueward loading.
Model 3: RPD with bar splinting the two implants during tissueaway loading.
Model 4: RPD: with clip bar attachment between the two splinted implants during tissueaway loading.

Fig. 7: Principle stresses during tissueward and tissueaway loading.

The maximum tensile stress was concentrated around the retentive tip of RPA clasps and measured 0.6 Mpa for the both models, while the highest tensile stresses were concentrated mesial placed occlusal rest for both model 3 and 4 and measured 1.7 Mpa.

The maximum compressive stress was concentrated around the mesial placed occlusal rest and measured 1.6 Mpa for both models 1 and 2, while the maximum compressive stress was concentrated around the retentive tip of RPA clasp measured 0.7Mpa for model 3 and 4.

The average values of the von Mises of the balancing tooth were 1.4 Mpa for the all models and concentrated around mesial placed occlusal rest.

2-Stresses induced around the splinted right implant with and without clip attachment during tissueward and tissueaway loading:

Table 4: Principle stresses around the right implant during tissueward and tissueaway loading.

<table>
<thead>
<tr>
<th>Design</th>
<th>Stresses</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
<th>Model 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max tensile</td>
<td>10.3MPa</td>
<td>10.2MPa</td>
<td>11.5MPa</td>
<td>12MPa</td>
<td></td>
</tr>
<tr>
<td>Max compression</td>
<td>14.3MPa</td>
<td>14.3MPa</td>
<td>9.1MPa</td>
<td>9.8MPa</td>
<td></td>
</tr>
<tr>
<td>Von Mises</td>
<td>13.6MPa</td>
<td>13.6MPa</td>
<td>14.2MPa</td>
<td>14.2MPa</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 8: Principle stresses during tissueward and tissueaway loading.

The highest tensile stresses were concentrated around the implant collar at the upper border of implant threads and measured 10.3 and 10.2 Mpa for model 1 and 2 respectively, and measured 11.5 and 12 Mpa for model 3 and 4 respectively.

The maximum compressive stress was concentrated around the cervical one third of the implant and measured 14.3 Mpa for both model 1 and 2, and measured 9.1 and 9.8 Mpa for model 3 and 4 respectively.
The average values of the von Mises of the left implant were 13.6 Mpa for both model 1 and 2 and concentrated around the cervical one third of the left implant, while The average values of the von Mises of model 3 and 4 were 14.2 Mpa for both models.

Discussion:

The effect of using clip bar attachment on the splinted implants in the anterior modification area was evaluated by Finite Element Analysis.

Finite element analysis was used in this study as it is the ideal solutions for problems involving complicated geometries. Finite element analysis is a technique for obtaining a solution to a mechanical problem of a complex by dividing the problem domain into a collection of much smaller and simpler domains (elements) in which the field variables could be interpolated with the use of shape functions. An overall approximated solution to the original problem was determined based on variation principles, the solution functions for each finite element that combines them properly to obtain the solution to the whole body. Since the components in a dental implant-bone system are extremely complex geometrically, FEA has been viewed as the most suitable tool for analyzing it. In contrast to strain gauge in which stress generated was attached to the surface of the prosthesis where the strain gauges can monitor, as a consequence of the load applied, the types and magnitudes of deformation occurs in the surface underneath the gauge (Glantz.O, and Nilner, K, 1997, Tanino, O, 2007). While using photoelastic method require the construction of one model for standardization which may be weakened due to multiple application of the load and if two models were constructed there was lack of standardization during the processing of the two models.

MIMICS software was used to create 3D object from scanned data and allow modification in the 3D object, In MIMICS software the 3D object was exported into other type of output format (ANSYS 11). All these files can be used directly into their respective software for Finite element analysis.

The assumption was made that all materials were homogeneous (the mechanical properties of the materials were within each zone of the considered zones), isotropic (the material property of each zone was the same in all directions), and linear elastic material behavior (the strain was proportional to the applied force and independent of the strain rate) characterized by two material constants of Young’s modulus and Poisson’s ratio. The mechanical behavior of bone (cortical or trabecular) is difficult to model as it is highly heterogeneous and dependent on many parameters such as age, sex, type of bone, consequently, it is not easy to introduce the correct material properties of the specific bone that is numerically studied. That is the reason why, in most finite element models, the mechanical properties of bone are supposed to be isotropic (Jiao et al, 2009).

Unilateral load of 300 N was applied in tissueward and tissueaway direction to evaluate the stress induced in the splinted bar implants used for support only or clip bar attachment for support and retention. 300N on second molar tooth was used as it is considered the average masticatory biting force in this area; the load was in vertical direction mimicking the effect of load in centric occlusion. The unilateral load was used to simulate the normal chewing pattern as the bilateral loads represent a para-functional habit.

Within the limitations of the present study, stress concentration was observed within the abutment teeth and around the splinted implants. The principle stresses obtained from this study were the same when evaluating the use of clip attachment on the splinted implants in the modification area of class I kennedy cases during tissue word and tissue away loading. This may be attributed to the splinted implants that were assumed to be 100% osseointegrated with the surrounding bone. So these implants can withstand all the stresses within its physiologic limit regardless the use of the clip bar attachment.

During tissue word loading the stresses were concentrated around the mesial occlusal rest on the abutment teeth as the occlusal rests act as a fulcrum during the tissue ward loading. While during tissue away loading the stresses were concentrated around the retentive tip of RPA clasp because the retentive tips of the retainers act as a fulcrum around which the distal extension base rotate in a tissue away direction.

The stresses around the splinted implants were higher than stresses around the abutment teeth because the implants were osseointegrated to the bone and stresses were directly transmitted to the bone, while the abutment teeth have periodontal ligaments that dissipate some of these stresses before reaching the surrounding bone.

The average compressive stresses induced around the splinted dental implants was 17.2 Mpa while the average tensile stresses induced around the splinted dental implants was 15.4 MPa which are less than the normal ultimate strength of human cortical bone which range from 72-76 MPa in tension and 140-170 MPa in compression (George, P., et al., 1996)

Conclusions:

Within the limitations of this study it could be concluded that:
• There is no difference in stress distribution or value around the splinted implants and abutment teeth whether the bar is used for support only or retention and support.
In free end saddle with anterior modification area, dental implants receive and transmit more stresses to its surrounding bone than the abutment teeth.

The cortical bone layer surrounding the implants receives most of the stresses transmitted to the implants.

References