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RESEARCH AND EDUCATION

Fatigue resistance of simulated single Locator overdenture system

ABSTRACT

Statement of problem. The incidence of single implant overdenture base fracture is increased in the region adjacent to the fulcrum implant.

Purpose. The purpose of this in vitro study was to evaluate the effect of bidirectional woven electrical glass (E-glass) fiber reinforcement on the fatigue resistance of a simulated single Locator-retained overdenture.

Material and method. Test specimens with a centrally positioned metal housing for a Locator stud attachment were fabricated from autopolymerizing acrylic resin. Specimens for the control group were fabricated without glass fiber reinforcement. The 4L group specimens had 4 layers of E-glass fiber weaves and were divided according to fiber location into the following subgroups: 4L-A with 4 fiber layers above the metal housing; 4L-N subgroup with 4 fiber layers adjacent to the metal housing; and 4L-A+4L-N subgroup with 4 fiber layers above and 4 fiber layers adjacent to the housing. Specimens were stored in distilled water for 1 week at 23ºC before cyclic fatigue testing at 10000 cycles by using a staircase approach (n=12).The results were analyzed with 1-way analysis of variance (ANOVA) and Tukey multiple comparisons post hoc analysis (α=.05). A 2-way ANOVA (α=.05) was conducted to detect the effect of fatigue cyclic loading, position of fiber layers, and their interaction on the fatigue resistance.

Results. The results of the investigated compressive fatigue limits (CFL) for the test groups were 190 ±15.9 N for the control group, 265 ±15.9 N for the 4L-A subgroup, 220 ±15.9 N for the 4L-N subgroup, and 275 ±15.9 N for the 4L-A+4L-N subgroup. A non-significant difference was found for creep values among the control group and reinforced subgroups ($P>.05$). The postfatigue flexural strength values in the 4L-A and 4L-A+4L-N subgroups were significantly higher than the control group ($P<.001$) and the 4L-N subgroup ($P=.004$ and $P=.005$). However, there was no significant difference in postfatigue flexural strength between the control group and the 4L-N subgroup ($P=.828$).

Conclusions. Placing 4 layers of bidirectional E-glass fiber weaves above the metal housing can increase the fatigue resistance and the postfatigue flexural strength of single Locator-retained overdentures.

CLINICAL IMPLICATIONS

Fracture around the metal housing has been reported as the main complication in a single implant-retained overdenture. The incorporation of bidirectional E-glass fiber reinforcement within the overdenture base can improve the fatigue resistance of the prosthesis and prevent fracture.

INTRODUCTION

The rehabilitation of the edentulous mandible with a single implant-retained overdenture is a well-accepted treatment with long-term effective outcomes.[1] It can successfully overcome the retention and stability problems related to conventional complete denture.[2,3] Moreover, it has lower treatment costs, more simplified procedures and saves chairside time since parallelism between structures is not an absolute requirement.[4, 5] Several attachment systems with different retention mechanism can be used with implant-retained overdentures. Stud attachments like ball and socket and Locator (Zest Anchors LLC) are commonly used and provide satisfactory retentive and stabilizing features.[6] Because of their shorter height, Locator stud attachments are recommended for patients with limited inter-occlusal space.[7] They also provide a dual retention and a self-aligning feature.[8]

Denture fractures may be caused by fatigue under repeated occlusal loads.[9] Small flexural stresses over time may lead to a significant decrease in the flexural properties of the denture base accompanied by microcracks formation and propagation.[10-15] Therefore, flexural fatigue resistance is a mechanical property which affects the clinical durability of the prosthesis.[16]

Force distribution alters when an implant-retained prosthesis is delivered.[17] Stresses become more concentrated around the attachment system components[18] leading to a high risk of fracture in this area of overdenture base.[19] Fracture has been reported to be a frequent complication associated with single implant overdenture.[20] High occlusal load,[21] rigid bone-implant interface,[22] and reduced thickness of denture base adjacent to the abutment[18] could be the main causes behind the high incidence of fracture. Moreover, the single implant abutment act as a fulcrum around which overdenture rotates under functional forces causing a high stress concentration in the area of the housing that may lead to overdenture base fracture.[23,24] Also, the lack of periodontal ligaments around dental implants could facilitate attachment or denture base fracture leading to implant failure.[19]

The use of glass fibers has been recommended for reinforcing denture base polymers.[25,26] Compared with metal reinforcement, glass fibers have better esthetics and bond chemical to the resin matrix with a silane coupling agent, making them a more durable reinforcement solution.[25-28] In implant-retained overdentures, they can enhance the toughness and flexural fatigue resistance of thin areas around the attachment components which are under high stress.[29-31] Continuous unidirectional fiber, continuous bidirectional fiber weaves, and chopped fiber strands are the commonly used forms for denture base reinforcement.[32,33]

Different factors can affect the strength of the fiber-PMMA (polymethylmethacrylate) composites such as fiber concentration in the polymer matrix,[32] fiber form,[33] orientation,[34] fiber adhesion to the matrix,[35] and the position of fibers.[26,28] Reinforcement placed over the top of the abutment in tooth and implant overdentures has been reported to effectively reduce strain and hence the risk of fracture.[18,19,30] However, inadequate bonding at the interface between the metal housing and denture base resin is a weak point in the prosthetic structure that needs to be considered.[36] Hence, proper locating of the reinforcement is a key factor in managing the mechanical complications of single implant-retained overdentures under heavy functional forces.

Therefore, the purpose of this in vitro study was to evaluate the effect of bidirectional woven electrical glass (E-glass) fiber reinforcement on the fatigue resistance of a simulated single Locator-retained overdenture. The research hypothesis was that the location of reinforcing fiber layers would significantly affect the flexural fatigue resistance of a single Locator-retained overdenture.

MATERIAL AND METHODS

Altogether 48 specimens of a simulated overdenture bases (65 mm long, 5 mm high, and 10 mm wide) fabricated from clear autopolymerizing denture base resin (Palapress; Kulzer GmbH) with metal housing for a Locator stud attachment. The powder/liquid ratio of the autopolymerizing resin was 10 g/7.0 mL. The Locator stud attachments selected for this study consisted of a model analog (4 mm in diameter) and a titanium housing (2.3 mm in height × 5.5 mm in diameter) with a clear inner retention insert (regular retention). (Zest Anchors LLC).

Stick Net (SN) E-glass fiber reinforcement system (Stick Net; GC Corp), a bidirectional silanated E-glass fiber weave preimpregnated with porous PMMA, was used as a reinforcement. The single fiber weave thickness was 0.06 mm, tensile strength 4.78 N/mm (when the fibers are cut in 0/90 degrees angulation), and 46 to 50 g/m2 mass.

Two test groups were designed for the study. The control group was fabricated without reinforcement (n=12). The other group was fabricated by using 4 layers of woven SN fiber as a reinforcement, identified as 4L, and subdivided according to the fiber weaves location into: 4L-A subgroup with 4 SN layers above the metal housing (n=12), 4L-N subgroup with 4 SN layers adjacent to the metal housing (n=12), and 4L-A+4L-N subgroup with 4 SN layers above the metal housing and 4 SN layers adjacent to it (n=12) (Fig. 1A).

The test specimens were fabricated in the same way as explained before in a previous study.[37] For fabricating the control group specimens, the metal housing for the Locator stud attachment was centrally placed in a polyvinyl siloxane laboratory putty mold (*Lab Putty*; Coltène) (5.2×10.2×65.2 mm), then a mixture of acrylic resin was poured to fill the mold. For preparing the fiber reinforced test specimens for the 4L group, SN fiber sheets were cut with scissors into equal layers (60 mm in length × 9 mm in width) and wetted for approximately 10 minutes with a powder-liquid mixture of autopolymerizing acrylic resin (Palapress; Kulzer Gmbh) between 2 plastic sheets. The fibers and resin matrix become nearly transparent when they are fully wetted. To prepare the specimens for 4L-A subgroup, the mold with the housing in the middle was partially filled with a 4-mm layer of acrylic resin, then 4 layers of wetted SN fiber weaves were placed above each other, and finally covered with another layer of acrylic resin mix. To fabricate the 4L-N subgroup specimens, a hole with a diameter less than 5.5 mm was made in the middle of 4 fiber sheets by using an explorer (LM 5-8 Si; LM-DENTAL) to displace the fibers laterally and create a space for placing the metal housing with a degree of friction. The housing and the surrounding wetted fiber layers were then centrally placed together in the mold and covered with a denture base resin mix. To prepare the 4L-A+4L-N subgroup specimens, the procedures for fabricating the subgroup 4L-N specimens were repeated in addition to placing 4 layers of SN fiber weaves above the metal housing and covering them with a layer of acrylic resin.

The specimens were then covered with glass plates and polymerized in distilled water maintained at 55 ±2°C under air pressure of 300 kPa for 15 minutes in a pneumatic polymerizing unit (Ivomat Typ IPR; Ivoclar Vivadent AG). The specimens were wet ground with successively finer grades of silicon carbide abrasive papers from P300 to P1200 (LabPol-21; Stuers A/S) to the predetermined dimensions (5×10×65 mm) and then stored in distilled water at room temperature (23 ±1ºC) for 7 days before testing.

Compressive fatigue limits (CFL) at 10 000 cycles were determined for the test groups according to the staircase approach. The test was performed with a universal testing machine (Model LRX; Lloyds Instruments Ltd) at a crosshead speed of 60 mm/min and a frequency of 0.5 HZ in a water bath at 37ºC. An implant analog was used for load application at the Locator metal housing (Fig. 1B). In this ‘up and down” method, specimens were sequentially tested so that the first specimen was tested at the initial stress level detected from preliminary data. The stress level for the next specimen was increased or decreased according to the survival or the failure of the first specimen. The magnitude of load by which the level was changed was 30 N.

Data analysis was based on the failure versus nonfailure events. The CFL and its standard deviation S[38-40] were calculated according to the following equations:

CFL= Xo+d (A/N±½)

S= 0.53.d

Where CFL is the compressive fatigue limit, Xo is the lowest load level at which failure occurs, d is the fixed load increment (30 N) used in the sequential test, and S is the standard deviation. A, N, and B are explained in Table 1.[38-40] The specimens which survived the 10 000 cycles, were then statically loaded to evaluate the flexural strength after fatigue testing, named here as postfatigue flexural strength (PFFS). A 95% confidence interval analysis was conducted for the CFL values of tested groups. Also creep values were collected from the test machine and analyzed.

After fatigue and postfatigue testing procedures, visual examination of the specimens was carried out to detect failure modes. Failure modes were classified as either the fracture path was arrested at fibers or the test specimen was fractured into 2 pieces.

The fracture surfaces of representative specimens were evaluated with a scanning electron microscope (SEM) (JSM 5500; Jeol Ltd). The selected specimens were ground wet (LabPol-21; Stuers A/S) with silicon carbide papers of decreasing abrasiveness (1000-, 1200-, 4000-grit) and then gold sputter coated before the SEM examination.

Statistical analysis of the PFFS and creep values for the test groups was carried out with 1-way analysis of variance (ANOVA) followed by Tukey multiple comparisons post hoc analysis (α=.05).The previous analyses were also used to compare the PFFS values of the tested specimens with the static flexural strength values of similar specimens previously tested under static dry loading conditions without exposure to cyclic loading before static testing.[37] They were named as controlx group and 4Lx group with 3 subgroups 4L-Ax, 4L-Nx and 4L-Ax+4L-Nx. A 2-way ANOVA (α=.05) was conducted to detect the effect of fatigue cyclic loading, position of fiber layers, and their interaction on the flexural strength. All analyses were conducted with statistical software (IBM SPSS Statistics v21; IBM Corp).

RESULTS

The results of the investigated CFL were 190 ±15.9 N for the control group, 265 ±15.9 N for the 4L-A subgroup, 220 ±15.9 N for the 4L-N subgroup and 275 ±15.9 N for the 4L-A+4L-N subgroup. The 95% confidence interval values showed an overlap between the 4L-A and 4L-A+4L-N subgroups which mean that they are statistically similar. All the others are statistically different at P<.05 as shown in in Table 2.

The PFFS and creep values of the tested groups are presented in Table 3. The 1-way ANOVA revealed a statistically significant difference on the PFFS values (P<.001) and a non-significant differences in creep values among the control group and reinforced subgroups (P>.005). The post hoc Tukey HSD test indicated a significantly higher PFFS values in the 4L-A and 4L-A+4L-N subgroups when compared with the control group (P<.001) and with the 4L-N subgroup (P=.004 and P=.005). Also, there was no significant difference in the PFFS values between the control group and the 4L-N subgroup (P=.828) and between the 4L-A and 4L-A+4L-N subgroups (P>.05).

When comparing the flexural strength values with and without 10 000 cycles among the groups with 1-way ANOVA, a statistically significant difference (P<.001) was found. The post hoc Tukey HSD test showed that all the uncycled specimens had a significantly higher flexural strength values than those exposed to cyclic loading before static testing (*P*<.001) as shown in Table 3.

The 2-way ANOVA showed that cyclic loading and fiber position both significantly affected the flexural strength (*P*<.001). However, the interaction between the 2 factors was not significant (*P*=.467).

The fracture modes are presented in Table 4. Visual examination revealed that all the specimens of the control group fractured into 2 pieces (Fig. 2). In group 4L, all the specimens for subgroup 4L-A fractured into 2 pieces (Fig. 3A). However, in subgroups 4L-N and 4L-A+4L-N the fracture was arrested at the fiber layers placed adjacent to the metal for all of the test specimens (Fig. 3B,C).

DISCUSSION

The results of the study confirmed the hypothesis that the location of reinforcing fiber layers significantly affects the flexural fatigue resistance of a single Locator-retained overdenture. Implant-retained overdentures are exposed to fatigue stress in everyday use. Previous studies have proven that correct placement of sufficient amount of well impregnated glass fiber reinforcements can significantly increase the fracture load values and interrupt fracture propagation within the denture base.[18,31] Moreover, it is recommended to locate the fiber reinforcement in the exact places associated with the highest tensile stresses.[15] High tensile stresses were recorded on the top surface and next to the abutments for single[41] and two[24] implant-retained overdenture. From the mechanical point of view, attachment systems place particular stresses on the overdenture base. Also, they transmit functional forces to the implant increasing the risk of complications.[19,23]

One characteristic feature of unsplinted Locator stud attachments is stress breaking, which has been reported to reduce lateral forces and implant loading. However, such resiliency was found to be associated with tensile deformation in the denture base area around attachments.[42] This deformations may not only lead to denture base fracture but can also transmit compressive stresses to the bone causing ridge resorption.[43]

Our study showed that the fiber position significantly affected postfatigue flexural strength values. Placing 4 layers of bidirectional woven E-glass fiber weaves as reinforcement only above or both above and adjacent to the metal housing resulted in the highest significant increase in cyclic fatigue limits and PFFS values as seen in subgroups 4L-A and 4L-A+4L-N, however both subgroups were not significant to each other. Placing the fibers closer to the side of tensile stresses was proven to be more effective in reinforcing the denture base resin against repeated bending than fiber reinforcement placed on the side of compression stresses.[15] Takahashi et al[19] reported that reinforcement of an implant overdenture on the top of copings can effectively decrease the denture base strains and stress transmission to the underlying implants and tissues. Gonda et al[18] also found that reinforcing the denture base above the copings resulted in reduction of strain values on mandibular telescopic overdentures. Metal reinforcement inserted in single implant overdenture bases can also provide better stress distribution throughout the whole prosthesis instead of concentrating it around the implant housing. Also, it reduced the tensile stresses around the housing portion of the implant by 61.8%.[41]

Placing the SN fiber reinforcement next to the Locator attachment significantly increased the CFL but did not increase significantly PFFS values. However, it showed a success in inhibiting the crack propagation and lead to only partial fracture of the test specimens (Fig. 3B). A previous study[19] showed that strains and deformation of denture base around the implant copings were not significantly reduced by fiber reinforcement placed on the sides of implant coping. Accordingly, as the deformation was reduced to a certain limit, it may be used in situations with insufficient space between the abutment and denture teeth. A similar finding was detected by Rached et al[31] that the strengthening capacity of fibers placed on the compression side of implant-supported overdenture simulating model was less than that of fibers placed at the middle section of the specimen.

The non-significant decrease in creep values may be due to the low fiber volume of SN fibers. This low fiber volume may not efficiently increase the fracture modulus (Y) which is directly proportional to the fiber concentration resulting in transmitting stresses to the adjacent denture base material.[29,41]

The 2-way ANOVA showed that cyclic loading and fiber position both significantly affect flexural strength (P<.001). However, the interaction between the 2 factors was not significant (P=.467). Hence, comparing the flexural strength values of cycled and uncycled specimens showed that the flexural strength was significantly affected by the fatigue cycling. A similar effect was reported in a previous study of denture base resin flexural and fatigue strength.[44] Another cause for low flexural strength values of the cycled specimens might have been the water saturation of fibers.[45] However, denture base polymers with properly silanated glass fibers do not weaken in water even over several years.[46]

Heat formation could affect the results of fatigue testing. To avoid that effect in our study, the frequency of loading the specimens was low (0.5 Hz), and the test specimens were immersed in water during testing.[15]

The in vitro model used in this study may not be an exact simulation of the failure modes and clinical stress conditions. The number of fatigue cycles might also have been low as a previous study showed that 10 000 fatigue cycles has a little impact on the flexural strength of some tested materials.[44]

CONCLUSIONS

Within the limitation of this in vitro study, the following can be concluded:

1. Placing 4 layers of bidirectional E-glass fiber weaves above the metal housing can increase the fatigue resistance and the postfatigue flexural strength of single Locator-retained overdentures.
2. Placing fibers adjacent to the metal housing doesn't reinforce the samples significantly after cyclic loading.
3. Placing the fiber reinforcement adjacent to the metal housing does not improve significantly the flexural strength of samples already reinforced with fibers above the metal housing.

REFERENCES

1. Nogueira TE, Aguiar FMO, de Barcelos BA, Leles CR. A 2-year prospective study of single-implant mandibular overdentures: Patient-reported outcomes and prosthodontic events. Clin Oral Implants Res 2018; 29:541-550.

2. Nogueira TE, Aguiar FMO, Esfandiari S, Leles CR. Effectiveness of immediately loaded single-implant mandibular overdentures versus mandibular complete dentures: A 1-year follow-up of a randomized clinical trial. J Dent 2018;77:43-50.

3. Burns DR, Unger JW, Coffey JP, Waldrop TC, Elswick RK. Randomized, prospective, clinical evaluation of prosthodontic modalities for mandibular implant overdenture treatment. J Prosthet Dent 2011;106:12-22.

4. Alsabeeha NHM, Payne AGT, De Silva RK, Thomson WM. Mandibular single-implant overdentures: Preliminary results of a randomised-control trial on early loading with different implant diameters and attachment systems. Clin Oral Implants Res 2011;22:330-7.

5. Amaral CF do, Pinheiro MA, Rodrigues Garcia RCM. Reinforcement of single implant-retained mandibular overdenture with a cobalt-chromium framework before implant surgery. J Prosthodont 2017. https://doi.org/10.1111/jopr.12732

6. Yunus N, Masood M, Saub R, Al-Hashedi AA, Taiyeb Ali TB, Thomason JM. Impact of mandibular implant prostheses on the oral health-related quality of life in partially and completely edentulous patients. Clin Oral Implants Res 2016;27:904-9.

7. Pasciuta M, Grossmann Y, Finger IM. A prosthetic solution to restoring the edentulous mandible with limited interarch space using an implant-tissue-supported overdenture: a clinical report. J Prosthet Dent 2005;93:116-20.

8. Evtimovska E, Masri R, Driscoll CF, Romberg E. The change in retentive values of locator attachments and hader clips over time. J Prosthodont 2009;18:479-83.

9. Im SM, Huh YH, Cho LR, Park CJ. Comparison of the fracture resistances of glass fiber mesh- and metal mesh-reinforced maxillary complete denture under dynamic fatigue loading. J Adv Prosthodont 2017; 9: 22-30.

10. Vallittu PK, Lassila VP, Lappalainen R. Evaluation of damage to removable dentures in two cities in Finland. Acta Odontol Scand 1993;51:363-9.

11. Vallittu PK. Fracture surface characteristics of damaged acrylic-resin-based dentures as analysed by SEM-replica technique. J Oral Rehabil 1996;23:524-9.

12. Kostoulas I, Kavoura VT, Frangou MJ, Polyzois GL. Fracture force, deflection, and toughness of acrylic denture repairs involving glass fiber reinforcement. J Prosthodont 2008;17:257-6.

13. Gurbuz O1, Dikbas I, Unalan F. Fatigue resistance of acrylic resin denture base material reinforced with E-glass fibres. Gerodontology 2012;29:710-4.

14. Narva KK, Vallittu PK, Helenius H, Yli-Urpo A. Clinical survey of acrylic resin removable denture repairs with glass-fiber reinforcement. Int J Prosthodont 2001;14:219-24.

15. Narva KK, Lassila LV, Vallittu PK. Flexural fatigue of denture base polymer with fiber-reinforced composite reinforcement. Dent Mater 2005;36:1275-81.

16. Banerjee R, Banerjee S, Prabhudesai P S, Bhide S V. Influence of the processing technique on the flexural fatigue strength of denture base resins: An in vitro investigation. Indian J Dent Res 2010;21:391-5.

17. Fontijn-Tekamp FA, Slagter AP, Van Der Bilt A, Van 'T Hof MA, Witter DJ, Kalk W, et al. Biting and chewing in overdentures, full dentures, and natural dentitions. J Dent Res 2000;79:1519-24.

18. Gonda T, Ikebe K, Dong J, Nokubi T. Effect of reinforcement on overdenture strain. J Dent Res 2007; 86:667-71.

19. Takahashi T, Gonda T, Maeda Y. Influence of reinforcement on strains within maxillary implant overdentures. Int J Oral Maxillofac Implants 2015;30:1327-32.

20. Passia N, Kern M. The single midline implant in the edentulous mandible: A systematic review. Clin Oral Investig 2014;18:1719-24.

21. Chee W, Jivraj S. Failures in implant dentistry. Br Dent J 2007;202:123-9.

22. Lahoti K, Pathrabe A, Gade J. Stress analysis at bone-implant interface of single- and two-implant-retained mandibular overdenture using three-dimensional finite element analysis. Indian J Dent Res 2016;27:597-601.

23. ELsyad MA, Errabti HM, Mustafa AZ. Mandibular denture base deformation with locator and ball attachments of implant-retained overdentures. J Prosthodont 2016;25:656-64.

24. Elsyad MA, El-Waseef FA, Al-Mahdy YF, Fouad MM. A comparison of mandibular denture base deformation with different impression techniques for implant overdentures. Clin Oral Implants Res 2013;24:127-33.

25. Vallittu PK. Flexural properties of acrylic resin polymers reinforced with unidirectional and woven glass fibers. J Prosthet Dent 1999;81:318-26.

26. Narva KK, Lassila LV, Vallittu PK. The static strength and modulus of fiber reinforced denture base polymer. Dent Mater 2005;21:421-8.

27. Vallittu PK, Narva K. Impact strength of a modified continuous glass fiber--poly(methyl methacrylate). Int J Prosthodont 1997;10:142-8.

28. Agha H, Flinton R, Vaidyanathan T. Optimization of fracture resistance and stiffness of heat-polymerized high impact acrylic resin with localized E-Glass FiBER FORCE reinforcement at different stress points. J Prosthodont 2016;25:647-55.

29. Dyer SR, Lassila LVJ, Jokinen M, Vallittu PK. Effect of cross-sectional design on the modulus of elasticity and toughness of fiber-reinforced composite materials. J Prosthet Dent 2005;94:219-26.

30. Fajardo RS, Pruitt LA, Finzen FC, Marshall GW, Singh S, Singh S, et al. The effect of E-glass fibers and acrylic resin thickness on fracture load in a simulated implant-supported overdenture prosthesis. J Prosthet Dent 2011;106:373-7.

31. Rached RN, de Souza EM, Dyer SR, Ferracane JL. Dynamic and static strength of an implant-supported overdenture model reinforced with metal and nonmetal strengtheners. J Prosthet Dent 2011;106:297-304.

32. Yu SH, Cho HW, Oh S, Bae JM. Effects of glass fiber mesh with different fiber content and structures on the compressive properties of complete dentures. J Prosthet Dent 2015;113:636-44.

33. Rahamneh A, Jagger DC, Harrison A. The effect of the addition of different fibres on the transverse and impact strength of acrylic resin denture base material. Eur J Prosthodont Restor Dent 2003;11:75-81.

34. Callister WD, Rethwisch DG. Materials science and engineering. 5th ed. New York: John Wiley & Sons Ltd; 2015. p. 634-6.

35. Vallittu PK. An overview of development and status of fiber-reinforced composites as dental and medical biomaterials. Acta Biomater Odontol Scand 2018;4:44-55.

36. Ozkir SE, Yilmaz B. Effect of different housing retaining materials on the flexural strength of an acrylic resin overdenture base. J Prosthet Dent 2017;118:500-3.

37. Gibreel M, Lassila LV, Närhi TO, Perea L, Vallittu PK. Load-bearing capacity of simulated Locator overdenture system. J Prosthet Dent 2018;120:558-564.

38. Pollak R, Palazotto A, Nicholas T. A simulation-based investigation of the staircase method for fatigue strength testing. Mechmat 2006;38:1170-1181.

39. Ornaghi BP, Meier MM, Lohbauer U, Braga RR. Fracture toughness and cyclic fatigue resistance of resin composites with different filler size distributions. Dent Mater 2014;30:742-51.

40. Bijelic-Donova J, Garoushi S, Vallittu PK, Lassila LV. Mechanical properties, fracture resistance, and fatigue limits of short fiber reinforced dental composite resin. J Prosthet Dent 2016;115:95-102.

41. Amaral CF, Gomes RS, Rodrigues Garcia RCM, Del Bel Cury AA. Stress distribution of single-implant-retained overdenture reinforced with a framework: A finite element analysis study. J Prosthet Dent 2018;119:791-6.

42. Takahashi T, Gonda T, Tomita A, Maeda Y. Effect of attachment type on denture strain in maxillary implant overdentures: Part 1. Overdenture with palate. Int J Oral Maxillofac Implants 2017;32:815-21.

43. Alsrouji MS, Ahmad R, Abdul Razak NH, Shuib S, Kuntjoro W, Baba NZ. Premaxilla stress distribution and bone resorption induced by implant overdenture and conventional denture. J Prosthodont 2018. https://doi.org/10.1111/jopr.12954

44. Diaz-Arnold AM, Vargas MA, Shaull KL, Laffoon JE, Qian F. Flexural and fatigue strengths of denture base resin. J Prosthet Dent 2008;100:47-51.

45. Arikan A1, Ozkan YK, Arda T, Akalin B. Effect of 180 days of water storage on the transverse strength of acetal resin denture base material. J Prosthodont 2010;19:47-51.

46. Vallittu PK. Effect of 180-week water storage on the flexural properties of E-glass and silica fiber acrylic resin composite. Int J Prosthodont 2000;13:334-9.

TABLES

Table 1. Method for analyzing staircase test data

Control Group				
Load (L)	**Stress level(I)**	**Failures (N) N=Σ ni**	**A=Σ i.ni i.ni**	***B =Σ i^2.ni i^2.ni***
130	0	0	0	0
160	1	3	3	3
190	2	3	6	12
		N= 6	**A= 9**	**B= 15**

4L-A Subgroup				
Load(L)	**Stress level(I)**	**Failures (N) N=Σ ni**	**A=Σ i.ni i.ni**	***B =Σ i^2.ni i^2.ni***
200	0	0	0	0
230	1	2	2	2
260	2	4	8	16
		N= 6	**A= 10**	**B= 18**

4L-N Subgroup				
Load (L)	**Stress level(I)**	**Failures (N) N=Σ ni**	**A=Σ i.ni i.ni**	***B =Σ i^2.ni i^2.ni***
170	0	0	0	0
200	1	5	5	5
230	2	1	2	4
		N= 6	**A= 7**	**B= 9**

4L-A+4L-N Subgroup				
Load (L)	**Stress level(I)**	**Failures (N) N=Σ ni**	**A=Σ i.ni i.ni**	***B =Σ i^2.ni i^2.ni***
220	0	0	0	0
250	1	4	4	4
280	2	2	4	8
		N= 6	**A= 8**	**B= 12**

Table 2. Cyclic fatigue limit (CFL) values in Newton (N) of tested groups at 95 % confidence intervals

Group	**Subgroup**	**CFL**	**Standard deviation (SD)**	**Standard error (SE)**	**T-value**	**Confidence interval (CI)**	**Lower limit**	**Upper limit**
Control	-	190	15.9	4.59	2.20	10.09	179.91	200.09
4L	4L-A	265	15.9	4.59	2.20	10.09	254.91	275.09
	4L-N	220	15.9	4.59	2.20	10.09	209.91	230.09
	4L-A+4L-N	275	15.9	4.59	2.20	10.09	264.91	285.09

Table 3. Mean flexural strength FS and creep values of tested groups

Test condition	**After 10^4 cycles**				**Without 10^4 cycles**				**one-way ANOVA**
Group	Control	4L (4 layers SN fiber)			Control x	4Lx (4 layers SN fiber)			
Subgroup	-	4L-A (4 layers SN fiber above metal housing)	4L-N (4 layers SN fiber adjacent to metal housing)	4L-A+4L-N N (4 layers SN fiber above metal housing and 4 layers SN fiber adjacent to metal housing)	-	4L-Ax (4 layers SN fiber above metal housing)	4L-Nx (4 layers SN fiber adjacent to metal housing)	4L-A+4L-Nx (4 layers SN fiber above metal housing and 4 layers SN fiber adjacent to metal housing)	
FS (MPa) Mean ±SD	53 ±8[a]	74 ±15[b]	57 ±5[a]	74 ±12[b]	92.4 ±13.9[c]	116 ±7.3[d]	106 ±11.7[dc]	117 ±6[d]	0.000
Creep (mm) Mean ±SD	0.7 ±0.1	0.7 ±0.2	0.8 ±0.1	0.8 ±0.2	-	-	-	-	0.192

SD, standard deviation

P<.05 significant

Same superscripted lowercase letters indicate groups not statistically significantly different when compared by Tukey multiple comparisons post hoc analysis (*P*>.05).

Table 4. Fracture mode of test specimens for investigated groups

Group	Subgroup	fracture behavior			
		Fracture arrested at fibers		**specimen fractured in to 2 pieces**	
		postfatigue static loading	**cyclic loading**	**postfatigue static loading**	**cyclic loading**
Control	--	--	--	6/12	6/12
4L (4 layers of SN fibers)	4L-A	--	--	6/12	6/12
	4L-N	6/12	6/12	--	--
	4L-A+4L-N	6/12	6/12	--	--

FIGURES

Figure 1. A, Fiber position (red line) within specimens a. above metal housing (4L-A), b. adjacent to metal housing (4L-N), and c. above and adjacent to metal housing (4L-A+4L-N). B, Flexural fatigue test set up in water.

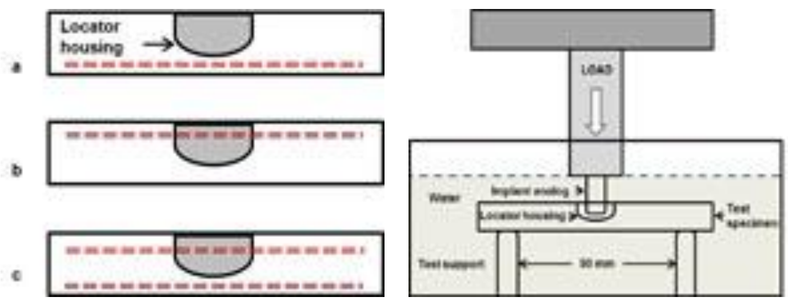

Figure 2. Fractured specimen of control group (top view).

Figure 3. SEM micrograph of the fracture path for 4L group and schematic drawing demonstrating fiber position (red and green arrows) within specimen A. Subgroup 4L-A with SN fiber above metal housing (red arrow), B. subgroup 4L-N with SN fiber adjacent to metal housing (green arrow), and C. Subgroup 4L-A+4L-N with SN fiber above metal housing (red arrow) and SN fiber adjacent to metal housing (green arrow).