Effect of Implant Height Differences on Different Attachment Types and Peri-Implant Bone in Mandibular Two-Implant Overdentures: 3D Finite Element Study

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Implant-supported overdentures with self-aligning attachment systems are preferred to improve the stability and retention of complete dentures. The positioning of the implant attachments is a very important aspect of two-implant overdentures in obtaining better stress distribution. Therefore, the objective of this study was to compare two different attachment systems in a two-implant overdenture by evaluating the stress distributions in peri-implant bone and stresses on the attachments with positioning at different height levels using the 3D FEA method. Six models with ball attachments and 6 models with locator attachments—totaling 12 models (including 2 controls)—with the left implant positioned unilaterally at different height levels were subjected to 3 loading conditions (anterior, right posterior, and left posterior). Data for Von Misses stresses were produced numerically, color coded, and compared among the models for attachments and peri-implant cortical bone. The configurations in which implants presented 3 mm height differences in the bone level showed the most successful results in the peri-implant bone. When stresses on the attachments were compared, greater stress values were obtained from the ball attachments. As a conclusion, the configurations with a considerable (3 mm) height difference between quadrants of the mandible in the anterior segment showed the most successful results in the peri-implant bone. On the contrary, peak stress values around the implant observed from the models with less (1 mm) bone height difference may require leveling of the bone during surgery. However, these findings should be corroborated with clinical studies.

Key Words: finite element analysis, dental implant, overlay, denture, bone resorption

INTRODUCTION

The prosthetic management of the edentulous patient has been a major issue for dentistry. The routine treatment procedure for the edentulous patient is conventional complete dentures.1–3 However, lack of stability and retention are very well-known problems that have to be taken into consideration in conventional complete dentures. Mandibular complete dentures can especially pose very problematic situations for patients even under ideal clinical conditions.4,5 Many alternative treatment options—such as base extension, ridge grafting, alveoloplasty, or the placement of dental implants for anchorage6—have been tried to find the solution for the aforementioned problems.7 Extensive research of dental implants has been carried out with more than 90% success rates (even after 10 years),8 suggesting that they are a reliable treatment option for supporting complete dentures.

Implant-supported overdentures (ISOD), which have become a routine treatment option in recent years, are preferred to improve the stability and retention of complete dentures because they are minimally invasive and present lower costs.3,8,9 The stability and retention of ISOD can be enhanced by increasing the number of implants; it was stated in the 2002 McGill consensus that a mandibular overdenture supported by two implants is the first choice of treatment for the mandibular edentulous patient. In 2009, a further statement by York was published to support the McGill consensus; however, two-implant retained mandibular overdentures are the minimum standard for treatment planning when patient satisfaction, cost, and clinical time are considered.10 To enhance the retention and stability of two-implant overdentures, various systems are commonly used, including bars, balls, magnets and self-aligning attachment systems.11–15 Within these systems, self-aligning attachment systems (eg, Locator, Escondido, Calif) and ball attachments (eg, Astra Tech Implant System, Mölnadal, Sweden) can be frequently used due to their simplicity. Specifically, ball attachments are considered to be the simplest type of attachments for clinical applications.16 Despite being resilient, the specific design of the ball attachment may influence the amount of its free movement, which can limit its resiliency.17 Recently, for anchoring ISODs, a locator attachment system has been presented and is available as a prefabricated device.18–20 Locator systems have become widely applied and have been presented as an alternative single attachment to the established ball anchor with its innovative ability to pivot, which increases resiliency and tolerance for high mastication forces.
for two-implant overdentures, because in the presence of pathological overloading the bone around the implants becomes deformed and resorbs due to the excessive stress and strain gradients. This situation may also lead to incompatibility of the components of the implant system and microfracture of the implant. To accomplish these tasks and thereby increase the success rates of the implant-supported dentures, implants should be placed at the optimum location in terms of height differences of the attachments from each other. Clinicians anticipated that the two independent implants should be positioned at the same occlusal height, parallel to the occlusal plane. If one implant was higher than the other, the prosthesis disengaged from the lower implant during function and rotated primarily on the higher implant. This situation will accelerate the wear of the attachment on the lower implant, and because the higher implant receives the majority of the occlusal load, an increased amount of crestal bone loss can occur. Additionally, there should be enough thickness inside the complete denture for the height of the attachment; otherwise, denture fractures may occur due to the inadequate acrylic resin thickness. However, in the completely edentulous patient, alveolar bone can be resorbed with different types of resorption patterns, which may affect the symmetry of the bone height in the anterior mandible.

Various methods, including photoelastic analysis, finite element analysis and strain measurement on the bone surface, can be used for the assessment of stress around the implant system. Within these methods, 3D finite element analysis (FEA) is regarded as an accurate and convenient approach for investigating stress and strain distribution by investigating the effect of the biomechanical properties of the prosthesis on dental implants. Generating computational data outside of the clinical situation is the best advantage of this method. Because of this valuable advantage, numerous studies have been published using FEA to evaluate stress distribution in implant-retained overdentures. However, these studies compared stress formation between implants with the same occlusal height, and there is currently no study that evaluates the stress derived from differences in implant position in terms of height in mandibular two-implant overdentures. Therefore, the objective of this study was to compare two different attachment systems in two-implant overdentures by evaluating the stress distributions in peri-implant bone and stresses on the attachments in which there is positioning in different height levels using the 3D FEA method.

Materials and Methods

The three-dimensional (3D) models that were used in the current study were prepared with the help of a single software to standardize all of the parameters of the models. Astra Tech Osseospeed implants, (Dentsply Implants, Mölndal, Sweden) supporting a mandibular overdenture, were placed in the areas of both lateral incisors at a distance of 7 mm from the central point of the arch. Models were divided into six groups (Figure 1):

- B1 (ball attachment) and B2 (locator attachment); the left implant and the alveolar bone on the left side is unilaterally 1 mm higher than the right side.
- C1 (ball attachment) and C2 (locator attachment); the left implant and the alveolar bone on the left side is unilaterally 3 mm higher than the right side.

The data obtained from the Visible Human Project (US National Library of Medicine, Bethesda, Md) were modified with the use of VRMESH (VirtualGrid Inc, Bellevue, Wash) and Rhinoceros 4.0 (McNeel North America, Seattle, Wash) software to establish a 3D mandible FEA model with 2 mm cortical bone covering the trabecular bone, and 2 mm mucosa to standardize the clinical situation. The geometry of the implant used was extracted from an OsseoSpeed TX 3.5 × 11 mm implant (AstraTech). Ball abutment with 2.25 mm diameter modeled to secure the implant-retained overdenture that consists of a titanium implant abutment (patrix) with a 2 mm cuff height and a corresponding retentive gold alloy housing (matrix) that is typically retained in the intaglio surface of the overdenture. The titanium patrix part of the locator attachment system was modeled with a 3.8 mm diameter 1.8 mm male seating area and a 2 mm cuff height. Additionally, 4.7 mm-diameter resilient nylon (blue), and 5.4 mm-diameter denture cap were also modeled for the matrix part of the system.

Mechanical properties of the materials that were simulated were taken from the literature and are presented in Table 1. Mandibular overdentures were designed to achieve full coverage of all stress-bearing tissues of the edentulous mandible. For standardization, the same denture was used by assuming the material properties were the same for both the base part and the artificial teeth. The implant-bone interface was considered to be static. The contact area of the overdenture and mucosa was assumed to be frictionless. The final models were meshed using ALGOR FEMPRO software (ALGOR Inc, Pittsburgh, Pa) with 3D parabolic tetrahedral solid elements with surface-to-surface contact. Immediately afterward, a refined mesh was performed in the interfornal region to reproduce the compound stress formation observed in peri-implant bone. The total numbers of elements and nodes are listed in Table 2. Static analysis of the models was also performed with the same software.

A spherical solid material (SSM) was used for occlusal loading (100N) and to simulate foodstuff in different biting configurations, as described by previous studies. To represent SSMs, a rigid surface was used to precisely describe its interaction with overdentures, thereby reducing the calculation time and simulating the contact management that can be achieved. SSMs were modeled spherically with a 20 mm diameter to avoid localized contact (Figure 2). For posterior load, SSMs were positioned on both the left and right sides, whereas for the anterior load, SSMs were positioned between the middle point of the left and right central incisors. Data for Von Misses stresses were produced numerically, color coded, and compared among the models for attachments and peri-implant cortical bone. To evaluate stresses from the peri-implant cortical bone and attachments, values were obtained separately from each implant side (right, left).
RESULTS

Stresses in peri-implant bone

The maximum equivalent stress values in the cortical bone around implants and stress distributions in the peri-implant cortical bone of each model under three loading conditions are illustrated in Figures 3 through 5.

Anterior Load

Similar stress values were observed in terms of attachment types within the control groups (A1, A2). The minimum stress values were found around the left implant of the C1 (18.600 N/mm²), whereas the maximum stress was obtained around the right implant of the B1 (64.196 N/mm²), which was 1.9 times higher than the control group, A1 (32.372 N/mm²) (Figure 6). The peak stress values were found to be concentrated around the right implants of B1 (64.196 N/mm²) and B2 (42.546 N/mm²), which were approximately 3.0 and 1.4 times higher than the left side of B1 (21.006 N/mm²) and B2 (28.777 N/mm²), respectively. When locator and ball abutments were compared, the stress around B1 was found to be approximately 1.5 times higher than B2 on the right side, while similar stresses were found on the left side. C2 showed similar stresses when compared with the control group (A2), whereas the left implant of C1 (18.607 N/mm²) exhibited approximately 1.8 times lower stress values when compared to the control group A1 (33.568 N/mm²), the left side of C2 (35.072 N/mm²), and the right side of C1 (32.498 N/mm²).

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<thead>
<tr>
<th>Table 1</th>
<th>Mechanical properties of the materials</th>
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<td>Elastic modulus GPa</td>
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<td>Model 2</td>
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<td>Model 3</td>
<td>Nodes 163 928  Elements 742 454</td>
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<td>Model 6</td>
<td>Nodes 160 769  Elements 724 556</td>
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Left Posterior Load
Stress values were found to be approximately the same in terms of attachment types within the control groups (A1, A2). Higher stress values were observed around the working side implants (left) of all groups when compared with the nonworking sides (Figure 7). In addition, C1 and C2 showed lower stress values than did the other groups on both sides. Minimum stress values were found in the right implant of the C2 (5.595 N/mm²), whereas the maximum stress values seemed to be similar in all the groups. The peak stress values were found to be concentrated around the working side implants of all groups except C1 (4.931 N/mm²), which was 2.4 and 2.3 times lower than the control group A1 (11.880 N/mm²) and the nonworking side implant of C2 (2.348 N/mm²), respectively.

Right Posterior Load
Similar stress values were observed in terms of attachment type within the control groups (A1, A2). Higher stress values were observed around the working side implants (right) of all groups when compared with the nonworking sides (Figure 8). In general, C1 and C2 showed lower stress values than the other groups in both sides. Minimum stress values were found around the left implant of the C1 (1.449 N/mm²), whereas the maximum stress values were observed around the right implant of B1 (15.494 N/mm²), which were not remarkably higher than the control group A1 (3.690 N/mm²).

Stresses on the attachments
Maximum equivalent stress values on the attachments and stress distributions around the attachments of each model under three loading conditions are illustrated in Figures 9 through 11. All of the stresses were located on the top area of the locator attachment while it was observed on the cervical area of the ball attachments.

Anterior Load
Stresses seemed to be approximately similar within the control group (A1, A2) attachments. Minimum stress values were found in the right attachment of B1 (11.269 N/mm²), whereas the implants with the same vertical height level. (c) Ball attachments, left implant and the alveolar bone on the left side is unilaterally 1 mm higher than right side. (d) Locator attachments, left implant and the alveolar bone on the left side is unilaterally 1 mm higher than right side. (e) Ball attachments, left implant and the alveolar bone on the left side is unilaterally 3 mm higher than right side. (f) Locator attachments, left implant and the alveolar bone on the left side is unilaterally 3 mm higher than right side. Figure 5. Distribution of stresses in peri-implant bone (right posterior load). (a) Ball attachments, left implant and the alveolar bone on the left side is unilaterally 1 mm higher than right side. (b) Locator attachments, left implant and the alveolar bone on the left side is unilaterally 1 mm higher than right side. (c) Ball attachments, left implant and the alveolar bone on the left side is unilaterally 3 mm higher than right side. (d) Locator attachments, left implant and the alveolar bone on the left side is unilaterally 3 mm higher than right side. Note that right posterior load considered as the same with left posterior load image of the implants with the same vertical height level.
maximum stress obtained around the left attachment of B2 (15.645 N/mm²) (Figure 6). However, no remarkable stress differences were found on the attachments of all groups when anterior load was applied.

Left Posterior Load

In control groups A1 and A2, higher stress values were observed in ball attachments, especially on the left side (5.272 N/mm²), which was approximately 1.7 times higher than the locator attachment of the same side (3.166 N/mm²). Locator attachments exhibited lower stress values in both sides of all groups when compared with ball attachments. Working side attachments showed greater stress values in all groups when compared with the nonworking sides, which were increased with the level differences (Figure 7). However, working sides of the 1 mm level difference groups—B1 (11.172 N/mm²) and B2 (6.241 N/mm²)—were affected much more than the 3 mm level difference groups—C1 (7.499 N/mm²) and C2 (4.094 N/mm²). The maximum stress value observed on the working side attachment of B1 was 2.1, 1.8, and 1.5 times higher than the control group A1, the working side attachment of B2, and the working side attachment of C1 (7.499 N/mm²), respectively.

Right Posterior Load

In control groups A1 and A2, higher stress values were observed in ball attachments (A1 [5.272 N/mm²]), especially in the working side, which was approximately 1.7 times higher than the locator attachment (A2 [3.166 N/mm²]) of the same side. Locator attachments exhibited lower stress values on both sides of all groups when compared with ball attachments. Working side attachments showed greater stress values in all groups when compared with the nonworking sides, which were increased with the level differences (Figure 8). The maximum stress value observed in working side attachment of B1 (6.493 N/mm²) was similar with the same side of C1 (6.323 N/mm²), and stresses were exposed approximately 2 times more on these attachments when compared with locator attachments.

Discussion

All in vitro analyses to simulate a physical problem presented an inherent limitation to accurately reproducing the properties and characteristics of in vivo structures. Especially in the cortical bone layer, there may be some changes, such as additional cortical bone formation around the implants (which results
Clinicians anticipated that the two independent implants should be positioned at the same occlusal height, parallel to the occlusal plane. If one implant is higher than the other, the prosthesis disengaged from the lower implant during function and rotated primarily on the higher implant. This situation will accelerate the wear of the attachment on the lower implant, and because the higher implant receives the majority of the occlusal load, an increased amount of crestal bone loss can occur, as described by Misch.

Nevertheless, according to our results, decreased stress values in the peri-implant bone were obtained in the models with 3 mm height differences (C1, C2) when compared with the control groups (A1, A2). This can be explained by arranging the height differences and by increasing the alveolar bone without increasing the mucosal thickness.

The authors believed that SSMs represent a good choice when applying loads to the FEM models. Previous studies performed inclined and vertical loads separately, which cannot simulate the natural environment. While chewing, vertical and horizontal forces are transferred to the denture concurrently, which led the authors to use a 20 mm-diameter spherical surface SSM to avoid localized contacts. By using a large diameter SSM, loads were applied across the cusp inclines and formed multivectoral forces, which are thought to be a more successful way to simulate chewing loads.

When anterior load was applied that simulated the action of cutting food with anterior teeth, decreased stresses were
observed with the increase of the height level around the peri-implant bone of the higher implant, especially in the ball attachment group (B1, C1). Peak stress values obtained from the lower implant of B1, which was not in contrast with Misch. According to Misch, the prosthesis disengages from the lower implant during function and rotates primarily on the higher implant, and higher implant receives the majority of the occlusal load. In the current study, it was discovered that in all levels of height differences, the majority of the stresses manifested in the peri-implant bone of the lower implant when anterior load was performed. It was also recognized that the stresses in the peri-implant bone of the lower implants of C1 and C2 were similar to those control groups (A1, A2), but the stresses were remarkably higher around the lower implants of B1 and B2. The authors thought that it could be attributed to the lever arm effect. The lever arm effect can be explained by the term “crown height space,” defined as the distance measured from the crest of the alveolar bone to the plane of occlusion. According to the published consensus report of Misch et al., there are 2 crown height considerations with implant retained overdentures. The first crown height space is the crown height of the attachment system to the crest of the bone, while the second crown height space is considered to be the distance from the top of the attachment to the occlusal plane. In the current study, the first crown height space was modeled the same in all groups, whereas the second crown height space was decreased 1 mm and 3 mm in the left implants of B and C groups, respectively. The second crown height represents the increase in prosthetic forces, thereby increasing the lever arm, and it was concluded that the higher the crown height distance, the more the forces applied to the implants. Increasing the crown height of an implant-supported prosthesis increases the risk of excessive occlusal overload because of an increased lever arm. In cases of fixed prosthesis, for each 1 mm increase of crown height space, the cervical load would increase by 20%. However, in removable prosthesis, with each 1 mm increase of crown height space, the cervical load would increase by 3.6%. The decreased stresses around left side implants of C1 and C2 by decreasing the lever arm (second crown height) could be explained with the aforementioned data. However, in B1 and B2, stress values around the lower implants were increased. The authors believe that this phenomenon could have arisen from the negative effect caused by the distance between the tops of the two attachments that can generate a worse impact than that gained from the mechanical advantage of 1 mm of alveolar bone height. The stress concentration on both locator and ball attachments seemed to be the same in all configurations, which can be explained in that the height differences will not affect the wear of attachments when an anterior load is applied. This finding was also not in line with the well-known concept of the accelerated wear of attachments on the lower implants, as described by Misch.

![Figure 10. Distribution of stresses on attachments (left posterior load).](attachment_image.png)
Higher stress values were observed around the working side implants when a posterior load (simulating chewing forces) was applied. Models with 3 mm height differences between the ball and locator attachments (C1, C2) showed the best results in the peri-implant cortical bone, which can be explained by the advantage of the increased amount of bone, as illustrated by Hong et al.\textsuperscript{8} In addition, stresses on the locator attachments showed lower values when compared with the ball attachment groups in all configurations. The authors think this might be attributed to the dual retention mechanism (through both external and internal mating surfaces) of the locator attachment, which provides vertical resiliency.\textsuperscript{38,39} Additionally, it was also described that the ability of the denture cap to gently pivot in any direction over the male accommodates natural movements during occlusion and the pliancy of the soft tissue supporting the overdenture, which may also provide additional resiliency.\textsuperscript{40} However, the ball attachment that was selected for the current study has rotational resiliency but no vertical resiliency because it was modeled with a direct contact on the top of the ball abutment with the matrix. As a result, most of the stresses were located on the top of the locator attachment instead of on the neck of the ball attachment.

When the posterior load from the higher implant side (left) was performed, peri-implant bone around C1 showed approximately 2.3 times lower stress values than the control group and C2. The decrease in the stress values can be explained with the decrease of the denture height space (DHS). DHS is the distance measured from the crest of the alveolar bone to the...
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plane of occlusion, which is related to the lever arm mechanics. In the current study, since 3 mm vertical height was obtained by increasing the alveolar bone height without changing the denture height, DHS was automatically decreased. In crown restorations, it was concluded that decrease in the crown height resulted with decreased stresses in crestal bone, especially if the direction of the load is off-axis with a lateral vector, which was also lateral on the working side implant while posterior load was applied. However, in contrast, the attachment of C1 (ball) showed greater stress values. The authors believed this can result from the wear of the ball attachment because stresses were absorbed by the attachments; in this manner, the ball attachment in the working side prevented the transmission of the stresses to the peri-implant bone. When chewing from the lower implant side was simulated, stresses in the peri-implant bone of the working sides of all groups were not remarkably changed because no adjustments were applied on the alveolar bone height in the corresponding sides.

In the current study, height differences were arranged by increasing the bone level around the implants. Additional studies that create height differences in the mucosal level could be conducted with improved simulation of the environment to understand the effect of the abutment height. The finite element modeling technique used in this study has limitations when predicting the response of the biological system. In a clinical situation, it would not be possible to control factors such as thickness of the cortical bone of the individual mandible, the position of the implants, the direction and intensity of loads, the denture fit, or the resilience of the mucosa. The current study did not simulate different cortical bone thicknesses. The effect of placement depth in different cortical bone thickness should be evaluated to outline better clinical situations. Resilience of the mucosae is also another important factor for the stress distribution. It was reported in previously published studies that stress values in supporting tissues decreased with the increase of the thickness and resiliency of the mucosae. The contact management could influence the results of this study as well. Sliding and movements between mucosa and denture were set to non-linear frictional contact to simulate different anticipated movements. Additionally, osseointegration was assumed to be 100%, which does not match clinical situations. Akagawa et al. found quite different stresses between 100% and partially osseointegrated implant models, and they suggested the need for models with uniform cancellous peri-implant bone. Therefore, it can be concluded that clinically higher stress values would be created by lower degrees of osseointegration since bone-implant contact percentage varies from 30–70%. However, the findings of this study may provide a broader understanding about the potential stress concentration locations. Hence, further research using 3D FEA combined with long-term clinical evaluation is required to determine the effect of different clinical situations.

CONCLUSIONS

Despite the limitations of the current study, the following conclusions can be drawn:

- The configurations in which implants were located with 3 mm height differences in the bone level showed the most successful results in the peri-implant bone. When this configuration exists, it can be recommended not to make any bone adjustments during surgery.
- Peak stress values in the peri-implant bone obtained from the models with implants that had 1 mm height differences, which should lead clinicians to reduce the minor level differences during surgery.
- Certain recommendations about the attachment types in terms of their effects on peri-implant bone cannot be drawn in two-implant overdentures when implants were positioned in different height levels.
- When stresses on the attachments were compared, generally more stress values were obtained from the ball attachments.

ABBREVIATIONS

3D: three-dimensional
DHS: denture height space
FEA: finite element analysis
ISOD: implant-supported overdentures
SSM: spherical solid material

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