ASDJ
AINSHAMS DENTAL JOURNAL

Print ISSN 1110-7642
Online ISSN 2735-5039

AIN SHAMS DENTAL JOURNAL
Official Publication of Ain Shams Dental School
September 2024 Vol. 35

Retention loss and Deformation of the Nylon Cap of Smart-Box Attachment System Retaining Mandibular Overdenture Supported by Two Malaligned Implants: An In-vitro Study

Mohamed Amr ELkhashab[1], Amr Ahmed Naguib[1]

Aim: To measure the effect of wear of nylon cap on the retention of OT equator smart box attachment system for mandibular overdenture supported by two malaligned implants when subjected to invitro chewing and insertion and removal cycles equivalent to 12 months.

Materials and methods: The current study included 3 groups, each group comprised 2 interformainal implants at the canine sites with different implant angulations. Group I (St-St) had two implant analogues parallel to each other, Group II (B-St) and Group III (D-St) had a 25 degrees buccal and distal implant angulations respectively. A smart box attachment was used for retaining the dentures for all groups. All models of the study groups were subjected to 150 000 in-vitro chewing cycles along with 1440 cycles of overdenture insertion and removal, which is clinically equivalent to 12 months of denture use. Wear was evaluated using digital microscopy and retention was measured using the universal testing machine before (T0) and after (T12) in-vitro chewing simulation.

Results: It was revealed that Group I (St-St) showed the greatest amount of deformation 1.18mm2 followed by Group III (D-St) 0.87mm2 then Group II (B-St) 0.79mm2. As regards to the retention values Group I showed the greatest loss of retention (9.71N) followed by Group III (6.9N) then Group II (3.12N).

Conclusion: The Smart box OT equator attachment showed equivalent performance in extreme implant deviations as axially straight ones. Adjacent aligned and malaligned implant attachment nylon caps display similar deformation values after 1 year of denture use.

Keywords: Smart box OT equator, chewing simulation, maligned implants, retention, wear

---

1. Lecturer of Prosthodontic Department, Faculty of Dentistry, Cairo University, Egypt.
Corresponding author: Mohamed Amr El Khashab, email: mohamed.elkhashab@dentistry.cu.edu.eg

Introduction

Implant-supported overdentures are considered a reliable option for the restoration of complete edentulism, offering substantial benefits over traditional complete dentures. These benefits include greater comfort and stability, better chewing efficiency, and cost-effectiveness. As a result, they significantly enhance patient satisfaction by addressing many of the common issues associated with conventional dentures, such as poor fit and limited functionality.[1] Various attachment systems can be employed for restoring implant supported overdentures to enhance stability and retention.[2] Among the most common types of attachments are studs, bars, and magnet types.[3] While implant overdentures can use one to four implants for support,[4–6] the standard care for a completely edentulous mandible is usually a two-implant-retained mandibular overdenture.[7–9]

Individual stud-style abutments are frequently favored for implant-retained overdentures over bar, telescopic, and fixed alternatives due to their greater simplicity and user-friendliness.[2] The locator system, are particularly advantageous in situations with limited inter-arch space because they require minimal prosthetic height.[6,10] Additionally, they offer superior retention and stability, coupled with straightforward clinical procedures.[11,12] The OT Equator Smart Box is an innovative attachment designed to facilitate passive insertion, even in cases of extreme implant divergences of up to 50°, thanks to its tilting mechanism with a rotational fulcrum. The OT Equator Smart Box is recognized as a cost-effective treatment solution for situations involving significant implant divergence.[13,14]

Anatomical features associated with mandibular edentulous ridges represent clinical challenges such as limited bone availability, [15] the need to avoid the inferior alveolar nerve, significant bony irregularities, or the patient's preference to avoid additional surgeries might necessitate placing dental implants at an angle.[16,17]

To ensure the structural integrity of the prosthesis and achieve a precise fit, it is ideal to position the implants in a parallel orientation whenever possible.[15,18] The inclination or angulation of the implants can affect the ease with which the prosthesis can be inserted and removed, thereby influencing the effectiveness of the attachment system and its longevity.[3] Improper angulation can lead to complications such as reduced retention, increased wear, and ultimately a shorter lifespan for the prosthesis.[19] Wear and retention are crucial when selecting any attachment system for overdentures, particularly because the majority of overdenture patients are elderly and prefer minimal maintenance visits[20]. Loosening of retentive mechanisms in overdentures has been recognized as the most prevalent prosthodontic issue,[5,21] occurring in 33% of implant-supported restorations.[22] The failure of these attachments negatively impacts the functionality and maintenance of the prostheses, as well as patient satisfaction.[23] Therefore, the purpose of this study was to study the changes in deformation and retention of the OT equator smart box attachment among three different implant angulations for a two-implant mandibular-retained overdenture after being subjected to in-vitro chewing cycles and repeated insertion and removal equivalent to 12-months. The null hypothesis was that different implant angulations will not have impact on retention and wear of the nylon caps of OT Smart Box attachments over time.

Materials and methods

This study was carried out on 3 models supporting 9 overdenture prostheses. The sample size was calculated according to the study of Xhanari *et al.*[24] Responses in each group were normally distributed with a standard deviation of 0.15. Assuming a true difference of 0.4 between experimental and control group means, 3 experimental subjects and 5 control subjects were needed to reject the null hypothesis. Sample size was calculated with a significance level α= 0.05 and a power of 80%.

A stone model of a completely edentulous mandible was selected with the interforaminal area having adequate ridge dimensions. The model was scanned using a desktop scanner (DOF, Mauchly, USA) to obtain a virtual model. A virtual teeth setup was made over the crest of the ridge using specialized software (Blue-Sky Plan® software; USA). Based on the teeth setup, two implant analogues were selected and installed in the canine area bilaterally. The current study included 3 groups; each group comprised 2 interformainal implants (J Dental Care, Modena, Italy) at the canine sites with different implant angulations (Fig 1a).

Group I (St-St) had two implant analogues installed parallel to each other with a zero-degree difference in implant analogue angulations (Fig 1b). Group II (B-St) (Fig 1c) and group III (D-St) (Fig1d) had a 25 degrees difference in implant angulations, this was achieved by preparing the left implant analogue socket axially straight and the right implant analogue socket with a 25-degrees buccal and distal angulations respectively.

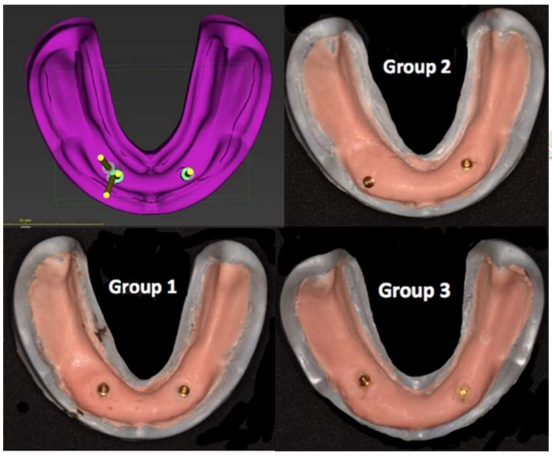

Figure 1: (a) virtual design of the study models of the 3 groups showing the different angulation of the right side implant. (b) 3d printed resin cast with OT Smart Box matrix of Group I (St-St). (c) 3d printed resin cast with OT Smart Box matrix of Group II (B-St). (d) 3d printed resin cast with OT Smart Box matrix of Group III (D-St)

A mandibular overdenture was constructed using the Blue-sky Bio denture module. The denture was designed to extend posteriorly to cover the retromolar pads, full depth of the buccal and lingual vestibules and including the implant analogues with their corresponding SmartBox attachment system for all study groups. The finished overdenture design was exported as an STL file to a mesh editing software (AutodeskR's MeshMixer software; San Francisco, USA) in order to design a cross-arch bar connecting the right and left premolar-molar sites and extending to the midline between the two central incisors forming a T shaped bar. The center of this bar represented the geometric center[23] at which the in-vitro simulation was conducted and outcomes were assessed (Fig 2).

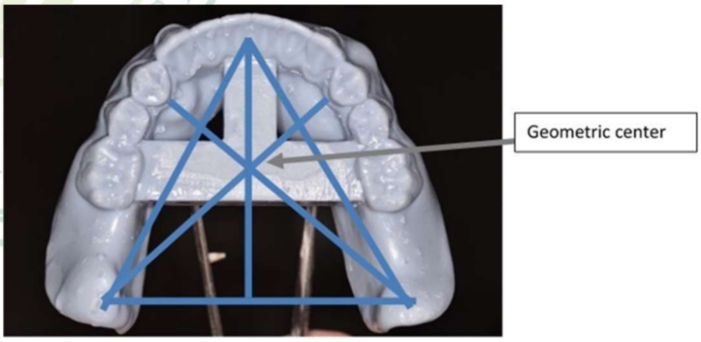

Figure 2: Polished surface of overdenture with the T form support bar. (Arrow) pointing at the geometric center

A total of nine overdentures were 3D printed using a dental model resin (Savoy, 3d printing resin, China) on an LCD, DLP 3D printer (AnyCubic, Mono X, China). Each overdenture had its fitting surface designed to accommodate the placement of the attachment housing corresponding to the implant angulation in all 3 groups. Two smart box housings (Rhein83, Italy) were picked up to each denture (Fig 3).

Figure 3: (Left) Fitting surface of the overdenture with housing sockets ready for pickup of metal housing. (Right) Fitting surface of the overdenture after the pick-up procedure of the metal housing.

All models of the study groups were subjected to 150000 in-vitro chewing cycles using a chewing simulator along with 1440 cycles of overdenture insertion and removal, which is clinically equivalent to 12 months of denture use. This was executed manually by a single operator simultaneously with the cycles of the chewing simulator. The newly developed ROBOTA chewing simulator, featuring four stations, operated with a thermo-cyclic protocol driven by a servo-motor (Model ACH-09075DC-T, AD-TECH TECHNOLOGY CO., LTD., Germany). This simulator was employed to conduct cyclic loading tests under programmed logic control. The models were positioned in a teflon holder located in the lower section of the simulator. A chewing force equivalent to 49 N or a weight of 5 kg was applied to the geographic center of each overdenture prosthesis. The test environment was maintained wet with distilled water and at a room temperature of 20±2 °C. Specific test parameters are as follows; vertical and horizontal movements: 3 mm and 1 mm respectively, rising and forward speed: 90 mm/s, descending and backward speed: 40 mm/s, cycle frequency 1.6 Hz, weight per sample: 3 kg and torque; 2.4 N.m

Deformation of retentive nylon caps is a multi-factorial process that may result in a change in caps' dimensions and/or change in caps' surface morphology. These changes were mainly measured using digital microscopy by drawing an external and internal circle on the image captured for each nylon cap. The outer circumference of the nylon cap that would be in contact with the titanium liner of the OT equator smart box while the internal circumference represents the inner boundary of the nylon cap that would be in contact with the attachment (Fig 4) . This was used to measure the diameter, circumference, and thickness of the caps' walls using a digital microscope (U500x Digital Microscope, Guangdong, China) integrated with image analysis software. The nylon caps were scanned using an optical system with a 3.6-megapixel digital camera (U500x Digital Microscope, Guangdong, China), placed 2.5 cm from the samples at a 90-degree angle to the light source. The system used 8 LED lamps, adjustable by a control wheel, with a color index near 95%. Images at a resolution of 1280 × 1024 pixels were captured at 40X magnification and connected to an IBM-compatible computer.

The first scan (baseline) was recorded for all caps while still intact (T0) (Fig 4a). Then after being subjected to the planned cycles (T12) the caps were digitized again (Fig 4b). All restrictions, boundaries, frames, and measurable parameters were expressed in pixels. The System calibration was therefore performed to translate the pixels into precise real-world units. To calibrate, a known-size object was compared to a scale produced by the Image J program software, by differentiating and comparing of image T0 and T12.

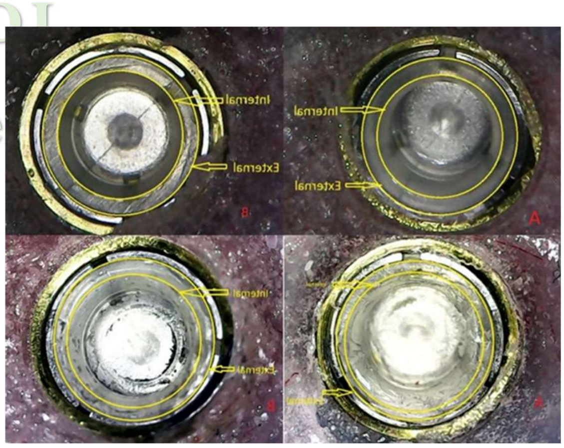

Figure 4: (A) Group III left nylon cap top view at T0 and T12 (B) Group III right nylon cap top view at T0 and T12

Retention was measured at T0 and T12 using the universal testing machine (Instron Instruments' Bluehill® Lite (Model 3345; Instron Instruments Ltd., USA). All study models were placed at a predetermined position attached to the metal hook of the universal testing machine through a circular hook fixed to the geographic center of the overdenture prosthesis (Fig 5). The retention of each overdenture prosthesis represented the mean retention of both attachment assemblies within each overdenture prosthesis.

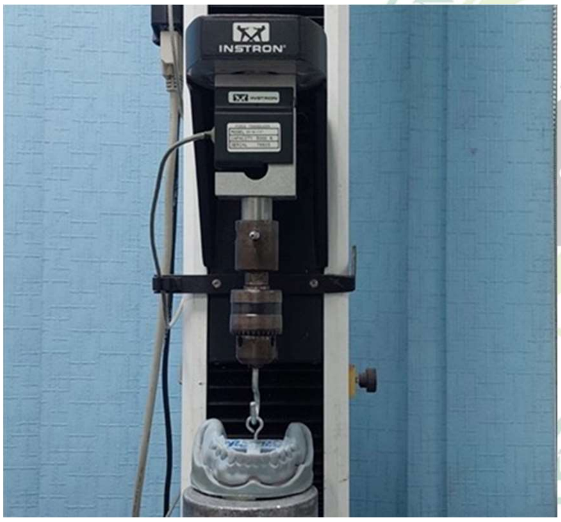

Figure 5: The connection of the circular hook of the overdenture to the metal hook of the universal testing machine during the pull

Statistical Analysis

Numerical data were given as mean values with 95% confidence intervals (CI), standard deviation (SD), and the range from minimum to maximum. Normality was checked using the Shapiro-Wilk test and visual inspection. Data were non-parametric, analyzed with the Kruskal-Wallis test for multiple groups, and Dunn's post hoc for intergroup comparisons. Within-group comparisons used Friedman's test and Nemenyi's post hoc. P-values were adjusted using Bonferroni's correction. Significance was set at $p<0.05$. Analysis was done with R version 4.4.0 for Windows.

Results

Comparing the overall change in dimension (combined mean deformation of right and left nylon cap) among the 3 studied groups revealed that Group I (St-St) showed the greatest amount of deformation 1.18mm2 followed by Group III (D-St) 0.87mm2 then Group II (B-St) 0.79mm2. Similarly, an analysis comparing the mean deformation of each side separately indicated that the greatest deformation occurred in Group I, followed by Group III, and then Group II, for both nylon caps. The right nylon cap which represents the angled implant demonstrated larger change in dimension than the left nylon caps in all groups with no statistical significance (Table 1).

Table 1: Descriptive statistics for change of dimension (mm^2) of nylon cap between T0 and T12

Interval	*Group*	*(Mean±SD)*		*Test statistic*	*p-value*
		Right implant	*Left implant*		
0-12 months	*Group (st-st)*	**0.70±1.06**	**0.48±0.30**	**3.00**	**1**
	Group (b-st)	**0.43±0.32**	**0.36±0.25**	**3.00**	**1**
	Group (d-st)	**0.46±0.44**	**0.41±0.12**	**4.00**	**1**
	Test statistic	**0.09**	**0.36**		
	p-value	**0.957**	**0.957**		

As regards to the retention values, the amount of retention at T0 and T12 was the greater for Group II (24.28N) (21.16N) and Group III (24N) (17.1N) than for Group I (18.04N) (8.33N) respectively. All groups showed reduction in retention values throughout the 12 months with no statistically significant differences within each group or between the 3 groups at any time interval. However, Group I showed the greatest loss of retention (9.71N) followed by Group III (6.9N) then Group II (3.12N) (Table 2).

Table 2: Descriptive statistics for retention (N) at T0 and T12

Time	*(Mean±SD)*			*Test statistic*	*p-value*
	Group (st-st)	*Group (b-st)*	*Group (d-st)*		
0 months	**18.04±21.23**	**24.28±15.53**	**24.00±6.48**	**0.62**	**0.733**
12 months	**8.33±4.41**	**21.16±8.33**	**17.10±6.17**	**3.29**	**0.193**
Test statistic	**2.67**	**0.67**	**4.67**		
p-value	**0.264**	**0.717**	**0.097**		

Discussion

The aim of this in-vitro study was to compare the change in retention and dimension of the nylon cap of OT equator smart box attachment system for mandibular overdenture supported by two malaligned implants when subjected to in-vitro chewing and insertion and removal cycles equivalent to 12 months. In the present study, OT smart box equator attachment system was used for retaining an overdenture prosthesis. This type of attachment allows for a tilting mechanism with a rotational fulcrum, designed for extreme implant divergence up to 50 degree (Fig 6).[13,25]

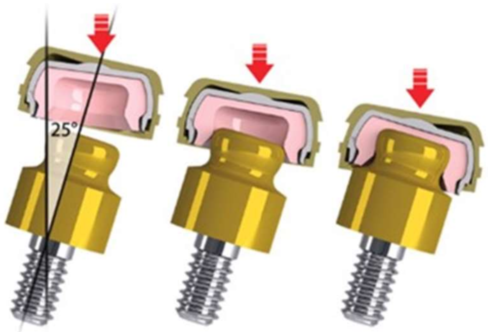

Figure 6: The mechanism of OT smart box housing and OT equator that enables passive cap insertion even in conditions of high divergence.

The retentive component of the OT equator attachments, known as the nylon cap, experiences dimensional changes due to the repeated insertion and removal processes. Wear, defined as the material loss occurring from contact between the matrix and patrix, leads to increased gaps between different parts of the attachment system. In this study, wear was quantified by assessing changes in the boundaries of the nylon cap through a detailed quantitative analysis conducted after subjecting the caps to a one-year chewing simulation.[18]

Statistical analysis of the baseline data was crucial for establishing a reference point against which data from subsequent time intervals could be compared. This analysis also confirmed that the dimensions of all caps were standardized across all study groups at T0, ensuring that any further changes in cap dimensions were attributable to the caps' behavior relative to the implant angulation. Given the uneven and progressive nature of wear, the symmetry and outline of the caps can be significantly affected over time. Consequently, substantial variations in cap diameter measurements may be observed within the same cap. Therefore, the authors calculated the difference between the external and internal boundaries of the nylon cap. This differential was then subtracted from the baseline value to determine the extent of deformation that had occurred.[2,22]

The initial results (T0) for prosthesis retention did not show a significant difference among the three groups. However, group III (d-st) and group II (b-st) recorded the highest initial retention values. This could be attributed to the presence of 25-degree distal and buccal angulations in the right implants of both groups respectively. This angular discrepancy created an undercut that interfered with the path of removal during the pull of the universal testing machine. Consequently, it increased the resistance to dislodgment of the overdenture prosthesis, leading to higher retention values compared to group I (st-st), which exhibited no angular discrepancies. This aligns with the findings of Elsonbaty et al[18], who similarly observed increased retention forces in cases with 30-degree implant malalignment and decreased forces with greater malalignment. In the 30-degree group, the distal side of the equator had a larger undercut than the mesial side, complicating removal because the retentive components had to be withdrawn together. Interestingly, the 60-degree group didn't show much higher retention, likely because the vertically positioned cap housings didn't engage the deepest undercuts on the distal sides. This matches the findings of Yang et al[15], who noted that retention forces decrease as the angle between the path of removal and the implants increases.

At T12, when all study groups were subjected to 150,000 cycles, all overdentures experienced a decline in retention values. This reduction can be attributed primarily to the frictional wear between the attachment components, leading to a loss of retention as noted by Aroso et al and Yilmaz et al[17,26]. Uludag et al.[7] also reported that all attachment systems tend to show decreased retention over time. Rutkunas et al. suggested that this retention loss mechanism in resilient overdenture attachments is due to dimensional changes and surface alterations over time causing permanent deformation. This is likely to be observed in all types of attachments which exhibit some degree of dimensional changes under functional loading or after repeated insertion and removal cycles, eventually a rapid loss of retention is likely to follow.[19,21,27,28,29]

In Group I, the implants on the right and left sides were installed parallel to each other. The OT Smart Box Equator, designed to accommodate significant implant divergences, was used in this setup. Numerous authors have emphasized the importance of aligning implants axially for overdentures to enhance maintenance and reduce attachment retention loss. They argue that divergent implants can interfere with the attachments functionality, leading to accelerated wear[9,25]. Nevertheless, this issue was not noted with the OT Smart Box Equator. The operational mechanics of the OT Smart Box Equator are not entirely clarified, as there are limited studies exploring the performance of this attachment.[13] Despite the parallel installation of implants, the specific feature of the attachment that allows tilting motion during the insertion and removal of the retentive cap actually increased the friction between the retentive components of the attachment. The straight position of both implants in Group I allowed the nylon caps to fully engage their corresponding patrix thus increasing friction as opposed to the other groups where nylon caps didn't fully engage allowing a passive insertion and removal.[13] This increased friction led to considerable wear, as evident in the overall change in dimension values as well as the greatest loss of retention recorded in group 1 (st-st) which was not matched by groups II and III. These results are in accordance with the study of Wakam et al who correlated the amount of retention loss with the locator wear pattern.[30] Moreover, the amount of deformation recorded for the right nylon cap in groups II and III although being slightly greater than the left one, it is statistically insignificant. The mode of action of the OT Smart Box enabled the nylon cap retaining the 25 degree buccally or distally angled implants to behave in a similar mechanism as its straight counterpart.[31] The authors explanation for such result is likely due to the angulation of one implant have interfered with the path of insertion and removal of the overdenture, which resulted in unnecessary friction at the left(st) nylon cap.

One of the main limitations of the current study arises from its in-vitro nature, which posed significant challenges in accurately mimicking the complex environment of the oral cavity. Wear and retention of attachment systems are influenced by number of implants, inter-implant distance, functional locations of attachments and material of matrix.[32] Additionally, the authors sought for a statistical correlation between wear and retention; however, the limited sample size may have contributed to the lack of meaningful results. Therefore, future research with greater sample size and longer follow-up period is recommended to explore the various factors that might impact overdenture retention and wear patterns across different scenarios and correlating it with denture wearer satisfaction.

Conclusion

It can be concluded from the present study that Smart-Box OT equator attachment showed equivalent performance in extreme implant deviations as axially straight ones. Adjacent aligned and malaligned implant attachment nylon caps display similar deformation values after 1 year of denture use.

Funding

This study was self-funded

Data Availability

The raw or processed data necessary to replicate the findings may be disclosed upon request.

Ethical approval

This study was approved by the Research Ethics Committee, Faculty of Dentistry, Cairo University (3-11-21).

Competing interests

The authors declare that they have no competing interests.

References

1.Ismail J, Radi IAEW, Nassouhy NMH, ElKahsab MA. Effect of Smoking on Dental Implant Failure: A Systematic Review. Ain Shams Dent J. 2021;23(3):86–111.

2.Büttel AE, Bühler NM, Marinello CP. [Locator or ball attachment: a guide for clinical decision making]. Schweizer Monatsschrift fur Zahnmedizin = Rev Mens suisse d'odonto-stomatologie = Riv Mens Svizz di Odontol e Stomatol. 2009;119(9):901–18.

3.Amini P, Abyari S, Pourmoshrefi P, Lashkarizadeh N, Lashkarizadeh L. Retention and wear of nylon matrix component in implant-supported overdentures based on insertion technique: A clinical trial. J Dent Mater Tech. 2023;12(3):134–41.

4.Elgendy DM, Elgendy AA, El-Segai AAEM. Clinical and retention assessment of soft Liner and O-ring attachment in single implant assisted mandibular overdenture: Randomized clinical Trail. Ain Shams Dent J. 2024;34(2):31–41.

5.Pasiga BD. Archives of Dentistry and Oral Health V3. Arch Dent Oral Heal. 2020;3(2):19–26.

6.Badr AMI. Effect of Using Two Different Mini Dental Implant attachments on Marginal Bone Height and Prosthetic Maintenance in Implant Retained Mandibular Overdenture. Ain Shams Dent J. 2022;26(2):6–14.

7.Uludag B, Polat S, Sahin V, Alper Comut A. Effects of Implant Angulations and Attachment Configurations on the Retentive Forces of Locator Attachment–Retained Overdentures. Int J Oral Maxillofac Implants. 2014 Sep 19;29(5):1053–7.

8.Marin DOM, Leite ARP, de Oliveira Junior NM, Paleari AG, Pero AC, Compagnoni MA. Retention force and wear characteristics of three attachment systems after dislodging cycles. Braz Dent J. 2018 Nov 1;29(6):576–82.

9.John J, Rangarajan V, Savadi RC, Satheesh Kumar KS, Satheesh Kumar P. A finite element analysis of stress distribution in the bone, around the implant supporting a mandibular overdenture with ball/O ring and magnetic attachment. J Indian Prosthodont Soc. 2012 Mar;12(1):37–44.

10.Wakam R, Benoit A, Mawussi KB, Gorin C. Evaluation of Retention, Wear, and Maintenance of Attachment Systems for Single-or Two-Implant-Retained Mandibular Overdentures: A Systematic Review. Vol. 15, Materials. MDPI; 2022.

11.Teimoori H, Shayegh SS, Zavaree MA, Hakimaneh SMR, Khodadad F, Shidfar S, et al. Effects of excessive implant angulation on retention of two types of overdenture attachments during cyclic loading. J Contemp Dent Pract. 2018 Oct 1;19(10):1221–7.

12.Sali G, Mathew T A, Joseph S, Susan Thomas A, Anna Abraham M, Rajesh P. Attachment systems in overdenture therapy: a review. J Prosthet Implant Dent. 2023 Jan 1;6(2).

13.Rostom D, Ragheb N. Retention and Wear Characteristic Assessment of OT Equator with Smart Box Attachment Versus Ball Attachment for Mandibular Two Implant Assisted Over Denture. In-vitro Study. Egypt Dent J. 2021;67(4):3525–32.

14.El-Sehly N, Abd Elgelel A, Rady N, El Banna A. Efficiency of Retention of Two Attachment Designs Used for All on Four Mandibular Inclined Implants Assisted Overdenture. Alexandria Dent J. 2021 Jul 23;0(0):0–0.

15.Yang TC, Maeda Y, Gonda T, Kotecha S. Attachment systems for implant overdenture: Influence of implant inclination on retentive and lateral forces. Clin Oral Implants Res. 2011 Nov;22(11):1315–9.

16.Alameldeen H, Elsyad M, Shawky A, Khirallah A. The Influence of Implant Inclination on Retention and Peri-implant Stresses of Stud-Retained Implant Overdentures During Axial and

Nonaxial Dislodgments: An In Vitro Study. Int J Oral Maxillofac Implants. 2020 May;35(3):543–50.
17.Aroso C, Silva AS, Ustrell R, Mendes JM, Braga AC, Berastegui E, et al. Effect of abutment angulation in the retention and durability of three overdenture attachment systems: An in vitro study. J Adv Prosthodont. 2016 Feb;8(1):21–9.
18.Elsonbaty MA, Alshimy AM, Abdul-Monem MM, Neena AF. Evaluation of retention and wear of a titanium-formed stud overdenture attachment with different interimplant angulations after simulated clinical use: An in vitro study. J Prosthet Dent. 2022;128(2):205.e1-205.e10.
19.Choi JW, Bae JH, Jeong CM, Huh JB. Retention and wear behaviors of two implant overdenture stud-type attachments at different implant angulations. J Prosthet Dent. 2017 May 1;117(5):628–35.
20.Ramadan RE, Mohamed FS, Abd-Ellah ME. Quantitative and qualitative assessment of the wear pattern of two attachment systems of dissimilar materials for mandibular implant-retained overdentures: an in-vitro study. BMC Oral Health. 2023 Dec 1;23(1).
21.Passia N, Ghazal M, Kern M. Long-term retention behaviour of resin matrix attachment systems for overdentures. J Mech Behav Biomed Mater. 2016 Apr;57:88–94.
22.Fromentin O, Lassauzay C, Nader SA, Feine J, De Albuquerque RF. Clinical wear of overdenture ball attachments after 1, 3 and 8 years. Clin Oral Implants Res. 2011 Nov;22(11):1270–4.
23.Ahmed Elmorsy A, Ahmed Ibraheem E, Ela A, Fahmy A, Nassani M. Do flexible acrylic resin lingual flanges improve retention of mandibular complete dentures? J Int Soc Prev Community Dent. 2015;5(5):365–71.
24.Xhanari E, Scrascia R, Kadiu B, Tallarico M. Two implants supporting a mandibular over denture to rehabilitate Cawood and Howell Class V and VI patients: a proof-of-concept study Within the limitations of this study, a mandibular overdenture support-ed by two implants can be considered an effective . J Oral Sci Rehabil. 2017 Jun 1;3:52–9.
25.Metwally NA, Abdel-Hamid AM, Hommos AM, Rady NA. Conservative approach for management of posterior atrophic maxilla using implant assisted overdenture (clincal trial). Alexandria Dent J. 2020;45(3):81–7.
26.Yilmaz B, Ozkir E, Johnston WM, McGlumphy E. Dislodgement force analysis of an overdenture attachment system. J Prosthet Dent. 2020 Feb;123(2):291–8.
27.Wolf K, Ludwig K, Hartfil H, Kern M. Analysis of retention and wear of ball attachments. Quintessence Int. 2009 May;40(5):405–12.
28.Evtimovska E, Masri R, Driscoll CF, Romberg E. The change in retentive values of locator attachments and hader clips over time. J Prosthodont Off J Am Coll Prosthodont. 2009 Aug;18(6):479–83.
29.Rutkunas V, Mizutani H, Takahashi H, Iwasaki N. Wear simulation effects on overdenture stud attachments. Dent Mater J. 2011;30(6):845–53.
30.Wakam R, Ramalingam S, Mawussi KB, Gorin C, Benoit A. Retention loss and wear assessment of three attachment systems for implant retained-mandibular overdentures: An in vitro study. J Mech Behav Biomed Mater. 2024 Feb 1;150.
31.Cervino G, Montanari M, Santonocito D, Nicita F, Baldari R, De Angelis C, et al. Comparison of Two Low-Profile Prosthetic Retention System Interfaces: Preliminary Data of an In Vitro Study. Prosthesis. 2019;1(1):54–60.
32.Wichmann N, Kern M, Taylor T, Wille S, Passia N. Retention and wear of resin matrix attachments for implant overdentures. J Mech Behav Biomed Mater. 2020;110:103901.