The Effect of Implant Position on Retention and Stability of Mandibular Implant-Supported Overdentures

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Abstract

Objective: Implant-retained overdenture is the standard treatment for edentulous patients. The aim of this study was to compare the effect of different implant locations (ABDE, 6AE6, 6BD6) on the retention and stability of mandibular implant-supported overdenture with ball attachment.

Methods: An experimental study was designed. An acrylic resin model of edentulous mandible with six implants in the location of first molar, first premolar and between lateral incisor and canine on the left and right side was fabricated. A metallic overdenture was fabricated precisely adapted to the model and attached to a Universal testing machine (crosshead speed of 51 mm/min). The ball attachments were screwed in three different patterns. The balls were first screwed in ABDE, then in 6AE6, and finally in 6BD6 position. Dislodging tensile forces were applied in three vertical, oblique and anterior-posterior directions for each sample. For each of these three situations, five tests were done. The maximum dislodging force was measured. Normal distribution of data was analyzed with Shapiro-Wilk test. Levene’s test analyzed the variances. A Three-Way ANOVA test was employed followed by Tukey’s test.

Results: The amount of vertical load was significantly higher than the oblique and anterior-posterior loads (P<0.001). The amount of ant-post load was significantly higher than the oblique load (P<0.001). The average of MDF was significantly higher in 6BD6 position (P<0.001). This average was also significantly lower in ABDE position (P<0.001). The amount of measured force was the lowest in ABDE and the highest in 6BD6 positions (ABDE=64.51 N and 6AE6=66.06 N). Vertical and oblique dislodging forces were the minimum and maximum measured forces, respectively (mean vertical=87.95 N, mean lateral=48.1 N and mean ant-post=63.5 N).

Conclusion: Lateral and ant-post dislodgement forces were higher in 6BD6 and 6AE6 positions, respectively. The greatest vertical dislodgement force was observed in 6BD6 position. Vertical retention was higher than lateral and ant-post retentions. The more posterior the position of the distal implant the more the retention and stability.

Key words: Dental implant, Retention, Stability, Mandibular overdenture


Received: 07.06.2011 Final Revision: 24.10.2011 Accepted: 26.10.2011

Introduction:

At present, treatment of completely edentulous patients is a significant portion of prosthodontic treatments (1). The most commonly performed treatment is complete denture therapy (1). From the public health’s point of view, although this treatment is simple and low cost, it cannot be a general therapy suitable for all edentulous patients (1). Patient’s perception and response to this type of treatment comprise an important part of clinical evaluation criteria for treatment outcome. Considering the patient’s high expectations, clinical experiences, their
dissatisfaction and incompatibility, gradual ridge atrophy and other problems, patients have started to avoid complete dentures and develop a tendency towards implant-supported overdentures (1).

There is a theory stating that in near future complete denture therapy will be replaced by implant-supported overdentures (1). In implant-supported overdenture therapy, at least 2 implants are inserted in the mandible of edentulous patients (1). Using higher number of implants in the future results in improved retention and stability and even fixed prosthodontic treatments can be used for these patients (1, 2).

In patients with completely edentulous mandible, poor stability and retention of the complete denture is a common problem (1). Researchers have found a direct correlation between the retention of denture and patient’s satisfaction (3, 4). The need for repeated visits due to ridge atrophy is an important issue that results in further reduction of retention and stability (1). This problem is more significant in the mandible than in maxilla because of the smaller base of mandibular denture (1, 2).

Various solutions have been recommended for maintaining retention and stability and bone preservation such as vestibuloplasty and bone grafting (5). One of the best solutions is implant placement (5).

Implant-supported overdenture includes 3 components:
1- Implant (Fixture)
2- Attachment
3- Suprastructure
Use of overdentures on the roots in tooth-supported overdentures has been common for long and their application has been associated with success (6-8). Intraosseous implants like teeth roots are currently used for maintaining the retention and stability of denture with the use of attachments (8). The main advantage of these implants is that the position of attachments can be selected through choosing the location of implants (8). Such ability is not present in tooth-supported treatments since it is the patient’s teeth that dictate the location of attachments.

At present, various positions have been suggested for placement of implants. The previous treatments were mostly bone-driven which means selecting the location of implants was based on the location of available bone (9). Based on this treatment philosophy, selection of the location of implant is mostly based on the optimal amount of bone and its location in the jaw. In the mandible, often the anterior segment would be chosen due to the lack of anatomical interferences (2).

Considering technical advancements and high expectations of patients and dentists, prosthodontic-driven treatments have been suggested which are based on determining the implant locations based on prosthodontic needs (2). In this regard, more attention is paid to posterior mandible locations. On the other hand, at present patients requiring implant-supported treatments are at a lower age than before and therefore, the remained bone usually has a better quality and quantity.

This study evaluated the effect of implant positions on retention and stability of overdenture and took a step towards selecting the locations of implants for overdenture according to evidence-based dentistry (EBD) guidelines.

This study aimed at comparing the effect of 3 different positions of implants on retention and stability of implant-supported overdentures. In this study, retention and stability of overdenture
were evaluated under vertical, oblique and anterior-posterior forces at 2 positions.

Methods:
In this in-vitro experimental study 6 stages were performed as follows:
1- Fabrication of the test model, drilling and placing the implants
2- Fabrication of overdenture housing
3- Preparing the attachments
4- Fabrication of load cell
5- Testing machine
6- Performing the test

This in-vitro experimental interventional study was performed on an edentulous mandibular acrylic model. Six implants were inserted into the model. At each test, 4 implants out of a total of 6 were activated as follows through the connection of implants and attachments.

1- Fabrication of the test model, drilling and placing the implants: In order to imitate mandible, a mandibular test model made of acrylic resin was used which had no undercut. In order to fabricate this model, a mandibular master cast belonging to a patient who had lost/extracted all his teeth about a year ago and had small even ridge atrophy was used. Using a surveyor, undercuts were blocked out with wax. After doing so, cast borders were extended to create a smooth, even surface 1-2 cm wide around the cast. Vestibules were also filled with wax. Then a duplicate cast was prepared and eventually, acrylic resin model was fabricated using Dublicate jel (Elite 32, Zermack, Italy) and self-cure Orthocryl acrylic resin (Ispringen, Germany). Then, locations of the points 6, E, D, B, A, and 6 were determined. Point A, was the location of first premolar tooth at one quadrant, point B was the contact point of mandibular lateral and canine teeth at one quadrant, point C was the mandibular symphysis, point D was the contact point of mandibular lateral and canine teeth of the other quadrant, point E was the location of first premolar of the other quadrant (in fact, the anterior mandible in between the mental foramina was divided into 5 equal columns) and the point 6 was the location of the mandibular first molar. In this study, points A and B were considered at the left and points D and E were considered at the right quadrant. Implant holes were drilled using ITI drill series and milling machine (Paraskop M, Bremen, Germany, Bego) in order to achieve parallel holes. Six implants of the ITI system (straumann-Switzerland) with 4.1 mm diameter and 10 mm length were placed parallel to each other using a milling machine (Paraskop M, Bremen, Germany, Bego) at 6, E, D, B, A, and 6 locations. In order to ensure the correct location of prepared holes after making the primary hole, the distance between the holes was measured using caliper (Fowler-Canada) with 0.1 mm precision according to the location of placed artificial teeth. This distance was 8 mm between the points A and B, B and C, C and D, and D and E. This distance was 16 mm between the points 6 and A and 6 and E. After making sure of the correct distance and direction of the holes, drilling was performed. Implants were eventually inserted in their respective locations. All measurements were performed on this model. In order to make sure that the implants would not be extracted from their respective holes during the test, the holes were prepared using a smaller size drill. After first insertion of implants into the holes and reassuring its correct positioning, the implants were extracted and inserted again using cyanoacrylate super glue on the base and then locations of points 6, E, D, B, A, and 6 were determined.
(Razi Co. Iran). The mentioned phases are demonstrated in Figures 1 and 2.

![Figure 1- Determining the points 6, E, D, C, B, A and 6 on the alveolar ridge crest for drilling the implant locations](image1)

Since there was no undercut, retention would be provided only from the attachments and implants. Although this was an in-vitro study, we tried our best to match the conditions with a clinical setting. Therefore, framework was made of chrome cobalt (Densply, Biosil f, Degudent, Germany) to work as a base. The advantage of using metallic overdenture is the minimum change in all tests and use of one framework for all tests. In order to fabricate a metallic framework, first a duplicate was made of the acrylic model and a cast was prepared using heat resistance dental gypsum (Nanovest, Germany). Waxing was done on this model. For waxing, a tunnel was made on the ridge for placement of housing and 4 hooks were created at 4 anterior, central, right and left lateral locations on a hypothetical equilateral triangle that surrounded the housing. After casting, housing was placed inside this tunnel shaped segment and acrylic resin was placed and formed (Figure 3).

![Figure 2- Parallel drilling using milling machine (Paraskop M, Bremen, Germany, Bego)](image2)

![Figure 3- Superior view of the fabricated framework on the cast](image3)

Two hooks were placed at anterior and central locations and 2 others were placed in right and left lateral positions. These hooks were connected to the load cell and from the load cell to the Zwick machine with polyester cords (Kiancord, Tehran, Iran). The used model was a one piece unit and all the tests were performed on this model.

2- Fabrication of overdenture housing: this acrylic piece can be fabricated as removable so that could be placed at various attachment positions. This part is fabricated inside the metallic framework. After insertion of the metallic framework, screwing the ball abutments (ITI), placing the Titanium attachment (ITI) on the ball abutment and performing the necessary block outs around the attachment, at 3 phases, powder and monomer liquid of the self-cure transparent acrylic resin (Meliodent, Kalan Co, Iran) were fixed according to the manufacturer’s instructions and poured into the framework. At each phase, framework was placed into the
pressure pot. At the end, the model was polished and prepared for testing (Figure 4). For minimizing errors, only one housing was fabricated.

![Figure 4- Completed housing](image)

3-Preparation of attachments: Extra acrylic resins around the attachments were removed if present. Complete sitting and adaptation of the framework on the acrylic cast at the anterior segment were evaluated using 50 micron articulation paper (Dentaives- Switzerland) through assessing the presence of contact points between the framework below the anterior hook and the cast (the paper would stick between the framework and acrylic model). We ensured the complete sitting at each time of testing.

4- Fabrication of the load cell: In alignment with the corresponding hooks on the metallic framework, a component was designed that contained 4 hooks (similar to framework) at its lower surface and one at the opposite side for connecting to the hook in the testing machine.

5-Testing machine: Zwick/Roell Z020 model made in Germany was used. This machine applied forces for dislodgement of samples from the model and had 2 components:

A: a hardware component in which the model is placed and tensile forces are applied to the model.

B: a software component into which the characteristics of the sample, crosshead speed of the machine and related force-length diagram are recorded.

The crosshead speed of the machine was adjusted at 51 mm/min which is similar to the speed of overdenture movement on the ridge during mastication (10). The model was fixed to the lower surface using a clamp in a way that vertical forces were completely in alignment with the path of insertion of housing and framework. An S shape hook with 15.5 mm length was attached to the center of load cell (the surface that contained a hook) using polyester cord with the cross sectional area of 0.407 mm². On the other side of the load cell 3 holes in the corners and one hole in the center were formed. A polyester cord was passed through each hole to reach the corresponding rings on the framework (of the right hole for the right ring on the framework, of the left hole for the left ring, of the anterior hole for the buccal ring and of the central hole for the lingual ring on the framework). If all cords were connected to the framework, vertical force would be applied. By releasing the right or left ring oblique force and by releasing the 2 posterior rings, anterior posterior force would be applied. Vertical force is for measurement of retention and other forces are for the measurement of stability.

Maximum dislodging force: is the maximum force applied before complete dislodgement of overdenture (complex of framework and housing) from the attachments on the model. Zwick testing machine recorded the amount of force and depicted it as a diagram. The highest figure for force (N) will indicate MDF.

6- Performing the test: related abutments were screwed for every position to be tested. Framework and housing were placed in their respective locations. After ensuring complete insertion using 50 micron articulation paper, load cell that had been connected to the framework with polyester cords was pulled from the other side by the hook of the testing machine in the adjusted speed to dislodge the overdenture from the cast. A total of 21 different positions and 105 tests were performed as follows:
A: Performing the test at position 1 (ABDE) with application of vertical force: ball attachments were screwed on the implants inserted in points A, B, D, and E and were tightened up to 20 Ncm. Acrylic model along with the its hook was placed on the Zwick platform. New springs were placed inside the attachments. The 4 hooks of the framework were connected with 4 corresponding hooks in the load cell using polyester cord. The hook on the other side of the load cell was connected to the Zwick machine hook with the use of intermediate hooks. The computer prompted the order for initiation of tensile force with crosshead speed of 51 mm/min. The tensile force was continued till the complete dislodgement of overdenture from the acrylic model. The diagram of the applied force until complete dislodgement was drawn using the computer. Finally, the greatest figure for applied force (N) was indicative of the MDF which was recorded in the Table. This test was repeated five times. The new test would be performed after completion of the previous one and complete dislodgement and repositioning of the overdenture on the model and ensuring its complete insertion using articulation paper (Figure 5).

B: Performing the test at position 1 (ABDE) with application of oblique force: this test was performed similar to the first one. The only difference was that one of the right or left hooks was not connected to the load cell. In other words, only the anterior, central and one of the posterior hooks were connected to the load cell. This test was also performed 5 times. In order for all the tests to be similar, right hook was not connected in any of them.

C: Performing the test at position 1 (ABDE) with application of anterior-posterior force: this test was performed similar to the first one and followed the exact same phases. The only exception was that the right and left hooks (both posterior hooks) were not connected to the load cell. In other words, only the anterior and central hooks were connected to the load cell. This test was also performed 5 times.

D: Performing the test at position 2 (6AE6) with the application of vertical force: ball abutments were screwed onto the implants inserted in locations 6, A, E and 6 and tightened up to 20 Ncm. Other phases up to the test F were similar to those of tests A to C and only the location of implants was different.

E: Performing the test at position 3 (6BD6) with application of vertical force: ball abutments were screwed onto the implants inserted in locations 6, B, D and 6 and tightened up to 20 Ncm. Other phases up to the test I were similar to those of tests A to C and only the location of implants was different.

F: Performing the test for the control group (not connecting the attachments): in this position, ball abutments were not screwed onto the acrylic model.

Shapiro-Wilk test was used for assessing the normal distribution of data. Variances were evaluated using Levene’s test. Three-Way ANOVA was used for analysis of variance and evaluation of the effect of three factors of implant position, force application method and...
force direction on quantitative dependent variable and amount of force while for paired comparisons, Tukey’s HSD test was used. Error rate was considered 0.01 and therefore, $P<0.01$ was considered statistically significant.

Results:

Normal distribution of data was assessed using Shapiro-Wilk statistical test and with minimum probability index of 0.164, distribution of data was proved to be normal. Equality of variances was evaluated using Levene’s test and this equality was accepted with $P=0.041$. Therefore, Three-Way ANOVA test was used for data analysis.

In comparison of the measured applied vertical force in 3 different positions of implant placement (ABDE, 6AE6, 6BD6) the highest recorded mean belonged to the 6BD6 position which was equal to 93.85±6.9 N. The lowest mean recorded was for ABDE position and equal to 81.70±3.1 N. The value obtained for 6AE6 position was somewhere in between these 2 rates and equal to 87.17±3.38 N.

When comparing the measured oblique force applied in 3 different implant positions (ABDE, 6AE6, 6BD6), the highest mean recorded belonged to 6AE6 position and was equal to 49.61±1.22 N while the lowest mean recorded belonged to the 6BD6 position and equal to 47.58±2.03 N. The figure obtained for ABDE position was within these two figures and equal to 48.02±1.22 N.

In comparison of the measured anterior-posterior force applied in 3 different positions of implants (ABDE, 6AE6, 6BD6), the highest mean recorded belonged to 6BD6 position and equal to 65.94±2.26 N whereas, the lowest mean recorded belonged to the 6AE6 position and equal to 60.74±0.35 N. The rate obtained for ABDE position was within this range and equal to 63.86±0.96 N. Complete results are demonstrated in Table 1.

The highest mean of measured force in all 15 measurements of tensile force for 3 directions of vertical, oblique and anterior posterior belonged to the vertical force and was equal to 87.95±5.35 N. Anterior-posterior force with a mean of 63.06±2.39 N ranked second. The lowest mean of force belonged to oblique force in an amount of 48.1±1.78 N.

According to the analysis of variance using Three-Way ANOVA, the correlation between implant position (ABDE, 6AE6, 6BD6) and direction of force application (vertical, oblique or anterior posterior) was not statistically significant ($P=0.821$). However, a significant ordinal correlation existed between the implant position and direction of force application ($P<0.001$). Implant position with $P<0.001$ and direction of force application with $P<0.001$ had a statistically significant effect on the amount of force.

Considering the implant position (ABDE, 6AE6, 6BD6) using Tukey’s HSD, the lowest and highest amounts of force were observed in ABDE and 6BD6 positions, respectively and all 3 positions had significant differences with each other ($P<0.001$ for all 3)(mean force was 64.51±14.22 N in ABDE, 66.06±16.55 N in 6AE6 and 68.54±19.78 N in 6BD6 position). Also, the amount of force in different directions of vertical, oblique and anterior-posterior was significantly different ($P<0.001$ for all 3). The lowest amount of force was applied in oblique and the highest was observed in vertical direction of tension (mean vertical force: 87.95±5.35 N, mean oblique force: 48.10±1.78 N and mean anterior-posterior force:63.06±2.39 N).
Table 1- Statistical indexes for vertical tensile forces at positions 1 and 2 for 3 different positions of implant placement

<table>
<thead>
<tr>
<th>Position</th>
<th>Force Implant position</th>
<th>Type of tensile force</th>
<th>Number of Samples</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Lowest Mean</th>
<th>Highest Mean</th>
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<td>16.89792</td>
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Figure 1- the amount of force based on 2 factors of implant position (ABDE, 6AE6, 6BD6) and direction of force application (vertical, oblique or anterior-posterior force).

Discussion:

Retention and stability of overdenture from the dentist’s point of view was evaluated by measuring MDF. This index was first introduced by Petropoulos et al, in 2002 (7) and helped in more scientific assessment and better comparison of results. During mastication, overdenture moves in various directions. These movements are complex and in order to facilitate...
their assessment, in this study we broke down these forces into 3 directions of vertical (for evaluation of retention), oblique and anterior-posterior (for evaluation of stability) direction similar to what was performed in Petropoulos et al, (2002), and Tabatabaian et al, (2010) studies (7, 10). Tension was used for assessment of all 3 forces. Vertical tensile force was similar to the force applied when chewing a sticky food which applies a force opposite to the path of insertion. Oblique tensile force is similar to unilateral chewing, and anterior-posterior force is similar to the situation where food is being chewed by the posterior teeth or when something is bitten by the front teeth. In this study, we changed the location of implants and evaluated the effect of this changed location on the amount of forces.

Assessments were performed at different positions by changing the connection of overdenture hooks to the load cell. For evaluation of the vertical force, 4 hooks of the framework were connected to the 4 corresponding hooks in the load cell using polyester cord. For evaluation of the oblique force right or left hook was not connected to the load cell. In other words, only the 3 anterior, central and one of the posterior hooks were connected to the load cell. For evaluation of the anterior posterior force, the 2 posterior hooks (right and left) were not connected to the load cell. In other words, only the anterior and central hooks were connected to the load cell. The latter is different from what was done in Petropoulos et al, (2002) and Tabatabaian et al, studies (2010) because in their studies only the 2 posterior hooks were connected to the load cell for evaluation of anterior posterior force (7, 10). The reason for this difference is that when pulling the 2 posterior hooks alone, the anterior border of framework gets involved with the acrylic model and can affect the outcome.

The crosshead speed of the device was adjusted at 51 mm/min. This rate was selected according to the calculation of the mean speed of denture movement in the mouth during functional movements (7, 10).

In this test, a metallic base was used to hold the matrices which results in minimum changes in their position and minimum error. This point has been confirmed in Petropoulos et al, (in 1997 and 2002) and Tabatabaian et al, (in 2010) studies (6, 7, 10).

Each test was repeated for 5 times which is similar to the number of tests performed in Petropoulos et al (1997, 2002) and Tabatabaian et al (2010) studies (6, 7, 10).

In Petropoulos et al, (2002) and Tabatabaian et al, (2010) studies a metallic chain was used for connecting the load cell to the overdenture (7, 10). Use of metallic chain makes equal distribution of forces difficult and requires repeated adjustment of chains to make the height of the chains equal. Another problem would be the weight of chains that may not be equal either. All these factors can result in error. That is why we used cord instead of chain in this study. Cord requires fewer adjustments. First, all the cords became equal in length and then the force was applied. The cord used was made of polyester, had a cross sectional area of 0.407 mm² and was in the form of twisted threads.

To date, no study has been performed to evaluate the effect of distance between the implants on the retention and stability of overdenture. In a clinical setting, this distance is determined based on number of implants that are planned to be inserted, type of attachment to be used, amount of bone loss, ridge atrophy and etc. (11). The minimum distance between the implants should be 3 mm (2). With such distance, it is feasible to use ball attachment (9). But if we want to use bar attachment this distance should be increased to 12 mm (9). In this study location of implants was determined
according to the Misch’s belief (2008) who divided the anterior mandible into 5 equal hypothetical columns (2). In this treatment plan, we can increase the number of implants without compromising the previously inserted ones (2).

The greatest force measured in this study among all 45 measurements of the tensile force applied in 3 directions of vertical, oblique and anterior-posterior belonged to the vertical force and was equal to 87.95±5.35 N. Anterior posterior force with a mean of 63.06±2.39 N ranked second. The lowest amount of force belonged to the oblique force and was equal to 48.10±1.78 N. When comparing the 3 positions of implants (ABDE, 6AE6, 6BD6), in all three the mean vertical force was greater than anterior posterior and the latter was greater than oblique force. In other words, the highest force was applied in vertical and the lowest in oblique position in all 3 groups. Also, the 3 positions had statistically significant differences in terms of the amount of force applied in various directions (vertical force, oblique or anterior posterior)(P<0.001 in all 3). The higher rate of vertical force was also mentioned in Petropoulos et al, (2002) and Tabatabaian et al, (2010) studies (7, 10). But in our study the lowest force was the oblique force which was not in concord with Petropoulos (2002) and Tabatabaian (2010) studies since they reported the anterior posterior force to be the lowest (7, 10). The reason for this difference may be different attachment of cords for application of anterior posterior force. In our study, for evaluation of the anterior posterior force, the posterior hooks were not connected to the load cell. In other words, only the anterior and central hook were connected to the load cell; whereas, in Petropoulos et al, (2002) and Tabatabaian et al, (2010) studies, only the posterior hooks were connected to the load cell (7, 10). The reason for such difference is that when applying tensile forces on the posterior hooks alone, the anterior border of framework gets involved with the acrylic model and can influence the outcome.

Comparison of the different implant positions (ABDE, 6AE6, 6BD6) using Tukey’s HSD showed that the lowest and highest rate of forces were applied in ABDE and 6BD6 positions, respectively and all 3 positions had statistically significant differences with each other in this respect (P<0.001 for all 3)(the mean force for ABDE:64.51±14.22 N, mean force for 6AE6: 66.06±16.55 N, and mean force for 6BD6: 68.54±19.78 N). It means that the more posterior the location of distal implant, the greater the retention and stability. This finding is in accord with Misch’s study (2008)(12). Misch (2008) believes that the more posterior the location of distal implant, the higher the support provided by the implant rather than the tissue for the overdenture (12).

In this study, attachments were placed parallel to each other which is similar to Gulizio et al, (2005) study (13). Gulizio stated that if metallic housing is not used, balls should have a 30° angle with each other but if gold matrix will be used, balls should be placed parallel to one another.

**Conclusion:**

The results of the present study showed that retention of overdenture at 6BD6 implant position and lateral stability of overdenture at 6AE6 implant position against oblique force were the highest. On the other hand, the amount of lateral stability of overdenture against anterior posterior force was the highest in 6BD6 implant position. This study also demonstrated that the more posterior the location of distal implant, the higher the retention and stability. Additionally, overdentureʼs retention was greater than its stability and the rate of anterior posterior stability was greater than lateral stability.
Acknowledgement:

The authors recommend that a similar study be performed in finite element format to evaluate the distribution of forces in the bone in 3 different implant positions.

References:

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