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

Evaluation of Strains Induced by Two Different Implant Systems on The Supporting Structures of Implant Retained Maxillary Overdenture

Sawsan Maged Fadl Aly[1], Hany Ibrahim Eid[1], Shaimaa Lotfy Mohammed[1], Amany Ibrahim Abd El-Hady[2]

Aim: The aim was to compare micro strains in the supporting structures around implants when using two different implant systems in implant retained maxillary overdentures by strain gauge analysis.
Materials and Methods: Digital fabrication of twelve maxillary edentulous models, each model had four implant beds at the canines and second premolars and strain gauge slots. According to the type of implant system, two groups were found; group A: Strauman, group B: JD Evolution. The universal testing machine was used to apply a 100 N load bilaterally then unilaterally. Functional simulation periods of three and six months were applied then application of same load was repeated, and data were statistically analyzed.
Results: A significant difference was found between the two groups and the lower micro strain values were in group A (Strauman). During bilateral loading, values were 39.39 and 53.52 in group A and group B respectively and during unilateral loading, values were 50.66 and 59.89 in the loaded side and 27.71 and 29.41 in the unloaded side in group A and group B respectively.
Conclusion: BLX Strauman system induced lower strain values around implants than JD Evolution system in implant retained maxillary overdenture after six months of functional simulation.

Keywords: Implant System; Strauman; Novaloc; Strain gauge analysis

---

1. Oral and Maxillofacial Prosthodontics, Faculty of Dentistry, Ain Shams University, Cairo, Egypt.
2. Prosthodontics, Faculty of Dentistry, Cairo University, Giza, Egypt.
Corresponding author: Sawsan Maged Fadl Aly E-mail: Sawsan.maged@gmail.com.

Introduction

Dental implant treatment options have been further expanded by advancements in design, materials, prosthetic elements, and surface properties. Implant-supported overdentures offer patients better satisfaction, chewing ability, and oral health-related quality of life when compared to traditional complete dentures.[1,2] Maxillary implant-supported overdentures were reported to enhance oral health and improve the satisfaction of patients [3], they are recommended in cases with compromised maxillary ridges, high lip lines, thin mobile mucosa, insufficient lip support, and severe xerostomia (Sjogren's syndrome) when the retention and stability of complete dentures are inadequate. [4]

Industry reports state that the global market for dental implants is estimated to be worth between 12 and 18 million annually, and more than 100 different commercial brands offer a variety of implant options. [5] As a result, selecting an implant system has become more challenging for clinicians. From a scientific perspective, several factors are thought to be important when choosing an implant system and manufacturer. This includes the reporting of technical, biological, esthetic complications, survival rates, and implant failures, as well as long-term clinical and radiographic outcome measures supported by scientific documentation. [6]

Recently, Straumann developed implants called Roxolid, which are formed of high-performance alloy of 85% titanium and 15% zirconium. In comparison to earlier tissue level implants, the Straumann Bone Level Implant with the SLActive surface design was designed to enhance prosthetic flexibility and aesthetic results in specific scenarios. Multiple formal clinical trials have assessed this implant.

A randomized clinical trail [7] concluded that no significant difference was found between Ti Grade IV and TiZr implants for bone level changes, soft tissue parameters, survival and success. Early loading in low-density bone (posterior maxilla) has also been shown to produce predictable osseointegration and clinical outcomes.[8] In partially edentulous posterior jaws, Nicolau et al. [9] reported implant survival rates of 97.4% for immediate loading and 96.7% for early loading of SLActive implants.

In routine clinical practice, deviations of the implant axes were observed ranging from 0.5◦ to 27◦ in the horizontal direction and between 0.1◦ and 12.9◦ in the sagittal direction, depending on the content of jawbone. [10,11] Hence to overcome the angulation problem of the implant, different attachments were used to counteract the tilt of it, among these systems are Novaloc and Sphero Flex attachments. [10]

The Sphero-flex attachment is titanium nitrate coated, the female part of the attachment is a multicolored nylon cap that snaps over the ball to improve retention and help prevent wear. It is compatible with most implant systems. With a diameter of 2.5 mm and flexibility up to 7.5 in any direction, the spheroflex swivel ball is intended to rectify angulation issues up to 43 degrees between two implant abutments.[12,13]

The Novaloc attachment has a carbon-based abutment coating with polyetheretherketone (PEEK) housing with peek inserts which has the potential to lessen housing insert wear. It enables angulation correction for implants, by overcoming up to 60° of implant divergence. This novaloc retentive system provides reliable and durable connection with excellent retention. [14,15] In a bench study, Passia et al. [16] demonstrated that this combination of materials may increase the attachment system's mechanical resilience against mechanical wear, retention loss, and potential prosthodontic complications.

The distribution of stress and strains in the system's components and surrounding the implant are among the factors that determine how long the implant prosthetic system will last. Design of the implant, prosthesis, materials of both of them, location and position of the implant, and quantity and quality of the bone all influence the distribution of stresses. [17-19]

As angulated implants are exposed to lateral forces, they cause the implant and the surrounding bone to undergo excessive stress [20,21] The excessive lateral force applied to an implant would increase the mechanical risk, including attachment assembly wear or fracture. It would also put more stress on the surrounding bone, which could contribute to increased vertical bone loss. [22] As such, measuring the stress on the area of peri-implant bone is essential.

The biomechanical behavior of implant-supported prostheses has been explained and the clinical scenario simulated by strain-gauge studies, mathematical, photo elastic, and finite element models [23,] each with pros and cons.[24]

So, it is essential to select the implant system correctly in order to ensure a uniform load distribution between the implant and the underlying residual alveolar ridge. [25,26] so the goal of this study was to assess and contrast micro strains developed in peri-implant tissues of two different implant systems used to retain maxillary implant overdentures.

Materials and methods

This study was carried out on 3D printed models simulating a maxillary completely edentulous arches with four implants placed at the canines and second premolars bilaterally. Solitary attachments were used to retain the maxillary implant overdentures.

Sample size calculation was performed using G*Power version 3.1.9.7 based on the results of a previous study El-Anwar et al. [27]. A power analysis was designed to have adequate power to apply a two-sided statistical test to reject the null hypothesis that there is no difference between groups. By adopting an alpha level of (0.05) and a beta of (0.2), i.e., power = 80% and an effect size (d) of (1.90) calculated based on the results of a previous study. The predicted sample size (n) was twelve, i.e., 6 samples per group. To detect the amount of change in the strains on mesial and distal sides of implants between groups.

A total of twelve maxillary implant retained overdentures were fabricated to evaluate the stresses induced on the supporting structures around implants using strain gauge analysis. In order to capture the micro-strains in the media around each implant, two strain gauges were placed, mesially and distally, on the models for each implant.

1. **Construction of the 3D model:**

A maxillary completely edentulous educational stone cast was enrolled in this study, it was scanned via a desktop scanner (Identica Hybrid, Medit.Seoul,Korea), then a Standard tessellation Language (STL) file was generated. Using a software (Exocad GmbH, Darmstadt, Germany), full anatomical teeth that were provided in the program were superimposed over the scanned model to properly plan the exact location of the implants. (Fig.1A & B)

Figure 1: A. Occlusal view for the scanned educational model. B. Full anatomical teeth superimposed over scanned model.

On the virtual model, four intended locations for the implants were represented by the design of four implant beds. (two at the canines and two at the second premolars). Eight slots were created, mesially and distally, at each implant site using the Exocad program to accommodate the strain gauge attachment. Each slot was prepared 1mm away from each implant, then the future mucosa was designed by removing two mm layer thickness from the virtual model.

A software (Chitubox Pro:CBDLtd, GUANGDONG, China) was used to create

75 % support structure with a 228 supporting arms that were oriented to the outer surface with their support at degree angles of 100, 135 and 150, then the printing machine (HALOT, printing machine, China) received the STL file to produce 12 models. The printed models were fabricated of a photopolymer material (3D printing UV sensitive resin, pro -shape, China). (Fig.2)

Figure 2: The printed model with different preparations designed by software.

2. **Fabrication of mucosal simulation:**

Rubber base material (Multisil-Mask soft, breedent, Senden, Germany) was used to simulate the mucosa. This material is an addition-linking silicon that was injected directly from a double-mix cartridge into clear acrylic resin stent with tissue stops in its fitting surface representing the two mm of the future mucosa.

3. **Study grouping:**

Implant and attachments were installed in their designed sites in the printed models, and according to the type of implant system used, we had two equal groups:

Group A: Six 3D printed maxillary models, for each one, four BLX® Straumann SLActive implants retained by Novaloc attachments were installed. (Fig. 3 A, B, C)

Group B: Six 3D printed maxillary models, for each one, four JD Evolution plus implants retained by Spheroflex attachments were installed. (Fig. 3 D, E, F)

For group A, implant fixtures, Straumann implants (Straumann, Basel, Switzerland) with size (3.7 and 10 mm) were used while for group B, implant fixtures, JD Evolution plus (JDental Care, Italy) with same size as in group A were used.

Sphero flex attachments were used to retain the overdentures in group B while Novaloc attachments were used in group A. (Fig. 4 A & B).

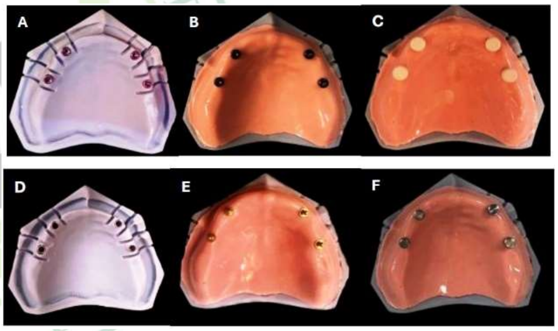

Figure 3: A. Implants placed in osteotomies for group A. B. Novaloc attachment. C. Peek housing. D. Implants placed in osteotomies for group B. E. Sphero Flex attachment. F. Metal housing.

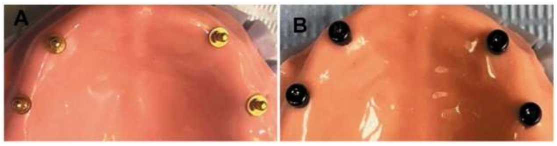

Figure 4: A. Sphero flex attachments. B. Novaloc attachments

4. **Maxillary overdenture construction and attachment picking up:**

Rubber base impression material (Zhermack elite HD+, Germany) was used to take a cast impression. After pouring a cast, a trial denture base was adapted on it, setting up of artificial teeth was done. Processing the denture was done in the conventional way. Pick up of each attachment housing was done in the denture's fitting surface using a soft lining material (Mollosil, Detax, GmbH& CO.KG, Germany).

5. Strain gauge analysis:

Eight strain gauges (Kyowa, Japan) were used for each model both on the distal and mesial aspect of the implants. All strain gauges were embedded in the grooves and positioned parallel to the groove walls. They were attached to 100-cm-long lead wires and secured in place with a thin layer of Cyano Acrylate base adhesive cement and bonding agent. A universal testing machine (LLOYD testing machine, LR5K,USA) was used to apply bilateral and unilateral loads on each overdenture.

-Recording measurement at base line:

Each overdenture's occlusal surface had a horizontal metal plate with a central slot attached to it by bilaterally autopolymerizing acrylic resin at the first molar area. Bilateral load was applied starting from zero up to 100 N by the machine's T-shaped load applicator bar. [28] Load was applied five times on each side on the central fosse of the first molar then, the mean micro strains values of the load application were taken. (Fig 5 A)

For unilateral loading, an I-bar-shaped load applicator was used to apply the same load five times on the left side, which represents the working side at first molar's central fossa and the mean micro strain values in the loaded and unloaded sides were recorded. (Fig.5 B)

- Chewing simulation and insertion / removal cycles: The chewing simulator machine (C4-4 SD Mechatronic chewing simulator, Germany) was used to apply dynamic cyclic loading to the overdentures. Each cast was fixed to the specimen holder through the cylindrical acrylic projection that was previously fabricated from self-cure acrylic resin and attached to the base of the cast. (Fig. 5 C) The load was applied to the denture by means of a stylus which was in contact with the center of the horizontal metal plate. (Fig. 5 D). Same testing conditions were applied for each group as i.e., filling the specimen chamber with the previously prepared artificial saliva and load settings of 50 N loads at room temperature. The software parameters were set at 60 min/speed, 3 mm vertical path, 0.7 mm horizontal path and 1.6 Hz frequency.

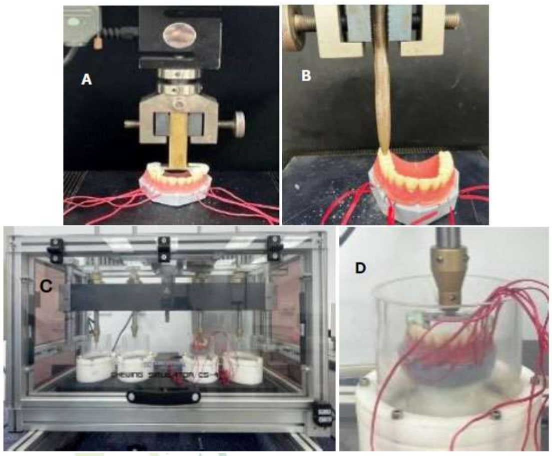

Figure 5: A. Bilateral load application. B. Unilateral load application. C. C4-4 SD Mechatronic chewing simulator. D. Point of load application in the center of metal plate

Every overdenture underwent 63,000 biaxial cycles and 270 cycles of repeated insertions and removals manually upon its cast which represent 3 months of overdenture use. Then for further 63,000 cycles and 270 cycles of repeated insertions and removals for a total 125,000 cycles of dynamic loading and 540 cycles of repeated insertion and removals to stimulate 6 months of clinical function. The microstrain values were recorded after each simulation period (3 &6 months) during both bilateral and unilateral loading for each group then sent for statistical analysis.

Results

Data entered to the Statistical Package for Social Science (IBM SPSS) version 23. The mean and standard deviation (SD) values were displayed for the quantitative data.

It was revealed by Kolmogorov-Smirnov test that data followed normal distribution, independent t-test was used for comparison between the two groups and paired t-test was chosen for the comparison within the same group.

The accepted margin of error was set at 5%, and the confidence interval was set at 95%. Thus, the p-value was deemed significant as: P-value >0.05: non-significant (NS); P-value <0.05: Significant (S); P-value< 0.001: highly significant (HS). The results were listed in tables (1-3)

A) Bilateral loading: -

Comparison between two studied groups regarding total micro-strain values (average mesial and distal) around implants at different time intervals was shown in table (1)

Table 1: Mean, standard deviation (SD) and p-value for comparison between the two groups during bilateral loading at different time intervals

Time intervals	Group A (Strauman)	Group B (JDEvolution)	P-value	Sig.
	Mean±SD	Mean±SD		
0-3 M	15.98±1.63	22.85±1.93	<0.001**	HS
3-6 M	23.41 ±1.74	30.74±1.95	<0.001**	HS
0-6 M	39.39±1.92	53.52±1.97	<0.001**	HS

As shown from the table, after 3 months of functional simulation, the mean of change in total micro-strains and standard deviation values were 15.98±1.63 and 22.85±1.93, from 3 to 6 months, the values were 23.41±1.74 and 30.74±1.95, and from baseline to 6 months, the values were 39.39±1.92 and 53.52±1.79 in group A and group B respectively, Throughout all time intervals, the difference was statistically highly significant.

B) Unilateral loading

1.Comparison between the two studied groups regarding total micro-strain values (average mesial and distal) around implants of the loaded side at different time intervals as shown in table (2) As shown from the table, after 3 months of functional simulation, the mean of change in total micro-strains and standard deviation values were 20.37±3.2 and 26.83±4.1, from 3 to 6 months of over-denture simulation, the values were 30.29±3.91 and 33.03±4.89, and from baseline to 6 months, the values were 50.66±4.21 and 59.89±5.12 in group A and group B respectively, the difference was statistically highly significant at the end of the follow up period.

2.Comparison between the two studied groups regarding total micro strain values around implants of the unloaded side at different time interval was shown in table (3)

Table 2: Mean, standard deviation (SD) and p-value for comparison between the two groups of the loaded side at different time intervals.

Loaded side	Group A (Strauman)	Group B (JDEvolution)	P- value	Sig
	Mean ± SD	Mean ± SD		
0-3 M	20.37±3.2	26.83±4.1	0.0124	S
3-6 M	30.29±3.91	33.03±4.89	0.3033	NS
0-6 M	50.66±4.21	59.89±5.12	<0.001**	HS

Table 3: Mean, standard deviation (SD) and p-value for comparison between the two groups of the un-loaded side at different time intervals.

Un-loaded side	**Group A (Strauman)**	**Group B (JDEvolution)**	**P-value**	**Sig**
	Mean ± SD	**Mean ± SD**		
0-3 M	12.38±1.14	13.19±2.13	0.2136	NS
3-6 M	15.32±1.63	16.22±2.61	0.3272	NS
0-6 M	27.7±2.26	29.41±3.01	0.0054*	S

As shown from the table, after 3 months of functional simulation, the mean of change in total micro-strains and standard deviation values were 12.38±1.14 and 13.19±2.13, from 3 to 6 months of functional simulation, the values were15.32±1.63 and 16.22±2.61, and from baseline to 6 months, the values were 27.71±2.26 and 29.41±3.01 in group A and group B respectively, the difference was statistically significant at the end of the follow up period.

Discussion

An in vitro study was conducted to assess stresses around implants supporting maxillary overdenture, because in vitro studies are more easily controlled and lead to more accurate results as the test can easily be repeated under the same conditions. [29] Twelve identical maxillary overdentures were fabricated on 3D printed casts for both groups to standardize all the study variables, since stereolithography technology is well acknowledged for its precision, experimental models were created using additive manufacturing techniques such as 3D printing.[30]

Implant fixtures were used in this study instead of using implant analogs to be able to distribute the loads applied in a similar manner to the oral conditions. [31] Software technology was used to design the location and angulation of the implants' ostectomies, also strain gauge slots were defined to ensure the accuracy of the duplication in all the printed models. [32] Artificial saliva was also utilized to simulate the oral conditions as it affects the properties of the materials and removes debris that develop from wear of the material. It was stated that absence of saliva changes frictional wear and therefore changes the stresses values. [33]

The universal testing machine cannot be used to replicate the intricate chewing movements because it can only generate static loads and follow intermittent movements in a single plane. Therefore, the chewing simulator was used to mimic the chewing cycles and the lateral forces acting on the overdentures during function. [34]

A statistically significant increase in stresses through the different loading cycles and after mechanical testing was found within the two groups, this could be attributed to the wear of the attachments occurring because of frictional contact between the two surfaces of the attachments during the insertion and removal cycles leading to increase in the stresses. This scenario was a common finding in many investigations performed. [35]

As much of the chewing is done in a unilateral manner, unilateral loading was performed.[36] The results showed that during bilateral loading, the micro strain values were less than that recorded during unilateral loading of the loaded side for both groups and this could be due to wide load distribution on the residual ridge and the implants while the stresses were concentrated at the loaded implants under unilateral loadings with smaller area of the ridge and due to the prosthesis's rotational movement. [37]

When comparing the results between the two tested groups, after 3 & 6 months of functional simulation, a significant difference in the total amount of change in micro strains during both bilateral and unilateral loading of loaded side and the values were higher in group B (JD Evolution) than group A (Strauman) , this is totally related to the peek material of the housings and inserts that proves to be better than metal housings with nylon inserts in maintaining retention and stability and this is based on research's which concluded that peek materials have advantageous characteristics e.g.: excellent dimensional stability, high stiffness, high tensile and flexural strength, superior chemical resistance and ease of processing.[38]

Also, the upper specimen components were clearly fixed along the abutment axis thanks to the geometry of the Novaloc matrices and the PEEK structure. As a result, tilting motions and other wear-promoting processes were significantly reduced, this allowed for better fit of over dentures in group A (Strauman) and allowed better load distribution. In addition to the excellent property of the peek as with an elastic behavior similar to that of bone and a modulus of elasticity of around 4 GPa, it lessens the stress placed on implants. [39]

These findings corroborated the findings of **De Souza et al.** [40] who reported that stud attachments usually need maintenance as they lose retention by time so they stated that there is an alternative is a novel form of attachment called Novaloc that may be more wear-resistant than the nylon used in other systems. It is based on mechanical retention from a polyetheretherketone (PEEK) matrix on a cylindrical patrix. This wear resistance increases stability of over denture and allows for better stresses distribution. Additionally, an amorphous carbon surface coating resembling diamonds is applied to the abutments in an effort to reduce surface roughness and improve the attachment components' resistance.

Another research supporting our study, Sabrina et al. [41] concluded that, one of the system's key advantages is the use of a single straight Novaloc attachment system, which allows for situations with extreme inter-implant angulations of up to 60°. This genuine compensation mechanism allows for the maintenance of very high retentive forces in these circumstances. They added that some degree of water absorption had happened during the experiment because every component was kept submerged in artificial saliva for the duration of the testing. This could partially account for retention differences, as nylon inserts appear to lose retention more quickly than PEEK inserts, and this loss of retention places more stress on the implants than does the novaloc attachment with peek inserts. Furthermore, the attachment system's behavior may also be influenced by the inserts' design, with systems with split-ring designs likely acting differently from those with full-ring designs in the event of possible dimensional changes.

According to Geyson et al. [42], PEEK material provided enough retention for long-term use over 30,000 insertion-separating cycles for both straight and tilted implants when it was incorporated into the attachment components. Novaloc attachments appear to be more favourable for long-term use and distribution of stresses than ball attachments with nylon, teflon and polyacetal inserts since they displayed less wear and less loss of retention.

Conclusion

Within the limitations of this study, it could be concluded that: BLX Strauman implant system induced lower strain values around implants than using JD Evolution implant system in implant retained maxillary overdenture after six months of functional simulation.

Funding:

This study was self-funded by the primary investigator.

Data Availability:

Data is available from the corresponding author upon request.

Competing interests:

The authors declare no conflicts of interest.

References

1. Bakke M, Holm B, Gotfredsen K. Masticatory function and patient satisfaction with implant-supported mandibular overdentures: a prospective 5-year study. International Journal of Prosthodontics. 2002; 15(6): 575-81.
2. Boven GC, Meijer HJ, Vissink A, Raghoebar GM. Maxillary implant overdentures retained by use of bars or locator attachments: 1-year findings from a randomized controlled trial. Journal of prosthodontic research. 2019; 64(1): 26-33.
3. Fadl S. Effect of degree of palatal coverage of implant retained maxillary overdenture on the crestal bone loss. Ain Shams Dental Journal. 2021; 21(1): 144-150.
4. Peñarrocha-Oltra D, Candel-Martí E, Ata-Ali J, Peñarrocha-Diago M. Rehabilitation of the atrophic maxilla with tilted implants: review of the literature. Journal of Oral Implantology. 2013; 39(5): 625-32.
5. Klinge B, Lundstrom M, Rosen M, Bertl K, Klinge A, Stavropoulos A. Dental Implant Quality Register-A possible tool to further improve implant treatment and outcome. Clin Oral Implants Res. 2018; 29(18): 145–151.
6. Papaspyridakos P, Chen CJ, Singh M, Weber HP, Gallucci GO. Success criteria in implant dentistry: a systematic review. J Dent Res. 2012; 91(3): 242–248
7. Quirynen M, Al-Nawas B, Meijer HJ, Razavi A, Reichert TE, Schimmel M, Storelli S, Romeo E. Small-diameter titanium Grade IV and titanium-zirconium implants in edentulous mandibles: three-year results from a double-blind, randomized controlled trial. Clin Oral Implants Res. 2015; 26(7): 831-40.
8. Marković A, Čolić S, Šćepanović M, Mišić T, Đinić A, Bhusal DS. A 1-Year Prospective Clinical and Radiographic Study of Early-Loaded Bone Level Implants in the Posterior Maxilla. Clin Implant Dent Relat Res. 2015;17(5): 1004-13.
9. Nicolau P, Korostoff J, Ganeles J, Jackowski J, Krafft T, Neves M, Divi J, Rasse M, Guerra F, Fischer K. Immediate and early loading of chemically modified implants in posterior jaws: 3-

year results from a prospective randomized multicenter study. Clin Implant Dent Relat Res. 2013; 15(4): 600-12.
10. Walton JN, Huizinga SC, Peck CC. Implant angulation: A measurement technique, implant overdenture maintenance, and the influence of surgical experience.', Int. J. Prosthodont. 2001; 14: 523–530.
11. Jabbour Z, Fromentin O, Lassauzay C, Abi Nader S, Correa JA, Feine J, de Albuquerque Junior RF. Effect of implant angulation on attachment retention in mandibular two-implant overdentures: A clinical study. Clin. Implants Dent. Relat. Res. 2014;16: 565–571.
12. Chung KH, Chung CY, Cagna DR, Cronin RJ. Retention characteristics of attachment systems for implant overdentures. J Prosthodont. 2019; 13(4): 221-226.
13. ALbatrik N, Eid H, and Lotfy S. Comparing Two Suggested Techniques to Correct Improperly Angulated Implants in Mandibular Kennedy Class I Implant Supported Partial Overdenture. Ain Shams Dental Journal. 2020; 20(4): 105-110.
14. Hatem M, Wagdy M, Fahim A. and Rekaby E. Wear Resistance and Long-Term Retention of Novaloc Versus Traditional Ball and Socket Implant Attachments Retaining Mandibular Complete Overdenture. J Prosthet Dent. 2022; 9(09): 2394-2967.
15. Metwally AF and Mohamed G. Evaluation of Stresses Distribution Pattern In Implant- Retained Maxillary Obturators Using Nova-Lock, Ball & Locator-Bar Attachment Systems. (Three-Dimensional Finite Element Analysis). EDJ. 2019;65: 2597-2605.
16. Passia N, Ghazal M, Kern M. Long-term retention behavior of resin matrix attachment systems for overdentures. J Mech Behav Biomed Mater. 2016; 57: 88-94.
17. Rubo JH, Capello Souza EA. Finite-element analysis of stress on dental implant prosthesis. Clin Implant Dent Relat Res. 2010; 12(2): 105-13.
18. Santiago Junior JF, Pellizzer EP, Verri FR, de Carvalho PS. Stress analysis in bone tissue around single implants with different diameters and veneering materials: a 3-D finite element study. Mater Sci Eng C Mater Biol Appl. 2013; 33(8): 4700-14.
19. Grando AF, Rezende CE, Sousa EA, Rubo JH. Effect of veneering material on the deformation suffered by implant-supported fixed prosthesis framework. J Appl Oral Sci. 2014; 22(3): 209-17.
20. Nimbalkar S, Dhatrak P, Gherde C and Joshi S. A review article on factors affecting bone loss in dental implants. Materials Today: Proceedings. 2021; 43: 970-976.
21. Gulizio MP, Agar JR, Kelly JR and Taylor TD. Effect of implant angulation upon retention of overdenture attachments. Journal of Prosthodontics. 2005; 14(1): 3-11.
22. Tokuhisa M, Matsushita Y and Koyano K. ln Vitro Study of a Mandibular Implant Overdenture Retained with Ball, Magnet, or Bar Attachments: Comparison of Load Transfer and Denture Stability. International Journal of Prosthodontics. 2003; 16(2): 128-34.
23. Naconecy MM, Geremia T, Cervieri A, Teixeira ER, Shinkai RS. Effect of the number of abutments on biomechanics of Branemark prosthesis with straight and tilted distal implants. J Appl Oral Sci.2010; 18(2): 178-85.
24. Geng JP, Tan KB, Liu GR. Application of finite element analysis in implant dentistry: a review of the literature. J Prosthet Dent. 2001; 85: 585–598.
25. Sadowsky SJ, Caputo AA. Effect of anchorage system and extension base contact on load transfer with mandibular implant retained overdentures. J Prosthet Dent. 2000; 84(3): 327-334.
26. Chun HJ, Park DN, Han CH, Heo SJ, Heo MS, Koak JY. Stress distribution in maxillary bone surrounding overdenture implants with different overdenture implants with different overdenture attachments. J Oral Rehabil. 2005;32(3): 193-205.
27. El-Anwar MI, Yousief SA, Soliman TA, Saleh MM, and Omar WS. A finite element study on stress distribution of two different attachment designs under implant supported overdenture. The Saudi dental journal. 2015; 27(4): 201-207
28. Shokr M., Talaat I., Tarek H., Eskander A. Effect of CAD/CAM zirconia versus cast metal attachment on stresses induced in Kennedy class I cases (Strain gauge analysis). Ain Shams Dental Journal. 2023; 30(2): 6-12.
29. Leblebicioğlu Kurtuluş I, Kilic K, Bal B and Kilavuz A. Finite element analysis of the stress distribution associated with different implant designs for different bone densities. Journal of Prosthodontics. 2022; 31(7): 614-622.
30. Aboelnagga M. Comparative stress analysis of BioHPP and PEKK CAD/CAM frameworks in mandibular All-on-Four fixed-detachable prosthesis on its supporting implants. Ain Shams Dental Journal. 2023; 32(4): 6-18.
31. Mohammed S. Effect of Two Different Digitally Constructed Bar Materials on The Supporting Structures of Implant-Retained Mandibular Overdenture (In-Vitro Study). Ain Shams Dental Journal. 2023; 29(1): 15-22.
32. Mora MA, Chenin DL and Arce RM. Software Tools and Surgical Guides in Dental-Implant-Guided Surgery. Dent Clin North. 2021; 8(3): 55-87.
33. Esguerra RJ. Technique for fabricating a custom gingival mask using a maxillary complete-arch implant-supported fixed interim prosthesis with an integrated verification cast. J Prosthet Dent. 2016; 11(5): 5–8.
34. Ghazal M, Yang B, Ludwig K and Kern M. Two-body wear of resin and ceramic denture teeth in comparison to human enamel. Dent Mater. 2008;24(3): 50-502.

35. Shehata RM, Cheta N, Alkady D and Borg H. Retention and Wear Evaluation of Rigid Telescopic and Nova Loc Attachments for Two Implant-Supported Mandibular Overdentures (An in vitro study). British Journal of Medical and Health Research. 2022; 8(3):2394-2967.
36. ELsyad MA, Elsaadawy MG, Abdou AM, Habib AA. Effect of different implant positions on strain developed around four implants supporting a mandibular overdenture with rigid telescopic copings. Quintessence Int. 2013; 44(9): 679-86.
37. Shawky AO, Mohammed SL. zirconia versus biohpp frameworks on stresses induced in implants supporting structures using all-on-4® protocol (strain gauge analysis). Egyp Dent J. 2018; 145-153.
38. Suphangul S, Rokaya D, Kanchanasobhana C, Rungsiyakull P, Chaijareenont P. PEEK Biomaterial in Long-Term Provisional Implant Restorations: A Review. J Funct Biomater. 2022;13(2):33.
39. Zhang X, Ma X, Lin Q, Xiao L, Wang S, Yang H, Liao L, Liu Y, Zhang C, Song J. Study on the Friction and Wear Properties of PEEK against Cortical Bone Tissue Under Different Lubricating Conditions. Macromol Biosci. 2023; 23(1): 5-22.
40. De Souza RF, Bedos C, Esfandiari S, Makhoul NM, Dagdeviren D, Abi Nader S, Jabbar AA, Feine JS. Single-implant overdentures retained by the Novaloc attachment system: study protocol for a mixed-methods randomized cross-over trial. Trials. 2018;19(1): 2-43.
41. Sabrina M, Isabelle B, François R, Herrmann N, Chebib P, Ammann M, Schimmel F and Müller S. In vitro retention force changes during cyclic dislodging of three novel attachment systems for implant overdentures with different implant angulations. Clin Oral Impl Res. 2020; 31(2): 315–327.
42. Geyson G, Marcos V, Ana P, Mariana L and Andréa G. In vitro assessment of polyetheretherketone for an attachment component for an implant-retained overdenture. JPD. 2022; 3(5): 319.