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The impact of chewing force simulation on stress distribution of implant retained mandibular overdenture with locator attachment system having matrix of PEEK versus nylon insert

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Abstract

The current study investigates the impact of chewing force simulation on stress strain distribution of Mandibular overdentures retained with locator attachment system having matrix of PEEK versus nylon insert. Twenty completely edentulous mandibular digitally printed models were fabricated with beds for two implants, which had been inserted in the estimated canine positions with two grooves mesial and distal at each implant site for the attachment of the strain gauges for each model. Nova loc group NLG with ten implant assisted mandibular complete overdentures were fabricated over ten printed models with nova loc attachments while locator group LG had ten implant assisted mandibular complete overdentures over ten printed models with locator attachments of same retaining force and geometric height. Bilateral vertical load was applied with a universal testing machine and strain induced to the implants was measured around the two implants medially and distally in each group using strain gauges pre & post one year simulated functional aging. Student t test was used for comparing the two types of attachments while paired t test was used for comparison of strain induced to the implants after one year of functional aging, with probability level $p < 0.05$ is considered statistically significant. Individual statistical analysis of the data revealed increase in the number of measured strains for both attachments which was statistically significant for locator. Comparing the two groups, significant increase for the locator attachment after one year simulated functional aging was detected compared to nova loc. Within the limitations of this study, one year simulated functional aging seems to cause disturbance in the load conveyed to the supporting structures of mandibular implant assisted overdenture retained with locator in contrast to nova loc that showed more resistance to aging process, thus nova loc attachment transmit less stresses than locator attachment to the surrounding implants supporting structures specially after time of service related to its combined materials superior physical properties .

Keywords: CAD-CAM**,** Chewing simulation, Locator, Nova loc, Stress analysis

Full length article **Corresponding Author*, e-mail: Mohamed-mustafa@dent.asu.edu.eg Doi # https://doi.org/10.62877/13-IJCBS-24-25-19-13

1. Introduction

Mandibular assisted overdenture has been an acceptable simple line of treatment; however, the needs for continuous monitoring and maintenance might complicate this treatment plan. The wear of attachment components necessitates continuous replacement of retentive components [1]. Matrices of non-splinted attachment systems are generally known to be the frequently component of implant overdentures, often requiring replacement. Clinical wear that happened in the retentive part results in reduced retention of the prosthesis, requiring activation or renewal of the matrix to restore the initial level of retention. [2, 3]. The locator attachment has been a subject of many clinical applications [4]. This attachment is self-aligning and has dual retention system in different colors with different retention values. Locator attachments are available in different vertical heights, they are resilient, retentive, durable, and have considerable ability to compensate the defects in implant angulation. In addition to repair and replacement are fast and easy [5]. This system consists of a patrix and a matrix, using a dual retention approach with different retentive values. It is classified as a resilient universal hinge device, and is designed for limited inter-arch space, enabling inter-implant angles to be fixed up to 40º. The retention value of the Locator attachment depends on the patrix, composed of a metallic cap with a replaceable nylon element [6]. The loss of retention over time has been confirmed due to excessive wear and increased maintenance requirements for the male inserts of the locater attachment which are made from nylon [7]. A modification in the attachment design along with an alteration of the attachment surface decreased the maintenance needs and enhanced its clinical performance [8]. A novel stud-type attachment called Nova loc was introduced by Straumann®, which is an improved solitary locator system. [9]. Nova loc patrix is made out of titanium alloy and coated with an amorphous diamond like carbon. According to the manufacturer, this coating increases hardness and sliding qualities, which decreases abrasion to the abutment and wear on retention inserts, and reduces surface roughness in contrast to alternative locator systems. [9]. Nova loc is able to compensate up to 40 degrees divergence between two implants. The matrix housing on the other hand made of either titanium or polyether ether ketone (PEEK), while the retention inserts is also made of PEEK plastic. [10]. Retention inserts vary in retentive force values from extra light, light, medium, strong, extra strong and ultra strong that are color coded as red, white, yellow, green, blue and black, respectively. [9]. PEEK outstanding physical qualities, which include high wear resistance, corrosion resistance, biocompatibility with surrounding tissue, low plaque affinity, and high modulus of elasticity, have led to its increasing usage in dentistry these days. [10]. An in vitro study was conducted to evaluate the retention of PEEK matrices compared to the traditional Locator system and showed promising results, location of maximum deformation was the tip of the attachment towards the applied load. Such small deformation was referred to the peek cap, while reinforcing the abutment by the amorphous carbon coating could increase its hardness and resistance to wear [11]. Before materials are used intra-orally, their mechanical properties must be thoroughly tested in a laboratory. The need for information about wear and fatigue characteristics of dental materials before they enter clinical use has resulted in development of a variety of mastication-simulating devices. [12,13] chewing simulator use dynamic loading as the functional principal of their mechanism for producing cyclic fatigue and mechanical aging, which mimics human masticatory function, these simulators are used to provide information about a material behavior over time [14]. The purpose of the current study was to investigate the change in stresses conveyed to the supporting structures of implant retained mandibular overdenture with locator and nova loc attachment before and after subjected to chewing simulation. Null hypothesis was adopted that both groups conveyed the same stresses distribution before and after chewing simulation.

2. Materials and Methods

2.1. Sample size

The Sample size calculation was performed using G*Power version 3.1.9.7 [15] based on the results of a previous study [16]. 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 (2.4) calculated based on the results of a previous study [16]. The predicted sample size (n) was (20), i.e., 10 samples per group. To detect the difference between the two groups.

2.2. Construction of the 3D model of mandibular edentulous arch

This in-vitro stress analysis was conducted on computer-generated three-dimensional models simulating a completely edentulous lower arch with two Straumann* implants inserted at the estimated canine positions retaining mandibular over denture prosthesis. Completely edentulous epoxy mandibular model was fixed on the scanner table and scanned using 3Shape D850 scanner (D850, 3Shape, Copenhagen, Denmark). The STL file was imported for designing and modifying the virtual model using DDS pro software (Czestochowa, Poland) [17].

2.3. Modification of virtual mandibular edentulous model

In this STL file, two implant beds were designed representing the planned osteotomy sites for the two implants of diameter 3.7mm with 0.1mm offset horizontally, [18] at the estimated canine positions (figure 1a), then two grooves were designed at each future implant site for the attachment of the strain gauges (figure 1b). These grooves were designed with a flat plane parallel to the long axis of the implants and separated by 1 mm from the implant beds at the mesial and distal aspects. A cut back of 2 mm was done on the ridge to create a space for mucosal simulation.

2.4. Mucosa key index design

A key index with 2 mm thickness and 2 mm offset with tissue stops was designed for creating a space for the mucosa simulator representing the future mucosa [19].

2.5. Additive manufacturing of the modified virtual model and mucosa key index

The STL files were directly sent to the additive manufacturing device, which is based on the idea of Continuous digital Light Projection (CDLP) that utilizes a DLP chip to print the cast layer by layer utilizing the projection of an ultraviolet light to polymerize the layers until the whole cast was printed starting from the base. The raw material used in production of the printed item is a photopolymer, which in fact is a mixture of acrylic acid esters and photo initiator [20].

2.6. Implants insertion, Simulation of the mucosa and dentures construction

Cyanoacrylate adhesive cement was applied to fix the implants in their implant beds to simulate osseointegration & mucosa simulation was achieved via gingival mask material (Gingisil special silicone gingival mask soft, (dent-E-con) (Germany).) It is an addition-linking silicone which was injected from the double-mix cartridge directly into the printed index, that was seated over the model. Figure (2). A rubber base impression (zetaplus, Zermach, Italy) was made for the final model with gingival simulator and poured to obtain a stone model. Wax up trial denture base was made over the stone model and artificial teeth were arranged on the trial denture base. The height of the occlusal plane was adjusted to the level between the upper and middle third of retromolar pad. A rubber base impression of the waxed up trial denture base was made to produce a mold for fabrication of 20 duplicate dentures. The upper piece of the mold was a negative of the denture polished surface and teeth. Artificial teeth were then inserted into the mold [21]. Twenty identical dentures (10dentures/group) were obtained by pouring molten base plate wax into the intervening space between the silicon mold and the stone cast. The waxed dentures were then flasked using heat cured acrylic resin (Acroston , Egypt) to obtain 20 duplicate dentures .

2.7. Grouping of study groups

Group I NLG

The two nova loc attachments of 1200gm retaining force and 2.5mm gingival height were placed for each implant and were tightened using their driver at a torque of 25 N cm. The peek matrices with block out shim were placed over the nova loc abutments, direct pick up was done for the mandibular over denture (figure 3, 4).

Group II LG

The locator abutments of the same height and retaining force were secured to the implants, direct pick up was done for the mandibular over denture (figure 3, 5).

2.8. Pre chewing simulation Strain gauge installation

The strain gauges (Kyowa strain gauges, Japan.) used in this study were supplied with fully encapsulated grid and attached wires. [22]. The gauge length was 1 mm and width of 2.4mm, the nominal resistance was 120.4 ±0.4 ohm and the gauge factor was2.09 ±1.0%. [23]. Strain gauges were connected to lead wires 100 cm in length; a packing material insulated the wire used for the strain gauges. (Figure 6 a, b). After removal the mucosa simulator from the cast, the strain gauges were fixed to the distal and mesial surfaces of every implant. All the strain gauges were positioned parallel to the long axes of the implants. [24]. All strain gauges were bonded in position on the printed model with delicate layer of Cyanoacrylate base adhesive, Light pressure was applied against the bonded gauges and the pressure was maintained for 3 minutes using a large ball burnisher. The strain gauges were left for 24 hours in order to guarantee that the adhesive had fully cured. All wires were labeled, so that each wire of the active gauge has a label indicating the surface to be measured. To prevent their unintentional dislodgement, the fine lead wires of the gauges were inserted in channels made specifically for this purpose and incorporated into the model's base. The terminals of the strain gauge wires were inserted into four channels strain meter (Kyowa, kyowa Electronic Instruments Co, Ltd, Tokyo, Japan) to measure the micro strains induced by the applied load.

2.9. Load application

Universal Testing machine (Lloyd LR5K instrument, Fareham, Hampshire, UK)) (Figure 7). was used for applying standardized vertical static loads ranging between 0-100 N on the loading points for 15 s at a cross head speed of 0.5 mm/min, which is equivalent to the moderate level of biting force as was recommended by Porter et al 2002[24], at the contact between second premolar and first *molar*, bilateral loading with notches to avoid slippage and reproducibility of the pin as recommended by Elsyad et al. 2013 [25]. The terminals of the lead wire of the strain gauges were connected to a multi-channel strain meter in order to calculate the micro voltage out-put which was converted into micro strain using special software (Kyowa PCD 300 A). A four-channel strain-meter was used to assess the strains induced by the applied load for each model. The T-shaped load applicator bar of the testing machine was allowed to touch the denture teeth at the contact between the second premolar and first molar. Simultaneous and even contacts between the bar and the artificial teeth on both sides at the previously mentioned positions were achieved by spot grinding guided by using articulating paper marks. Load was applied using the universal-testing machine at contact between second premolar &first molar bilaterally. The applied load started from zero up to 100N, the micro strains of the four strain gauges were recorded to measure the strains developed at the mesial and distal sides of both implants. Once the load was completely applied, the micro strain readings were transferred to micro strain units from the four channels strain meter. Enough time was given to the strain gauges to be in zero balance and to allow complete rebound of the resilient structures [26]. The same steps were followed to the other group. Data were analyzed using the software (Kyowa PCD-300A) and statistically analyzed.

2.10. Chewing simulation

Then models were fixed to the chewing simulator Teflon specimen holder by the previously made acrylic projection and then the holder was mounted on the specimen chamber. The specimen chamber was wet environment filled with artificial saliva (Isotonic 0.9% sodium chloride solution at 22ºC) (Figure 8) after sacrificing and debonding of the attached strain gauges [27]. The Chewing Simulator* was used to apply a dynamic cyclic loading by means of a falling stylus at the center of the metal plate that was attached previously to the occlusal surface of complete overdentures at load settings of 50 N [28] and the software parameters were set at 60 mm/sec speed, 3 mm vertical path, 0.7 mm horizontal path and 1.6 Hz frequency. Each group was subjected to bi-axial cyclic loading for a total of 245,000 cycles as a one year of service [29] [30]. * CS_4.4 –SD Mechatronic Gmbh, Germany.

2.11. Post chewing simulation load application and Strain analysis

After chewing simulation as one year of service and aging procedure by application of 245,000 cyclic loading for both groups models, new strain gauges were again secured, then analysis was achieved to assess the stresses values received for both groups mesially and distally as described before. The same steps were followed as before for both groups. Data were analyzed using the same software (Kyowa PCD-300A) and statistically analyzed.

3. Results and discussion

Recorded data were analyzed using the statistical package for social sciences, version 23.0 (SPSS Inc., Chicago, Illinois, USA). The quantitative data were presented as mean± standard deviation and ranges as their distribution was parametric (normal) Data were explored for normality using Kolmogorov-Smirnov and Shapiro-Wilk Test. Student t test was used for comparing the two studied attachments before and after one year simulated functional aging while paired t test was used to compare strains within each group during the investigation. The results of comparing the two studied attachments are presented Table (1) and figure (9) revealed greater amount of strain for the locator attachment than nova loc attachment with mean ± SD 53.06 ± 15.39 and 49.73 ± 15.91 respectively before functional aging and the difference was statistically insignificant. Table (2) and figure (10) One year after simulated functional aging, revealed greater amount of strain induced to the implants bearing locator attachment than nova loc and the difference showed a statistical significance. Table (3) and figure (11) shows that there was a statistically significant difference between pre chewing simulation phase and post chewing simulation phase during bilateral loading in locator group, p-value ($p<0.05$), while for the Nova loc group insignificant difference between pre and post chewing simulation phase, with p-value ($p>0.05$). A major advantage of the freestanding implants is the fact that they allow for usage of the prefabricated stock retentive abutments [5]. Locator as a solitary attachment is known in the literature as a satisfying anchorage device for overdenture in a well-controlled clinical trials [31], however introduction of new polymers in dentistry has made evolution in the attachment design. So this study was conducted on computer generated three dimensional models simulating a completely edentulous lower arch with two implants were inserted at the estimated canine positions retaining mandibular over denture prosthesis, two model groups were constructed, group I NLG and group II LG. In the current study, the gauges were bonded on the prepared mesial and distal surfaces around the implants because the alveolar crest in these areas are the most important areas where the stresses are usually initiated and thus bone loss is expected and therefore overloading may occur from the compression of the cortical bone around the alveolar crest. [32]. The strain analysis was achieved bilaterally to simulate the patients chewing patterns, as some patients had a preferable chewing side (unilateral) while others prefer to chew on both sides (bilateral) [33] in two stages; pre chewing simulation and post chewing simulation to see its effect regarding the load transferred to the implants as a one year of service and aging. It is well known that the first molar and second premolar area is the area where the maximum occluding forces are exerted where there is maximum contraction of the elevator muscles, so this area was chosen for load application during this study. [34]. Although there was no statistically significant difference between both groups during bilateral loading pre chewing simulation, it was observed that the micro strain values were higher in the locator attachment group LG than nova loc attachment group NLG. While post chewing simulation functional aging there was a statistical significant difference between both groups; this could be attributed to the fact that nova loc patrix is made out of titanium alloy and coated with an amorphous diamond like carbon, which reduces surface roughness in comparison to other locator systems, increases the hardness and increases sliding characteristics which reduces abrasion to the abutment and transmitted load and due to biocompatible peek retentive inserts [9]. That may also account for the statistical significance increase in locator group LG as a result of paired t- test for both groups with absence of statistical significance in group I NLG. Passia et al. showed in a bench study that the material combination used to fabricate the nova loc attachment improved the mechanical resilience of the attachment system against mechanical wear, loss of retention, potential prosthodontic complications and less load to the implant. [11] this may also explain the result of this study. The retentive behavior and wear of the Locator and Nova loc attachment systems with different retention inserts under cyclic load were investigated and the results showed that nova loc insert on both abutments exhibited less wear (decrease to 56%–85% of initial force) and a slower decrease in retention force compared to Locator inserts (decrease to 6%–31% of initial force) [35]. This finding may account for the insignificant stresses measured for nova loc attachment after one-year simulated functional aging than the locator during this study.

Table 1. Comparison between Nova loc group (I) and locator group (II) regarding strain gauge analysis for bilateral loading pre chewing simulation phase

Bilateral loading pre chewing simulation	Locator group *(n=10)*	Nova loc group *(n=10)*	Change	95% C.I.	t-test	p-value	Sig.
Mean±SD	53.06±15.39	49.73±15.91	3.33±0.57	2.76-3.90	0.476	0.640	NS
Range	12-96	10-92					

P-value >0.05: Non significant (NS); P-value <0.05: Significant (S); P-value< 0.01: highly significant (HS)

Table 2. Comparison between Nova loc group (I) and locator group (II) regarding strain gauge analysis for bilateral loading post chewing simulation phase

Bilateral loading post chewing simulation	Locator group *(n=10)*	Nova loc group *(n=10)*	Change	95% C.I.	t-test	p-value	Sig.
Mean±SD	71.32±16.25	56.17±14.85	15.15±2.58	12.6-17.7	2.176	0.043	S
Range	13-131	13-108					

P-value >0.05: Non significant (NS); P-value <0.05: Significant (S); P-value< 0.01: highly significant (HS)

Table 3. Comparison between pre chewing simulation phase and post chewing simulation according to bilateral loading in each group

Bilateral loading	Pre chewing simulation phase	Post chewing simulator	Paired sample t-test				
	Mean±SD	Mean±SD	Mean±SD	95 C.I.	t-test	p-value	sig.
Locator group *(n=10)*							
Mean±SD	53.06±15.39	71.32±16.25	18.26±4.57	13.7-22.8	2.58	0.019	S
Range	12-96	13-131					
Nova loc group *(n=10)*							
Mean±SD	49.73±15.91	56.17±14.85	6.44±1.74	4.7-8.2	0.936	0.362	NS
Range	10-92	13-108					

NS: Non significant; S: Significant; HS: Highly significant

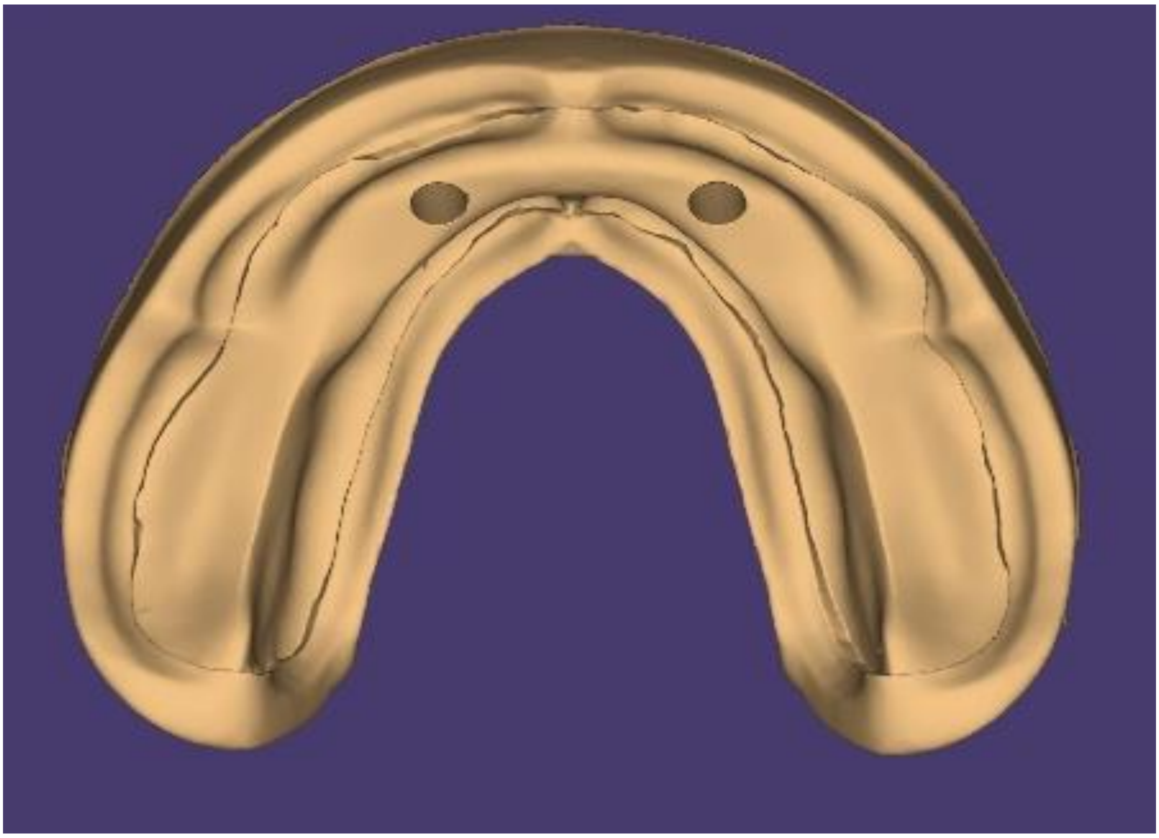

Figure 1(a). The two implant beds

Figure 1(b). The two grooves for strain gauges

Figure 2. Mucosa simulation secured by the key index

Figure 3. Overdentures for each model.

Figure 4. Picked up overdentures with nova loc group with peek insert

Figure 5. Picked up overdentures with locator retentive insert

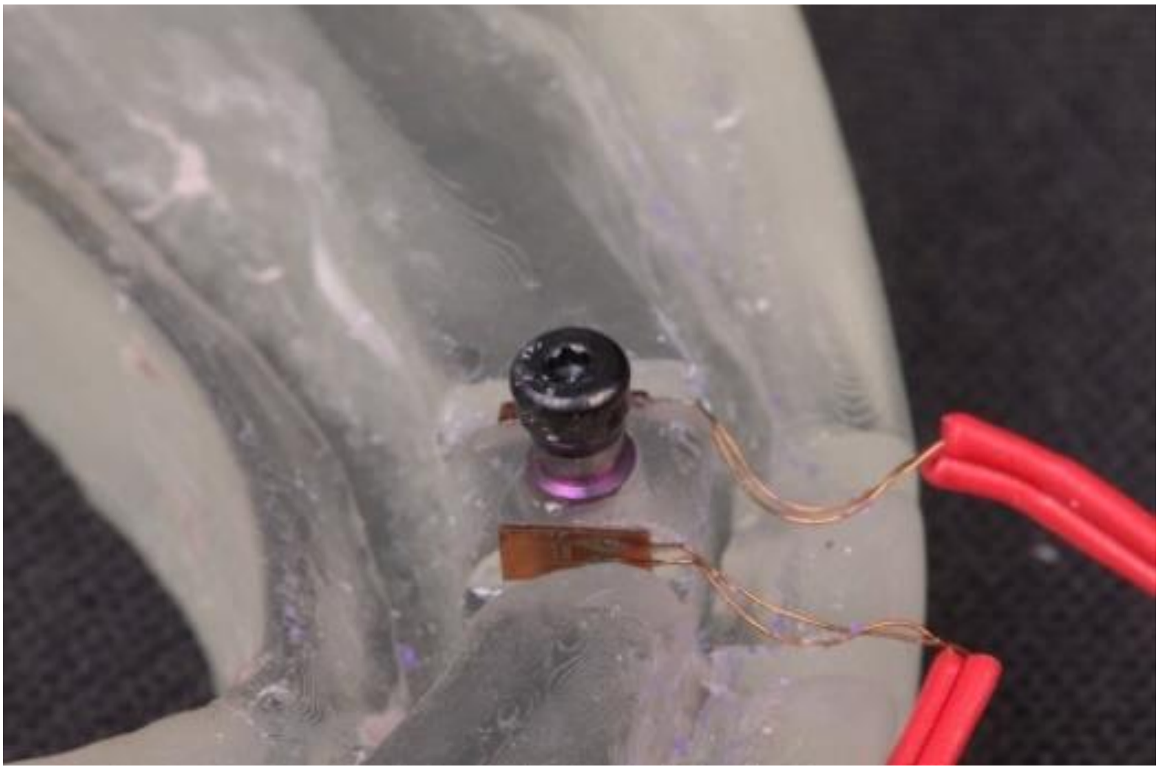

Figure 6 (a). Strain gauge connected around the implant analogues

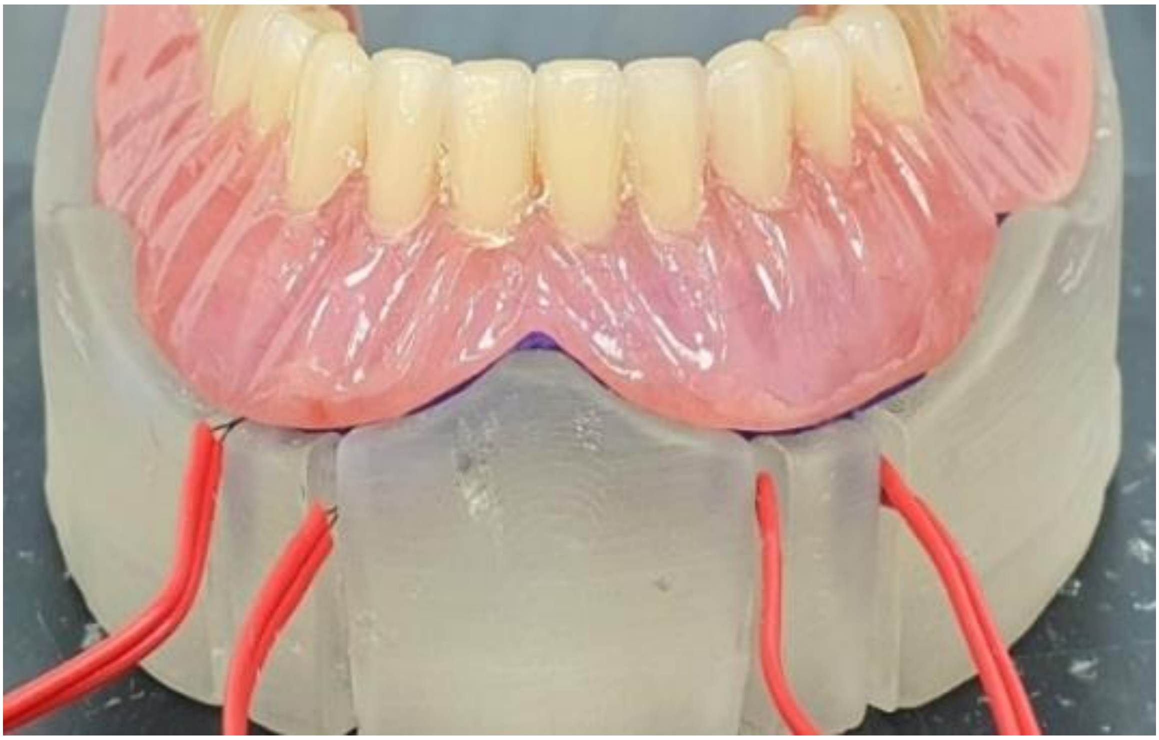

Figure 6 (b). Seated overdenture with connected strain gauges

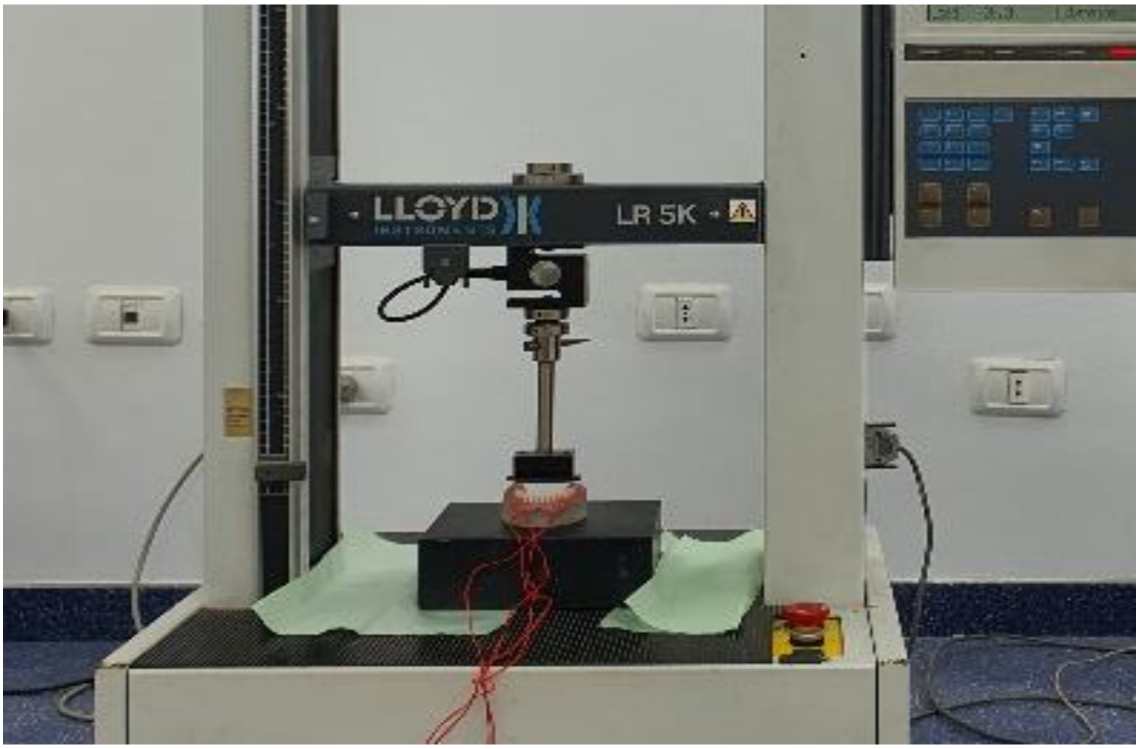

Figure 7. Universal testing machine

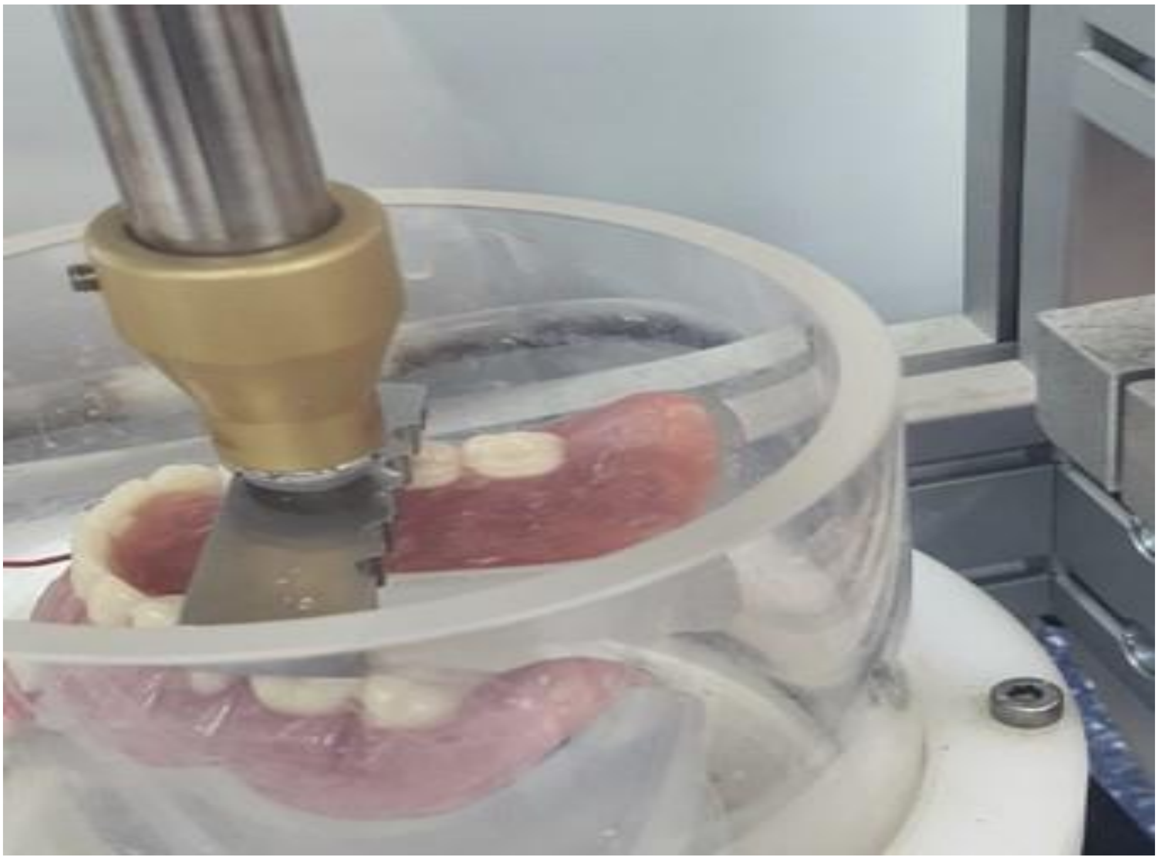

Figure 8. The models were fixed to the chewing simulator

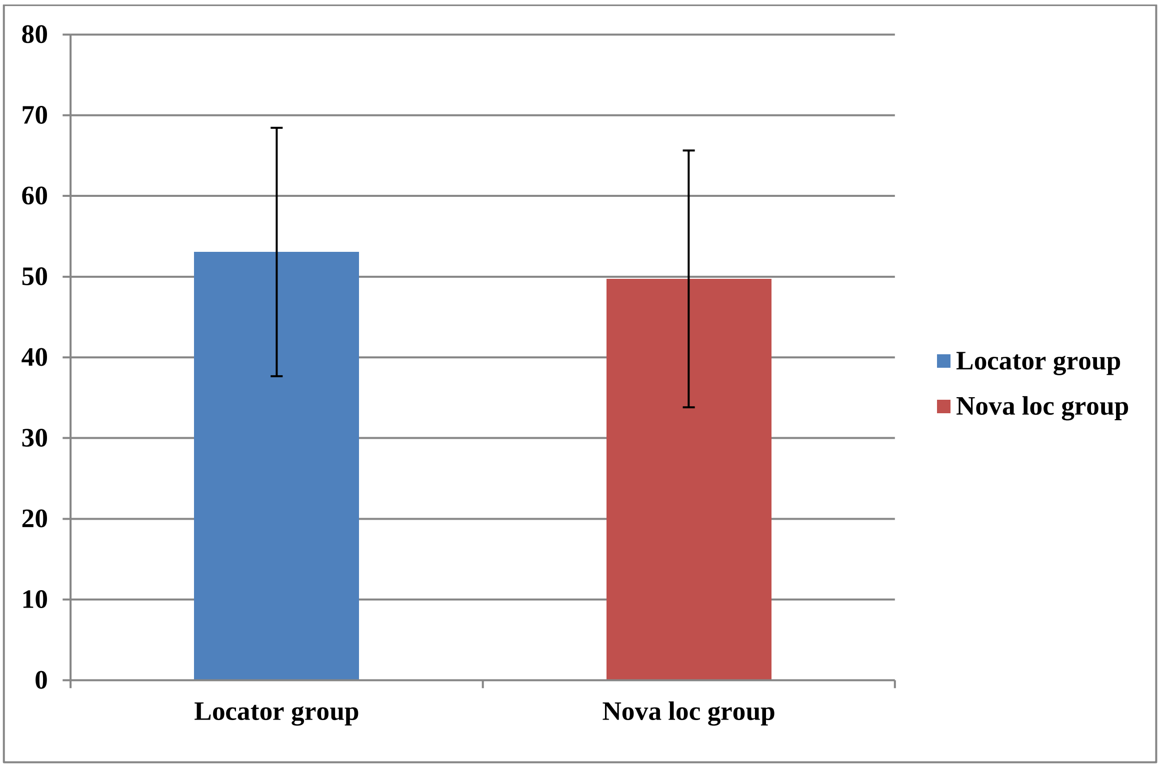

Figure 9. Bar chart showing comparison between Nova loc group (I) and locator group (II) regarding strain gauge analysis for bilateral loading pre chewing simulation phase

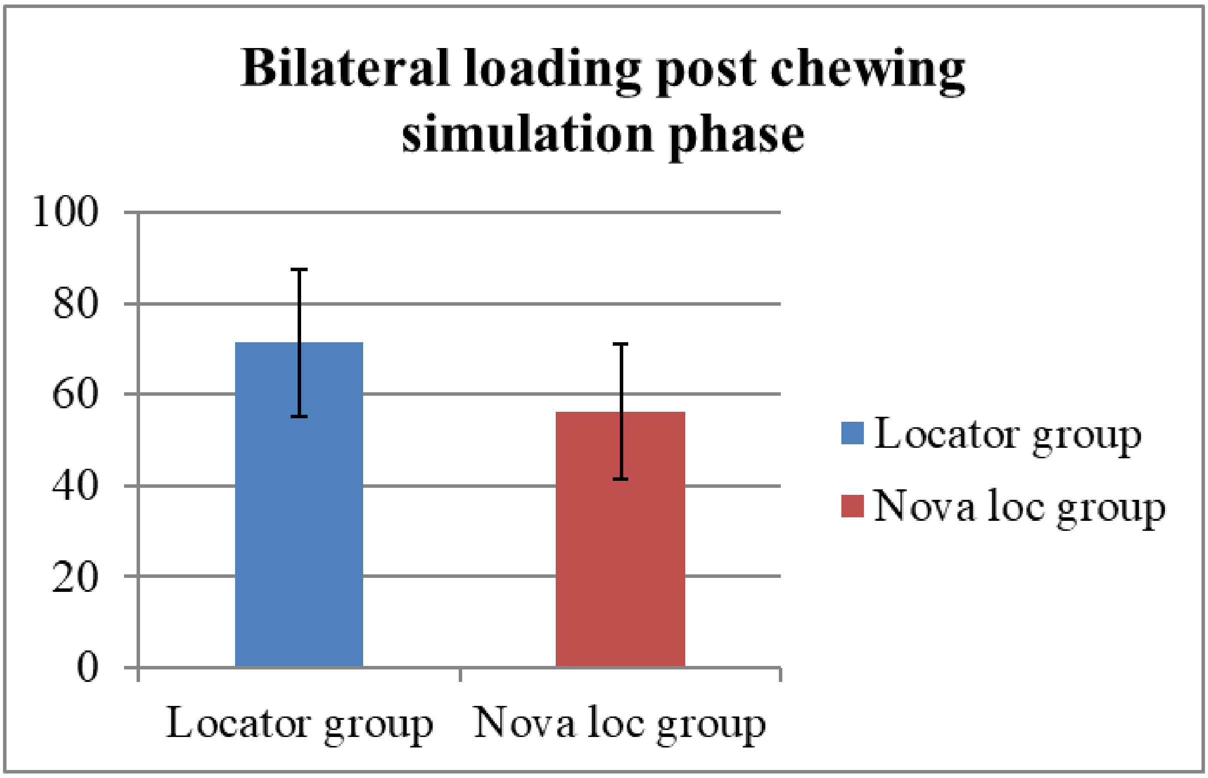

Figure 10. Bar chart showing Comparison between Nova loc group (I) and locator group (II) regarding strain gauge analysis for bilateral loading post chewing simulation phase

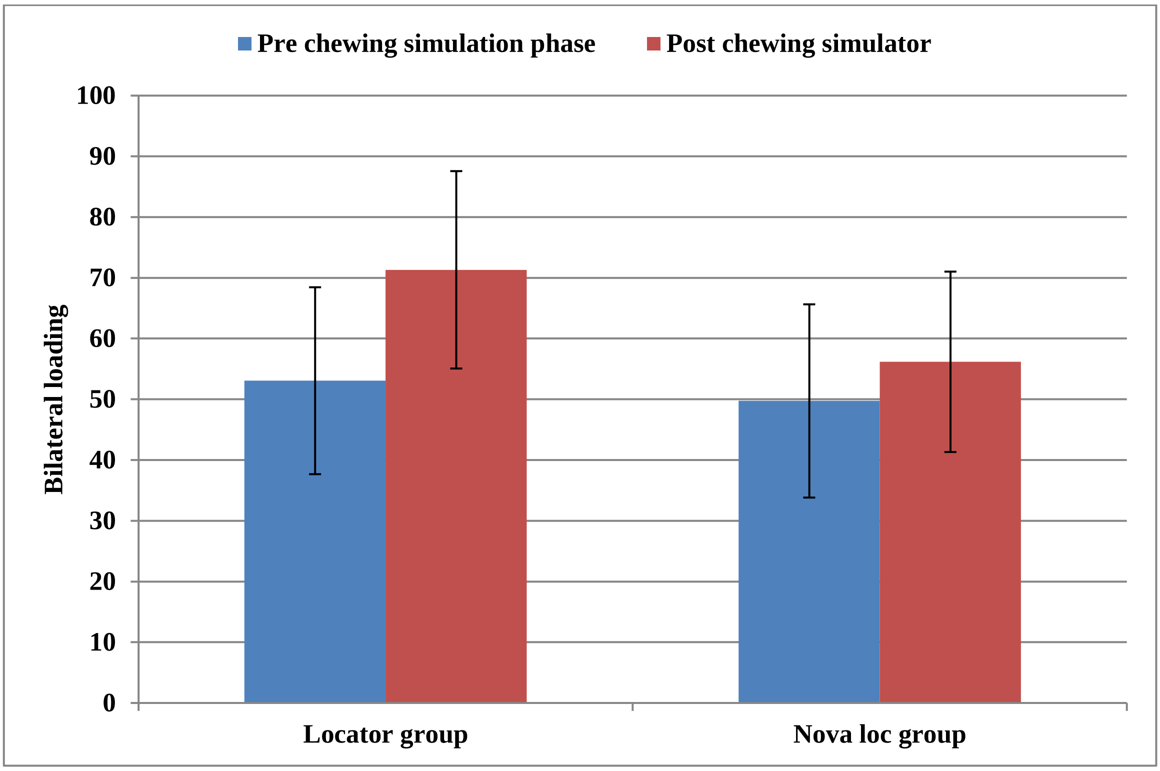

Figure 11. Comparison between pre chewing simulation phase and post chewing simulation according to bilateral loading in each group

4. Conclusions

Within the limitation of this study, one year service simulation seems to cause disturbance in the load conveyed to the supporting structures of mandibular implant assisted overdenture retained with locator in contrast to nova loc that showed more resistance to aging process, thus nova loc attachment transmit less stresses than locator attachment to the surrounding implants supporting structures specially after time of service related to its combined materials superior physical properties. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.”

Conflict of Interest

The authors declare no conflict of interest, financial or otherwise.

Ethical statement

This study does not require ethical approval. It does not involve experiments in humans or animals.

References

[1] O. Fromentin, C. Lassauzay, S.A. Nader, J. Feine, R.F. de Albuquerque Jr. (2011). Clinical wear of overdenture ball attachments after 1, 3 and 8 years. Clinical oral implants research. 22 (11) 1270-1274.

[2] O. Fromentin, C. Lassauzay, S. Abi Nader, J. Feine, R.F. de Albuquerque Jr. (2012). Wear of matrix overdenture attachments after one to eight years of clinical use. The Journal of prosthetic dentistry. 107 (3) 191-198.

[3] S.M.M. Spyrides, F.R. da Silva Schanuel, E.B. de Mello. (2017). Comparative study of splinted and unsplinted implant-retained maxillary overdentures without palatal coverage: A literature review. Brazilian Dental Science. 20 (4) 32-41.

[4] R. Wakam, A. Benoit, K.B. Mawussi, C. Gorin. (2022). Evaluation of retention, wear, and maintenance of attachment systems for single-or two-implant-retained mandibular overdentures: a systematic review. Materials. 15 (5) 1933.

[5] S. Cakarer, T. Can, M. Yaltirik, C. Keskin. (2011). Complications associated with the ball, bar and Locator attachments for implant-supported overdentures. Med Oral Patol Oral Cir Bucal. 16 (7) e953-9.

[6] A.M.Q.P. Miler, A.R.M. Correia, J.D.C. Rocha, J.C.R. Campos, M.H.G.F. da Silva. (2017).

Locator® attachment system for implant overdentures: a systematic review. Stomatologija. 19 (4) 124-9.
[7] C. Guédat, U. Nagy, M. Schimmel, F. Müller, M. Srinivasan. (2018). Clinical performance of LOCATOR® attachments: A retrospective study with 1–8 years of follow-up. Clinical and experimental dental research. 4 (4) 132-145.
[8] J.W. Choi, B.H. Yun, C.M. Jeong, J.B. Huh. (2018). Retentive Properties of Two Stud Attachments with Polyetherketoneketone or Nylon Insert in Mandibular Implant Overdentures. International Journal of Oral & Maxillofacial Implants. 33 (5).
[9] C. Sotova, O. Yanushevich, N. Kriheli, S. Grigoriev, V. Evdokimov, O. Kramar, P. Peretyagin. (2023). Dental Implants: Modern Materials and Methods of Their Surface Modification. Materials. 16 (23) 7383.
[10] S. Najeeb, M.S. Zafar, Z. Khurshid, F. Siddiqui. (2016). Applications of polyetheretherketone (PEEK) in oral implantology and prosthodontics. Journal of prosthodontic research. 60 (1) 12-19.
[11] N. Passia, M. Ghazal, M. Kern. (2016). Long-term retention behaviour of resin matrix attachment systems for overdentures. Journal of the mechanical behavior of biomedical materials. 57 88-94.
[12] E. Conserva, M. Menini, T. Tealdo, M. Bevilacqua, F. Pera, G. Ravera, P. Pera. (2008). Robotic chewing simulator for dental materials testing on a sensor-equipped implant setup. The International Journal of Prosthodontics. 21 (6) 501-508.
[13] W. Singhatanadgit, P. Junkaew, P. Singhatanadgid. (2016). Effect of bidirectional loading on contact and force characteristics under a newly developed masticatory simulator with a dual-direction loading system. Dental Materials Journal. 35 (6) 952-961.
[14] S.D. Heintze, A. Eser, D. Monreal, V. Rousson. (2017). Using a chewing simulator for fatigue testing of metal ceramic crowns. Journal of the mechanical behavior of biomedical materials. 65 770-780.
[15] F. Faul, E. Erdfelder, A. Buchner, A.G. Lang. (2009). Statistical power analyses using G* Power 3.1: Tests for correlation and regression analyses. Behavior research methods. 41 (4) 1149-1160.
[16] M. Alqarni. (2021). Measurement and comparison of retention load values between three implant overdenture attachment systems (Doctoral dissertation, University of British Columbia).
[17] A. Villias, H. Karkazis, S. Yannikakis, A. Theocharopoulos, N. Sykaras, G. Polyzois. (2021). Current status of digital complete dentures technology. Prosthesis. 3 (3) 229-244.
[18] L.G.O. de Vasconcellos, R.S. Nishioka, L.M.R. de Vasconcellos, I. Balducci, A.N. Kojima. (2013). Microstrain Around Dental Implants Supporting Fixed Partial Prostheses Under Axial and Non–Axial Loading Conditions, In Vitro Strain Gauge Analysis. Journal of Craniofacial Surgery. 24 (6) e546-e551.
[19] A. Paras, S. Ma, J.N. Waddell, J.J.E. Choi. (2021). Real-time in vitro measurement of denture-mucosa pressure distribution in a typical edentulous patient with and without implants: Development of a methodology. Journal of the Mechanical Behavior of Biomedical Materials. 119 104531.
[20] Z.C. Zhang, P.L. Li, F.T. Chu, G. Shen. (2019). Influence of the three-dimensional printing technique and printing layer thickness on model accuracy. Journal of Orofacial Orthopedics/Fortschritte der Kieferorthopadie. 80 (4).
[21] M.A. ELsyad, H.M. Errabti, A.Z. Mustafa. (2016). Mandibular denture base deformation with locator and ball attachments of implant-retained overdentures. Journal of Prosthodontics. 25 (8) 656-664.
[22] R. Stegarolu, A. Khraisat, S. Nomura, O. Miyakawa. (2004). Influence of superstructure materials on strain around an implant under 2 loading conditions: a technical investigation. International Journal of Oral & Maxillofacial Implants. 19 (5).
[23] M.A.M. Ahmed, A.M. Hamdy, G.A. Fattah, A.K.A. Effadl. (2022). Prosthetic design and restorative material effect on the biomechanical behavior of dental implants: strain gauge analysis. Brazilian Dental Science. 25 (3).
[24] J.A. Porter Jr, V.C. Petropoulos, J.B. Brunski. (2002). Comparison of Load Distribution for Implant Overdenture Attachments. International Journal of Oral & Maxillofacial Implants. 17 (5).
[25] M.A. ELsyad, M.G. Elsaadawy, A.M. Abdou, A.A. Habib. (2013). Effect of different implant positions on strain developed around four implants supporting a mandibular overdenture with rigid telescopic copings. Quintessence Int. 3 (4) 10.
[26] W. Wang, H. Liu, R. Huang, Y. Zhao, C. Huang, S. Guo, L. Li. (2018). Thermal expansion and magnetostriction measurements at cryogenic temperature using the strain gauge method. Frontiers in Chemistry. 6 72.
[27] D.M. Botega, M.F. Mesquita, G.E.P. Henriques, L.G. Vaz. (2004). Retention force and fatigue strength of overdenture attachment systems. Journal of oral rehabilitation. 31 (9) 884-889.
[28] G. Tehini, N.Z. Baba, A. Berberi, Z. Majzoub, H. Bassal, K. Rifai. (2020). Effect of simulated mastication on the retention of Locator attachments for implant-supported overdentures: an in vitro pilot study. Journal of Prosthodontics. 29 (1) 74-79.
[29] P.K.S. Sia, R. Masri, C.F. Driscoll, E. Romberg. (2017). Effect of locator abutment height on the retentive values of pink locator attachments: An in vitro study. The Journal of prosthetic dentistry. 117 (2) 283-288.
[30] E.A. Fontijn-Tekampl, A.P. Slagter, M.A. Van't Hof, M.E. Geertman, W. Kalk. (1998). Bite forces with mandibular implant-retained overdentures. Journal of dental research. 77 (10) 1832-1839.
[31] S. Takeshita, M. Kanazawa, S. Minakuchi. (2011). Stress analysis of mandibular two-implant

overdenture with different attachment systems. Dental materials journal. 30 (6) 928-934.
[32] W.K. Kleis, P.W. Kämmerer, S. Hartmann, B. Al-Nawas, W. Wagner. (2010). A comparison of three different attachment systems for mandibular two-implant overdentures: One-year report. Clinical implant dentistry and related research. 12 (3) 209-218.
[33] M.R. Heath, J.R. Morris, A.M. Ferman. (2002). Differences in chewing strategies used by edentate people. Journal of Oral Rehabilitation. 29 (9) 876-876.
[34] L. Kong, Y. Sun, K. Hu, D. Li, R. Hou, J. Yang, B. Liu. (2008). Bivariate evaluation of cylinder implant diameter and length: A three-dimensional finite element analysis. Journal of Prosthodontics. 17 (4) 286-293.
[35] M. Friedrichsen, D. Dirksen, C. Runte. (2024). In vitro measurement of the retention force of two stud attachment systems during cyclic load. Journal of Prosthodontics. 33 (2) 164-170.