

Comparison of the Effect of Ball and Bar Attachment Designs on Retention and Stability of Mandibular Implant-Supported Overdentures

Abolfazl Sabouri¹ Negar Barjini*¹ Farhad Tabatabaian¹

¹Dept. of Prosthodontics, School of Dentistry, Shahid Beheshti University of Medical Sciences, Tehran, Iran

Abstract

Objectives: The present study evaluated the effect of bar and ball attachment designs on retention and stability of a mandibular overdenture supported by four implants.

Methods: An edentulous mandibular acrylic resin model with four implants in the anterior part of the ridge (A, B, D and E) was fabricated. A metal framework simulating the overdenture was also fabricated. Totally, 30 overdentures were divided into three groups based on the attachment design; BL: Four ball attachments in A, B, D and E positions; BB: One bar attachment between B and D positions and two ball attachments at positions A and E; BR: Bar attachments between the positions A, B, D and E with two posterior extensions. To evaluate the retention and stability of the overdenture, tensile dislodging forces were applied in three directions of vertical, oblique and anterior-posterior by a universal testing machine. One-way ANOVA and Tukey's HSD test were performed to analyze the data. All tests were carried out at 0.05 level of significance.

Results: There were statistically significant differences between the groups in the peak load ($P < 0.001$). The peak load values for vertical, oblique and anterior-posterior dislodging forces were the highest for BL with 49.38 ± 2.19 N, 52.19 ± 1.44 N, and 49.03 ± 5.89 N, respectively, while these values were the lowest for BR with 29.78 ± 2.52 N, 12.10 ± 0.45 N, and 6.26 ± 0.45 N, respectively.

Conclusion: The attachment designs affected the retention and stability of mandibular implant-supported overdentures.

Key Words: Denture Precision Attachment; Denture Retention; Denture, Overlay; Dental Implants; Mandible

How to cite:

Sabouri A, Barjini N, Tabatabaian F. Comparison of the Effect of Ball and Bar Attachment Designs on Retention and Stability of Mandibular Implant-Supported Overdentures. *J Dent Sch* 2017; 35(1): 41-52.

*Corresponding Author:
Barjini N.
E-mail: negar66@gmail.com

Received: 19.12.2016
Accepted: 09.03.2017

Introduction

Dental rehabilitation of an edentulous mandible is a challenge for prosthodontists. Use of dental implants has improved the treatment options in the past few decades. Complete dentures have been replaced with implant-supported overdentures, and complete dentures are no longer considered the first standard treatment choice for the edentulous mandible (1-5). In comparison with the mandibular implant-tissue-supported overdentures using two dental implants, the mandibular implant-supported overdentures

use a minimum of four implants. This provides more retention, stability and support for the overdenture (6-11). It has been reported that patient satisfaction is usually higher among those using implant-supported overdenture compared to complete denture (12-19). It has been well established that retention and stability are critical for the patient to resume function (13,20). Hence, the mandibular implant-supported overdenture must be carefully designed to achieve adequate stability and comfort and optimal shape, contour and esthetics (21). The retention and stability of overdenture are

affected by many factors including attachment type and design (6,22-30), wear of components, implant angulation (31,32), implant number and position (33,34) and occlusion (35). There are different attachments available for implant-supported overdentures. Among them, bar and ball are the simplest and most popular attachments. Available space (36,37), maintenance requirements, force distribution to the soft tissue and implants, and the required level of retention and stability are the factors that have to be considered when choosing the type of attachment design.

Sadig (30) found that type of attachments and connectors affected the retention and stability of implant overdentures supported by four implants. Burns *et al.* (38) demonstrated that the four-implant bar design provided greater retention than the other attachment designs, but patients were more satisfied with the independent implant treatment. Williams *et al.* (39) evaluated the effect of different designs of bar attachment on retention and stability of overdenture retained by four implants. The highest mean retention was observed in combination of ERA and Hader clip design. The lowest retentive values were recorded for the two and four Hader clip designs. Elkerdawy and Radi (40) found the ball attachment to be more retentive than telescopic attachment in mandibular overdenture supported by four implants. Alsabeeha *et al.* (41) suggested to perform further studies on the factors affecting the retention and stability of implant supported overdentures to separately assess these factors under well-controlled conditions.

The aim of this in vitro study was to evaluate the effect of three different bar and ball

attachment designs on retention and stability of an implant-supported mandibular overdenture.

Methods

This in vitro study was performed on 30 overdentures divided into three groups of BL, BB, and BR, based on the attachment design (n=10). Each overdenture was tested three times with vertical, oblique and anterior-posterior tensile dislodging forces. For equal distribution of forces, a hypothetical triangle with 5 cm sides was created. The three corners and the center of the triangle were used for force transmission.

Test cast fabrication:

A mandibular acrylic cast was fabricated using clear auto-polymerized acrylic resin (Meliodent, Heraeus Kulzer, Senden, Germany). The undercuts were relieved and the borders were adjusted to match the triangular design. Four implants (ITI Straumann, Bern Switzerland) were symmetrically placed at predetermined positions in a parallel fashion and named A, B, D, and E at both sides of the midline. Silicone material for gingival simulation (Gingifast Elastic, Zermack, Badia Polesine, Italy) was applied on the test cast (Figure 1).

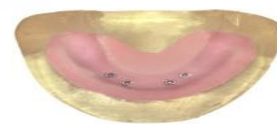


Figure 1- Mandibular acrylic cast

Overdenture fabrication:

An overdenture was made of two parts: a metal framework and an acrylic part. A cast framework, made of chromium-cobalt alloy (Remanium GM 800+; Dentaurum,

Ispringen, Germany), was fabricated as a framework structure. Four loops were placed on the framework at four locations: Two loops in the anterior and posterior borders of the framework in the midline and two loops at the posterior borders of the framework in the molar areas according to the aforementioned triangular design. These loops connected the overdenture to the load cell. This framework was the same in all overdentures.

Before preparation of the acrylic part of the overdenture, the attachment components were placed in the implants in their relevant locations. The abutments were screwed and torqued to 30 Ncm with a torque wrench (Institut Straumann, Waldenburg, Switzerland).

The acrylic part of the overdenture which filled inside the framework and covered the implants and the ridge, was made of self-polymerizing acrylic resin (Meliodent, Heraeus Kulzer, Senden, Germany). This part connected the metal framework to the attachment housings. The procedures of fabrication of the acrylic part were initially done with relief and block out of the undercuts around the attachments. Then, the acrylic resin was applied incrementally in three steps in order to decrease the polymerization shrinkage and was done according to the manufacturer's instructions. It was poured into the framework while the framework was fixed to the test cast.

After the primary setting time of acrylic resin, the framework was placed in the pressure pot at 45°C for 30 minutes. Eventually, the acrylic metal overdenture was finished and polished. For each sample, complete seating of overdenture on the test

cast was confirmed by engaging a 50 μ thick articulating paper (Dentaives, Switzerland) between them (Figure 2).

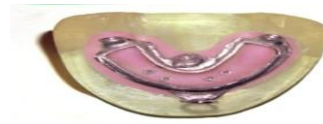


Figure 2- Metal framework

Attachment designs:

Totally 30 overdentures were fabricated in three groups (10 in each group) based on three attachment designs. Two types of attachments (Table 1) were used for the three designs. The groups were coded as BL, BB, and BR.

Table 1- Attachment designs

| Attachment type | Manufacturer | Component |
|-----------------|---------------|--|
| Ball | ITI Straumann | Titanium matrix retentive anchor Synocta gold coping Dolder bar regular |
| Bar | ITI Straumann | Dolder bar matrix regular occlusal screw |

BL: For each sample in this group, four separate ball abutments (ITI Straumann, Bern, Switzerland) were placed onto the implants at positions A, B, D, and E and torqued. A titanium matrix (ITI Straumann, Bern, Switzerland) was engaged on each ball abutment while all the titanium matrices were positioned parallel using a dental surveyor (Dental Surveyor, Krupp Medizintechnik, Essen, Germany). The overdenture was fixed to the test cast and the acrylic part of the overdenture was fabricated as explained previously (Figure 3).



Figure 3- BL design in cast and impersion

BB: For each sample in this group, two abutments (ITI Straumann, Bern Switzerland) were screwed onto the implants at positions B and D and torqued. A Dolder bar (ITI Straumann, Bern Switzerland) was installed between the abutments. Soldering process was appropriately performed using a soldering device. The respective gold clip (ITI Straumann, Bern, Switzerland) was placed on the bar and engaged. A Dolder bar matrix (ITI Straumann, Bern, Switzerland) was placed onto the clip. Two ball abutments (ITI Straumann, Bern, Switzerland) were placed onto the implants at positions A and E and torqued. Two titanium matrices (ITI Straumann, Bern, Switzerland) were installed on the ball abutments and engaged. The titanium matrices were positioned parallel to each other and vertically positioned on the test cast using the same dental surveyor. The overdenture was fixed on the test cast and the acrylic part of the overdenture was fabricated as explained previously (Figure 4).



Figure 4- BB design in cast and impersion

BR: For each sample in this group, four ITI abutments were screwed onto the implants at positions A, B, D, and E and torqued. A Dolder bar (ITI Straumann, Bern, Switzerland) was placed between the implants at positions B and D and soldered. A Dolder bar (ITI Straumann, Bern, Switzerland) were installed between the abutments at positions A and B and another bar between the abutments at positions D and E, and soldered. From the abutments at positions A and E, an ITI Dolder bar was extended posteriorly and parallel to the ridge.

An 8 mm ITI gold clip was placed on BD bar. A 6 mm ITI gold clip was placed on each posterior bar (Table 1). Three relevant ITI titanium matrices were located on the clips and engaged. The titanium matrices were positioned parallel to each other and vertically positioned to the test cast using the same dental surveyor. The overdenture was fixed to the test cast and the acrylic part of the overdenture was fabricated as explained previously (Figure 5).



Figure 5- BR design in cast and impersion

Testing:

In order to attach the overdenture to the universal testing machine (Zwick Z020; Zwick/Roell, Ulm, Germany), a load cell was fabricated matching the triangular design. It was a metal plate with 7 cm diameter. At its inferior side, four hooks were designed corresponding to the overdenture loops. At its superior side, one hook was applied in the center to connect to the universal testing machine via a metal S-shaped hook with 15.5 mm length. The load cell transmitted and evenly distributed the force from the machine to the overdenture (Figure 6).



Figure 6- The Load cell transmitted the force from the machine to the overdenture

A piece of polyester cord with 0.407 mm² diameter (Kian Cord, Malayer, Iran) and 40 cm length was used for load transmission from the load cell to the overdenture attached to the test cast. The cord was passed through

the corresponding loops on the overdenture and hooks on the load cell and tied at the end. To measure the peak load for the vertical dislodging forces, the cord was passed through all hooks. For measuring the peak load for the oblique dislodging forces, three hooks were involved (all except one of the posterior hooks); whereas, for anterior-posterior dislodging forces only the two posterior hooks were involved. The test cast was fixed to the inferior plate of the machine with a clamp in a way that vertical forces were applied parallel to the path of insertion of the overdenture.

The crosshead speed was adjusted at 51 mm/minute, which would approximate the rate of denture movement during mastication (42). The machine applied and measured tensile dislodging forces in three directions of vertical, oblique, and anterior-posterior. The peak load was measured and was represented with the peak load profile curve demonstrated for each test.

One-way ANOVA was used to evaluate the peak loads for vertical, oblique and anterior-posterior dislodging forces separately for the three groups of BL, BB and BR. Also, the

Tukey's HSD test was used for pairwise comparison of the three groups. The results were reported with 95% confidence interval.

Results

According to the two-way ANOVA, the correlation between the type of attachment design (ball/bar, ball and bar) and direction of force application (vertical, oblique and anterior-posterior) was statistically significant ($P<0.05$). For multiple comparisons, Tukey's HSD test was used.

The lowest amount of vertical, oblique and anterior-posterior forces was observed in bar attachment design while the highest rate of forces was observed for ball design. The three attachment designs were significantly different in this respect ($P<0.001$ for all three). Also, the amount of force applied in vertical, oblique and anterior-posterior directions was significantly different in the three designs. The lowest mean force was anterior-posterior and the highest was vertical (mean vertical force=38.61 N, mean oblique force=27.87 N and mean anterior-posterior force:22.66 N; Table 2).

Table 2- Mean vertical force (N) in the three attachment designs (n=30)

| Attachment design/Force | Mean | Standard deviation | Minimum | Maximum |
|-------------------------|-------|--------------------|---------|---------|
| Vertical | 38.61 | 9.63 | 22.16 | 52.12 |
| Oblique | 22.66 | 15.41 | 11.33 | 54.62 |
| Anterior posterior | 27.87 | 17.75 | 7.45 | 49.12 |

Discussion

Retention and stability of overdenture in this study were evaluated with MDF measurement. This index was first introduced by Petropoulos and Mante (42) in 2002

making the evaluations more scientific and the comparison of results easier. 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

three directions of vertical (for evaluation of retention), oblique and anterior-posterior (for evaluation of stability) similar to what was done by Petropoulos and Mante (42), Sadr *et al.*, (43) and Tabatabaian *et al.* (44). Tension was used for assessment of all three forces.

In studies by Petropoulos and Mante (42) and Tabatabaian *et al.*, (44) a metal chain was used for connecting the load cell to the overdenture. Use of metal chain complicates equal distribution of forces 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. This is similar to what was done by Sadr *et al.* (43). Cord requires fewer adjustments. First, all the cords became equal in length and then the force was applied (43). The cord used was made of polyester, had a cross-sectional area of 0.407 mm² and was in the form of twisted threads.

In this test, a metal base was used to hold the housing, which results in minimal changes in the position of matrices and minimum error. This point has been confirmed by Petropoulos *et al.*, (42) Tabatabaian *et al.*, (44) and Sadr *et al.*, (43). Each test was repeated for 10 times which is greater than the number of tests performed by Petropoulos and Mante (42) and Tabatabaian *et al.* (44) (5 times).

When comparing the three attachment designs (BL, BB and BR), in all three, the mean vertical force (38.61 N) was greater than oblique (27.87 N) and the latter was greater than the anterior-posterior force (22.66 N). In other words, the maximum force was applied in vertical and the minimum in anterior-posterior direction in all

3 groups. Therefore, retention was greater than stability. Also, the difference in force applied in vertical, oblique and anterior-posterior directions was statistically significant ($P < 0.001$ for all). The lowest mean force was recorded in anterior-posterior direction in our study, which is in accordance with what was reported by Petropoulos *et al.*, (42) Sadr *et al.*, (43) and Tabatabaian *et al.* (44). Also, in this study, the highest mean force recorded was vertical, which is in accord with the three aforementioned studies (42-44). Number of implants in our study was four similar to that in the study by Sadr *et al.*, (43) but Petropoulos *et al.*, (42) and Tabatabaian *et al.*, (44) used only two implants.

The magnitude of vertical force was greater than oblique force and the latter was higher than the anterior-posterior force, which is probably due to the insertion of implants at the anterior segment and not having sufficient resistance against anterior-posterior forces.

In a total of 90 tests, the mean vertical force in BL design was greater than that in BB and BR designs. The mean anterior-posterior and oblique forces were greater in BL design. Therefore, both retention and stability were greater in BL design. In other words, retention is generally greater than stability. The difference between the recorded vertical and oblique forces only in the BL design was not statistically significant. The reason may probably be the difference in type of attachments since in BL design four attachments cause great resistance against the movement of overdenture compared to BB and BR designs. Tabatabaian *et al.*, (44) in their study used Biocare bar and clip, Nobel

Sterngold ERA Red and Nobel Biocare standard ball. Two of these attachments were different from the ones we used and the ball attachment used in their study had a smaller diameter than the one we used. The ball attachment used in the present study was from the ITI system with 2.25 mm diameter, which has a larger diameter than many other systems and subsequently provides greater retention and stability. Also, in the study by Tabatabaian *et al.*, (44) number of attachments was fewer and therefore resistance against dislodging forces was lower.

Multiple comparisons by Tukey's HSD test demonstrated that the lowest and the highest amount of forces were observed in BR and BL designs, respectively. The amount of force was significantly different in the three designs ($P < 0.001$ in all three). It means that the retention and stability are greater in BL design because in this design, four retentive anchors actively create retention. Also, in order to justify the values obtained in BB and BR designs, we can state that in ball/bar design, three retentive anchors are present; out of which, two provide active retention (posterior balls) and the anterior bar creates frictional retention. Whereas, in bar design, only three retentive anchors are present that create frictional retention. Williams *et al.* (39) stated that the retention of ball and bar was greater than bar, which is similar to our findings. The highest average retentive value after 10 pulls was 19.8 lb for the combination of ERA and Hader clip design. Their study results are comparable with ball/bar and bar designs in our study since two Hader clips

with two posterior ERA attachments yielded the highest retention.

Petropoulos *et al.*, (45) in 1997 found that bar and clip create greater retention than ball attachment. The difference between their results and ours may be due to the different attachment systems used. Manju and Sreelal (46) in their study about three different types of attachments (ball-ring, bar-clip and magnetic) found the least denture displacement in ball design due to the presence of rubber O-ring and the resultant high stability. We recommend future studies on other attachment systems. Also, evaluation of stress distribution in bone is recommended in the three different designs using photoelastic and finite element analyses.

Conclusion

- 1- Overdenture retention in ball design was greater than that in ball and bar and the latter was greater than that in bar design.
- 2- Overdenture stability in ball design was greater than that in ball and bar and the latter was greater than that in bar design.
- 3- In all three designs, resistance against vertical force was greater than that against oblique and anterior-posterior forces.
- 4- Retention of overdenture was greater than its stability.
- 5- Lateral stability was greater than anterior-posterior stability.

Acknowledgement: "None Declared"

Conflict of interest: "None Declared"

References:

1. Doundoulakis JH, Eckert SE, Lindquist CC, Jeffcoat MK. The implant-supported overdenture as an alternative to the complete mandibular denture. *J Am Dent Assoc.* 2003 Nov;134(11):1455-8.
2. Turkyilmaz I, Company AM, McGlumphy EA. Should edentulous patients be constrained to removable complete dentures? The use of dental implants to improve the quality of life for edentulous patients. *Gerodontology.* 2010 Mar;27(1):3-10.
3. Carlsson GE, Omar R. The future of complete dentures in oral rehabilitation: A critical review. *J Oral Rehabil.* 2010 Feb;37(2):143-56.
4. Cooper LF. The current and future treatment of edentulism. *J Prosthodont.* 2009 Feb;18(2):116-22.
5. Kuoppala R, Napankangas R, Raustia A. Outcome of implant-supported overdenture treatment--a survey of 58 patients. *Gerodontology.* 2012 Jun;29(2):e577-84.
6. Mumcu E, Bilhan H, Geckili O. The effect of attachment type and implant number on satisfaction and quality of life of mandibular implant-retained overdenture wearers. *Gerodontology.* 2012 Jun;29(2):e618-23.
7. Sadig W. A comparative in vitro study on the retention and stability of implant-supported overdentures. *Quintessence Int.* 2009 Apr;40(4):313-9.
8. Rocuzzo M, Bonino F, Gaudio L, Zwahlen M, Meijer HJ. What is the optimal number of implants for removable reconstructions? A systematic review on implant-supported overdentures. *Clin Oral Implants Res.* 2012 Oct;23 Suppl 6:229-37.
9. Bilhan H, Geckili O, Mumcu E, Cilingir A, Bozdog E. The influence of implant number and attachment type on maximum bite force of mandibular overdentures: a retrospective study. *Gerodontology.* 2012 Jun;29(2):e116-20.
10. Batenburg RH, Meijer HJ, Raghoobar GM, Vissink A. Treatment concept for mandibular overdentures supported by endosseous implants: a literature review. *Int J Oral Maxillofac Implants.* 1998 Jul-Aug;13(4):539-45.
11. de Jong MH, Wright PS, Meijer HJ, Tymstra N. Posterior mandibular residual ridge resorption in patients with overdentures supported by two or four endosseous implants in a 10-year prospective comparative study. *Int J Oral Maxillofac Implants.* 2010 Nov-Dec;25(6):1168-74.

12. Raghoobar GM, Meijer HJ A, Stegenga B, Van't Hof MA, Van Oort RP, Vissink A. Effectiveness of three treatment modalities for the edentulous mandible: A five-year randomized clinical trial. *Clin Oral Implants Res.* 2000 Jun;11(3):195-201.
13. Burns DR, Unger JW, Elswick RK, Giglio JA. Prospective clinical evaluation of mandibular implant overdentures: Part II--Patient satisfaction and preference. *J Prosthet Dent.* 1995 Apr;73(4):364-9.
14. Wismeijer D, Vermeeren JI, van Waas MA. Patient satisfaction with overdentures supported by one-stage TPS implants. *Int J Oral Maxillofac Implants.* 1992 Spring;7(1):51-5.
15. Meijer HJ, Raghoobar GM, van't Hof MA, Geertman ME, van Oort RP. Implant-retained mandibular overdentures compared with complete dentures: a 5-years follow-up study of clinical aspects and patient satisfaction. *Clin Oral Implants Res.* 1999 Jun;10(3):238-44.
16. Hobkirk JA, Abdel-Latif, HH, Howlett J, Welfare R, Moles DR. Prosthetic treatment time and satisfaction of edentulous patients treated with conventional or implant-stabilized complete mandibular dentures: a case-control study (part 2). *Int J Prosthodont.* 2009 Jan-Feb;22(1):13-9.
17. Awad M A, Lund JP, Dufresne E, Feine JS. Comparing the efficacy of mandibular implant-retained overdentures and conventional dentures among middle-aged edentulous patients: satisfaction and functional assessment. *Int J Prosthodont.* 2003 Mar-Apr;16(2):117-22.
18. Balaguer J, García B, Peñarrocha M, Peñarrocha M. Satisfaction of patients fitted with implant-retained overdentures. *Med Oral Patol Oral Cir Bucal.* 2011 Mar;16(2):e204-9.
19. Andreiotelli M, Att W, Strub JR. Prosthodontic complications with implant overdentures: a systematic literature review. *Int J Prosthodont.* 2010 May-Jun;23(3):195-203.
20. Burns DR, Unger JW, Elswick RK, Beck DA. Prospective clinical evaluation of mandibular implant overdentures: Part I--Retention, stability, and tissue response. *J Prosthet Dent.* 1995 Apr;73(4):354-63.
21. Zitsmann NU, Marinello CP. A review of clinical and technical considerations for fixed and removable implant prostheses in the edentulous mandible. *Int J Prosthodont.* 2002 Jan;15(1):65-72.

22. Uçankale M, Akoğlu B, Özkan Y, Ozkan YK. The effect of different attachment systems with implant-retained overdentures on maximum bite force and EMG. *Gerodontology*. 2012 Mar;29(1):24-9.
23. Hong HR, Pae A, Kim Y, Paek J, Kim HS, Kwon KR. Effect of implant position, angulation, and attachment height on peri-implant bone stress associated with mandibular two-implant overdentures: a finite element analysis. *Int J Oral Maxillofac Implants*. 2012 Sep-Oct;27(5):e69-76.
24. Prakash V, D'Souza M, Adhikari R. A comparison of stress distribution and flexion among various designs of bar attachments for implant overdentures: a three dimensional finite element analysis. *Indian J Dent Res*. 2009 Jan-Mar;20(1):31-6.
25. Cune M, van Kampen F, van der Bilt A, Bosman F. Patient satisfaction and preference with magnet, bar-clip, and ball-socket retained mandibular implant overdentures: a cross-over clinical trial. *Int J Prosthodont*. 2005 Mar-Apr;18(2):99-105.
26. Ellis JS, Burawi G, Walls A, Thomason JM. Patient satisfaction with two designs of implant supported removable overdentures; ball attachment and magnets. *Clin Oral Implants Res*. 2009 Nov;20(11):1293-8.
27. Cune M, Van Kampen F, Van der Bilt A, Bosman F. Patient satisfaction and preference with magnet, bar-clip, and ball-socket retained mandibular implant overdentures: a cross-over clinical trial. *Int J Prosthodont*. 2005 Mar-Apr;18(2):99-105.
28. Cune M, Burgers M, van Kampen F, de Putter C, van der Bilt A. Mandibular overdentures retained by two implants: 10-year results from a crossover clinical trial comparing ball-socket and bar-clip attachments. *Int J Prosthodont*. 2010 Jul-Aug;23(4):310-7.
29. MacEntee MI, Walton JN, Glick, NA clinical trial of patient satisfaction and prosthodontic needs with ball and bar attachments for implant-retained complete overdentures: three-year results. *J prosthet Dent*. 2005 Jan;93(1):28-37.
30. Sadig W. A comparative in vitro study on the retention and stability of implant-supported overdentures. *Quintessence Int*. 2009 Apr;40(4):313-9.
31. Hong HR, Pae A, Kim Y, Paek J, Kim HS, Kwon KR. Effect of implant position, angulation, and attachment height on peri-implant bone stress associated with mandibular two-implant overdentures: a finite element analysis. *Int J Oral Maxillofac Implants*. 2012 Sep-Oct;27(5):e69-76.

32. Al-Ghafli SA, Michalakis KX, Hirayama H, Kang K. The in vitro effect of different implant angulations and cyclic dislodgement on the retentive properties of an overdenture attachment system. *J Prosthet Dent.* 2009 Sep;102(3):140-7.
33. Damghani S, Masri R, Driscoll CF, Romberg E. The effect of number and distribution of unsplinted maxillary implants on the load transfer in implant-retained maxillary overdentures: an in vitro study. *J Prosthet Dent.* 2012 Jun;107(6):358-65.
34. Shaarawy MA, Aboelross EM. The effect of varying implant position in immediately loaded implant-supported mandibular overdentures. *J Oral Implantol.* 2013 Jun;39(3):345-54.
35. Abi Nader S, De Souza RF, Fortin D, Fromentin O, Albuquerque Junior RF. Effect of simulated masticatory loading on the retention of stud attachments for implant overdentures. *J Oral Rehabil.* 2011 Mar;38(3):157-64.
36. Ahuja S, Cagna DR. Classification and management of restorative space in edentulous implant overdenture patients. *J Prosthet Dent.* 2011 May;105(5):332-7.
37. Ahuja S, Cagna, DR. Defining available restorative space for implant overdentures. *J Prosthet Dent.* 2010 Aug;104(2):133-6.
38. Burns DR, Unger JW, Coffey JP, Waldrop TC, Elswick RK. Randomized, prospective, clinical evaluation of prosthodontic modalities for mandibular implant overdenture treatment. *J Prosthet Dent.* 2011 Jul;106(1):12-22.
39. Williams BH, Ochiai KT, Hojo S, Nishimura R, Caputo AA. Retention of maxillary implant overdenture bars of different designs. *J Prosthet Dent.* 2001 Dec;86(6):603-7.
40. ElKerdawy MW, Radi IA. Effect of dislodging forces on mandibular implant attachment-retained overdenture. *Implant Dent.* 2011 Jun;20(3):246-54.
41. Alsabeeha NH, Payne AG, Swain MV. Attachment systems for mandibular two-implant overdentures: a review of in vitro investigations on retention and wear features. *Int J Prosthodont.* 2009 Sep-Oct;22(5):429-40.
42. Petropoulos VC, Mante FK. Comparison of retention and strain energies of stud attachments for implant overdentures. *J Prosthodont.* 2011 Jun;20(4):286-93.
43. Sadr SJ, Saboury A, Hadi A, Mahshid M. The effect of implant position on retention stability of mandibular-supported overdentures. *J Dent Sch.* 2012;30(1):40-9.

44. Tabatabaian F, Alaie F, Seyedan K. Comparison of three attachments in implant-tissue supported overdentures: an in vitro study. *J Dent (Tehran)*. 2010 Summer;7(3):113-8.
45. Petropoulos VC, Smith W, Kousvelari E. Comparison of retention and release periods for implant overdenture attachments. *Int J Oral Maxillofac Implants*. 1997 Mar-Apr;12(2):176-85.
46. Manju V, Sreelal T. Mandibular implant-supported overdenture: an in vitro comparison of ball, bar, and magnetic attachments. *J Oral Implantol*. 2013 Jun;39(3):302-7.