Stress Analysis of Ball and Locator Attachments and Bone in Overdenture Supported by Tissue Level and Bone Level Implants: A Three-dimensional Finite Element Analysis

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How to cite the article:

Abstract:
Background: This study evaluates the stress distribution and force distribution on the surrounding bones in ball and locator attachments in bone level and tissue level implants.

Materials and Methods: Primarily scan of training GOS model, fabricated denture, ball, and locator attachments was prepared. After assembling dens point clouds in CATIA V5R21 software, two bone level implants and two tissue level implants were inserted into the computer modeling of the mandible and for both, ball and locator attachments were applied. 100 N/cm occlusal load was applied on incisor, canine, and first molar areas. Modes were analyzed in ABAQUS 6.13 and the map of force distribution and numerical values were obtained.

Results: The highest obtained von Mises numerical value belongs to ball attachments of bone level implants in molar areas (11.14 Mpa). The highest amount of stress for ball attachments was from hex to first thread area. Numerical values of transferred stress to the hex and first thread of screw in ball attachments were higher than locator attachments. The highest numerical value of von Mises was belongs to locator attachments of tissue level implants.

Conclusions: Given the limitation of this study, it is cleared that the probability of overloading and screw fracture in ball attachments is more than locator attachments and also in bone level implants is more than tissue level implants. While the transferred force to the bone in locator attachments is higher than ball attachments and also it is higher in tissue level compared to bone level implants.

Key Words: Ball attachment, finite element analysis, implant supported overdenture, locator attachment, stress distribution

Introduction
A treatment of toothless elderly and disabled patients can be challenging. A lack of sufficient denture retention and stability in these patients is one of the major problems. The osseointegrated implants introduced new methods for treating these patients. Using implant supported overdenture, particularly in the mandible, is an effective way to solve the problems of these patients. It is proven that patients with implant supported overdenture in the mandible have more bite force and are more satisfied than patients with complete denture. Retention and stability of implant supported overdentures are achieved principally through attachments. There are different types of attachments for overdentures. Splinted bar type attachments and ball, o-ring, and locator independent attachments are most common types of attachments. Independent attachments are the most common and the most economical ones for overdenture. Although non-parallelled implants may decrease retention of independent attachments, they are hygienic, cheap, and their technique are more convenient. They can insert minimum amount of torques to the implant and can also maintain the health of bone around the implant. Splint designs (bar types) are useful in severe ridge resorption because they have an extra plan for stabilization. Ball attachments insert less stress to implants and compared to bar attachments; they make less bending. Locators are self-aligning and can make dual retention. They have ideal flexibility and durability.

Using overdentures and attachments has its own problems. Screw fractures are rare in overdenture attachments, but it has been reported in some cases (Figure 1). In a study of 173 ITI implants on 41 patients with overdentures by Kiener et al., it was obtained that the most complication was associated with prosthesis. Among these complications connection bar screw loosening and the need to fix it was the most common ones. In the study of Karabuda et al., two groups of patients with overdentures on bar and ball attachments were compared. The most common prosthetic problems were deformation of socket ball and retention of clips in patients with ball attachment. They reported three abutment screw fractures in their study, one for patients with ball attachment and two for patients with bar attachment. Nergiz et al. reported a screw fracture in the magnetic attachment on overdenture of mandible on two IMZ implants. The broken part was removed successfully.
Thus a study on the mechanical structure of attachments, distribution of forces in connections, and screws under different forces seems essential.

In the past two decades, finite element analysis (FEA) has been a useful tool to predict the effects of stress on implant and its surrounding bone.⁶,¹⁵ Although in many articles, FEA was used to examine the stress distribution and mechanical behavior of the bone,²,⁸,¹¹,¹⁸,¹⁷ its use in evaluation of prosthetic components, screws, abutments and attachments was mentioned in some articles.¹⁵,¹⁸-²⁰ Gomes et al. analyzed different amounts of prosthetic misfits on retaining screws and surrounding bones by use of two-dimensional FEA.¹⁹ The distribution map of their study showed a gradual increase of stress on the prosthesis and a steady stress on implant and trabecular bone.¹⁹ Using FEA Alkan et al. analyzed three implant and abutment connection systems under three horizontals, vertical and inclined forces.¹⁸

There are not sufficient FEA studies about stress distribution on structure of attachments, implant connections, and screws. Considering the clinical cases of screw fractures in attachments, detailed study of stress distribution in different parts of the attachments is important. The aim of this study was to investigate the distribution of stress in connection and screw areas and also surrounding bones in ball and locator attachments on bone level and tissue level implants of Biodenta system (Biodenta Swiss AG, Switzerland) with the use of 3 Dimensional FEA.

Materials and Methods
In this experimental study, computer modeling includes mandible modeling, overdenture modeling, modeling of implants and attachments areas, and simulation of forces.

Figure 1: A clinical case of a 55 years old woman with two fractured ball attachment after 2 years of overdenture delivery (Dental school, University of medical science, Isfahan, Iran).

<table>
<thead>
<tr>
<th>Poisson ratio</th>
<th>Young modulus (pa)</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cortical bone</td>
<td>1.37*10⁶</td>
<td>0.30</td>
</tr>
<tr>
<td>Trabecular bone</td>
<td>1.37*10⁶</td>
<td>0.30</td>
</tr>
<tr>
<td>Mucosa</td>
<td>1.0*10⁶</td>
<td>0.40</td>
</tr>
<tr>
<td>Acrylic resin</td>
<td>2.7*10⁶</td>
<td>0.35</td>
</tr>
<tr>
<td>Titanium</td>
<td>1.17*10⁶</td>
<td>0.33</td>
</tr>
<tr>
<td>Gold</td>
<td>1.0*10⁶</td>
<td>0.30</td>
</tr>
<tr>
<td>Rubber</td>
<td>5.0*10⁶</td>
<td>0.45</td>
</tr>
</tbody>
</table>

Mandible modeling
For mandible modeling, GOS™ (GOS™ Göttinger-OP-Simulationssystem, Northeim, Germany) training model was used. This model was scanned by SolutionixRexcanIII, 3 D optical scanner and Geomagic software. In mandible model, the soft tissue (2 mm), cortical bone (2.5 mm), and cancellous bone were defined, and their mechanical properties (Modulus of elasticity and Poisson ratio) were defined in the software⁶,²¹ (Table 1).

Overdenture modeling
An acrylic denture with acrylic teeth on the crest of ridge was built on instructional model in a conventional way. The denture was scanned by an optical scanner (SolutionixRexcanIII). Mechanical properties of acrylic were defined in the software.

Implants and attachment areas modeling
Implants were placed 22 mm from each other in computer modeling of mandible. These areas were exactly like canine denture area. Housing and plastic cap of attachments were installed within the denture in computer model (Figure 2). Titanium attachments were installed on implants. In this modeling, bone level and tissue level implants were used. Tissue level (4.1 × 12) and bone level (4.1 × 12) were selected from Biodenta (Biodenta Swiss AG, Switzerland) system. For both ball and locator attachments, the same system was used on both types of implants. Implants were osseointegrated by defining tie connection with surrounding bone. For modeling of attachments, optical scan and manufacturer information were used, and threads sizes and pitches were described in the software. Contact connection was used to describe the closing and engaging of threads and attachments in implants. After completing all scans, the obtained dense point cloud was assembled in CATIA v5R21 software (DassaultSystemes Americas Corp).

Simulation of forces
To simulate static bite force in patients with overdenture, 100 N in the incisor area (d1), 100 N in canine area (d3), and 100 N in molar area (d6) were applied.⁹,²²

Thus with two implant variables (tissue level, bone level), two attachment variables (ball, locator), and three force locations (d1, d3, d6) 12 different modes were defined in the software and the obtained results and images were analyzed. The ABAQUS 6.13 was used to analyze the amount of stress in studied models.

Results
Maximum von Mises numerical values in studied samples are shown in Table 2. Among all obtained numbers in two attachment types, two implant types and three force area, the highest amount of stress was related to bone level ball type attachments, with force in distal area (d6) (14/11 Mpa). In
In general, in both ball and locator attachments, the amount of stress concentration was higher in bone level implants. Furthermore, amount of stress concentration in ball attachments was higher for both bone level and tissue level implants (Figure 3).

In all three types of force, the maximum stress concentration was on entire hex and ball neck areas for ball attachments in bone level implants. For tissue level implants the maximum stress was on the first thread and ball neck areas. In locator attachments in bone level implants, the maximum stress concentration was from hex to first thread and in tissue level implants was higher than first thread and adjacent to the hex (Figure 4). Among three implied force models the maximum numerical value of stress concentration of implied force was in molar tooth (d6) (more distal than attachment) for both attachments.

To study the stress concentration on the bones, 12 different modes were compared too. Cortical bone of tissue level implants with locator attachments and d3 force had the maximum stress concentration (Table 3 and Figure 5). In bone level and tissue level implants numerical values of stress concentration were higher on surrounding bones of tissue level implants, especially those with Locator attachments. In both implant types, numerical values of stress concentration in locator attachments were higher.

**Discussion**

Usually, independent or splinted attachments are used to create retention system in overdentures. Retention, stress transfer, restorative space, and Maintenance are important factors for choosing attachments. Transfer of masticatory forces has a great impact on success of implant restorations. Studies showed that compared to implants with splinted Bar, use of non-splint implants in overdentures can reduce stress concentration on supporting bone.

To find the areas with the highest stress concentration and a higher risk of a fracture, in this study, we attempted to analyze the map of stress distribution in two ball and locator independent attachments in two tissue and bone level implants. Furthermore, amount of stress transmission to the bone was evaluated for each attachment and implant. In this study, maximum von Mises numerical value was for hex to first thread area of ball and locator attachments. This value was higher in ball attachments in bone level implants. This result matches Bilhan’s study in which the maximum stress concentration was in abutment screws and prosthetic screws in connection between the shank and first thread. FEA study of Chang et al. showed that neck area of abutment screw has the highest stress concentration.
In this study, Ball attachments had high-stress concentration in shank and thread areas. It seems that this result is because of longer outside part of ball attachment from implant body. This can make a longer lever arm to intensify force in screw attachment areas. Locator attachments using internal retention system reduce the length of lever arm. Stress concentration in connection and screw areas for both attachments types was higher in bone level implants. This result is different from Chang’s study on bone level and tissue level abutments. On the basis of manufacturer information and scan of different parts, the involved area in implant for ball and locator attachments in bone level implants are shorter than tissue level implants. This can justify a longer lever arm above implant-attachment connection and also can justify increased force in screw and attachment. In addition, the distance between the threads is less in attachment of bone level implants which can create more stress concentration areas.

Since the connection area of ball and locator attachments in bone level implants were conical and platform switch connection was used for them, the results of studies that have examined platform switching and conical connections of abutments are useful for this study. Queresma et al. in a FEA study on two types of implants, one on stepped cylinder implant with internal hexagon abutment and the other on conical implant with internal conical abutment, found that the second implant has more stress concentration on abutment and abutment-implant connection area while it has less stress concentration on cortical bone around implant. In contrast, the first system (stepped cylinder) transfers more stress to bone which is in accord with the results of this study. This study shows that both types of attachments in bone level implants have more stress on connection and abutment screw areas, while force concentration on cortical bone is more for both types of attachments in tissue level implants. Study of Tabata et al. showed that platform switch abutments transfer less stress to bone and implant but increase von Mises in prosthesis and screw which is in accord with this study. Stress concentration on threads and screw neck can be seen in all models. It should be noted that studies of Chang et al., Quaresma et al., and Tabata et al. were done on single implants and abutments, and none of them were done on denture attachments.

But in terms of force distribution in bones, the results of this study were consistent with Ebadian et al., Chang et al., and Quaresma et al. studies. In this study, the maximum amount of stress on the bone was for locator attachments.

### Table 3: Numerical values of stress generated in cortical bone based on implant-bone attachment.

<table>
<thead>
<tr>
<th>Implant type/attachment</th>
<th>Location of force</th>
<th>Maximum stress amount (Mpa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bone level/ball</td>
<td>d1*</td>
<td>3.154</td>
</tr>
<tr>
<td></td>
<td>d3**</td>
<td>2.687</td>
</tr>
<tr>
<td></td>
<td>d6***</td>
<td>2.103</td>
</tr>
<tr>
<td>Tissue level/ball</td>
<td>d1</td>
<td>4.439</td>
</tr>
<tr>
<td></td>
<td>d3</td>
<td>4.322</td>
</tr>
<tr>
<td></td>
<td>d6</td>
<td>4.205</td>
</tr>
<tr>
<td>Bone level/locator</td>
<td>d1</td>
<td>6.156</td>
</tr>
<tr>
<td></td>
<td>d3</td>
<td>5.724</td>
</tr>
<tr>
<td></td>
<td>d6</td>
<td>5.444</td>
</tr>
<tr>
<td>Tissue level/locator</td>
<td>d1</td>
<td>6.717</td>
</tr>
<tr>
<td></td>
<td>d3</td>
<td>6.542</td>
</tr>
<tr>
<td></td>
<td>d6</td>
<td>6.401</td>
</tr>
</tbody>
</table>

*d1: Central incisor area, **d3: Canine area, ***d6: First molar area

### Figure 4: Stress distribution in bone level (a) and tissue level (b) locator attachment in d6 load applied.

### Figure 5: Stress distribution in bone surrounding tissue level implants with ball (a) and locator (b) attachments in d3 applied load.
in tissue level implants in loading at d3. In general, for any types of implants, the amount of transferred stress in locator attachments was more than ball attachments. This result is similar to Ebadian’s study on ball and locator attachments in the same crown height space\textsuperscript{a} and photoelastic study of Celik and Uludag.\textsuperscript{b} This study also showed that compared to bone level implants, all attachments showed more von Mises values in tissue level implants. This fact is in consistent with Chang’s study. According to Ebadian’s study, it can be concluded that because of rigid behavior of locator attachment; the movement of overdenture is limited and this fact can increase the stress on the bone around the implant.\textsuperscript{a} Using resilient attachments such as ball attachments, a part of force can be transferred to the posterior ridge.

**Conclusion**

Despite the limitation of this study, based on obtained map of stress distribution in bone level and tissue level implants and ball and locator attachments, it can be concluded that stress concentration areas in connections and first thread of screw of attachments can be predictive of areas with high risk of fracture in cases of severe long-term force. Hence, while implanting in a bone with good quality and situation, it is better for prosthodontist to focus on prosthetic components to prevent problems such as screw fracture. In this case, the use of locator attachments in tissue level implants is suggested. If patient’s bone is not in a proper situation and the risk of bone loss and fail of implant is high, the use of ball attachments in bone level implants is recommended. In these cases, preserving cortical bone is more important. It should be noted that the results of this study should be completed by clinical studies. In the end, it is suggested that other experimental studies with more force and different directions should be done to analyze force distribution in different people such as bruxers. The clinical evaluations are necessary to confirm or reject the findings of this study.

**References**

19. Gomes EA, Assunção WG, Tabata LF, Barão VA,


