Moftah et al., Yemeni J Med Sci 2017; 11: 31–37.
https://doi.org/10.20428/YJMS.11.1.A5

ORIGINAL ARTICLE OPEN ACCESS

Fracture Strength of Acrylic Resin Reinforced with Glass Fibers in Simulated Implant-Supported Overdenture Abutments

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ABSTRACT

Objective: To evaluate the effect of glass fibers on acrylic resin fracture strength in simulated implant-supported overdenture (IOD) abutments.

Methods: A model was designed to simulate the clinical situation of an IDO (50×12×1.5 mm). Thirty models were divided into three equal groups: ten models not supported with glass fibers (control group), ten models with one layer of glass fibers (experimental group I) and ten models with two layers of glass fiber (experimental group II). All models were exposed to a three-point bending test, and fracture loads were analyzed using a one-way analysis of variance (ANOVA) followed by Bonferroni post-hoc test.

Results: IOD models reinforced with two layers of glass fibers (experimental group II) showed a mean ultimate load at fracture of 48.69 ± 3.71 Newton (N) compared to mean loads of 32.78 ± 2.41 N and 24.42 ± 2.73 N for the models reinforced with one layer (experimental group I) and non-reinforced with glass fibers (control group), respectively. ANOVA showed a statistically significant difference between the three groups regarding the mean ultimate load at fracture, and Bonferroni post-hoc test showed statistically significant differences between both experimental groups and the control group as well as between experimental group I and experimental group II.

Conclusions: The fracture strength of IDO abutments increases significantly by the addition of acrylic resin pre-impregnated with glass fibers, even when the thickness of acrylic is thin.

Keywords: Acrylic resin, Fracture strength, Glass fiber, Implant-supported overdenture

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1. Introduction

An overdenture is a removable dental prosthesis that covers and rests on one or more remaining natural teeth, their roots and/or dental implants (1). Research on the methods of dental support that stabilize the denture is dated back to 1856, when Ledger (2) proposed the use of natural teeth to anchor a removable denture. Since then, several modifications have been introduced into traditional complete denture designs to confer them additional support and stability (3). Moreover, Mericske-Stern et al. (4) proved the effectiveness of implant-supported overdentures (IODs) as an alternative to conventional dentures (CDs). In addition, roots under the denture base were found to preserve the alveolar ridge, provide sensory feedback and stabilize the dentures (4).

Morais et al. (5) reported that IODs have been more popular for edentulous patients because of their maladaptation to complete CDs. Despite the difference between the biologic basis of implants installed in the bone and the roots surrounded by a periodontal membrane, the prosthetic concept is similar. Lack of periodontal proprioceptors reduces the tactile sensation caused by dental implants. The main advantages of IODs include decreased residual ridge resorption, improved psychologic status of the patient and maintained masticatory efficiency (5). Moreover, IODs tend to be more successful compared to root-supported overdentures (6).

On the other hand, CDs are no longer recommended as the first choice for edentulous subjects because of their reduced retention and stability, difficulty in speaking and chewing, accelerated residual ridge resorption and psychologic effect on the elderly subjects. The two-IOD has been suggested as the standard method for edentulous mandibles (7). Although IOD improves the masticatory efficiency of edentulous patients (8), several complications still occur. These include surgical complications, implant or bone loss, peri-implant soft tissue problems, mechanical issues and esthetic/phonetic complications (9).

Mechanical complications include fracture of prosthesis framework, which may occur as a result of an increase in biomechanical forces (10). Moreover, fracture of denture bases tends to occur more frequently around abutments due to insufficient thickness of acrylic resin resulting from attachment thickness (11). Despite the annual global cost of repairing fractured dentures, repaired dentures are not so strong or functional as intact ones (12). Therefore, several methods have been suggested to strengthen the denture base material, including the chemical modification by copolymerization with rubber graft copolymer or adding cross-linking agents or fibers (13). However, each method has its disadvantages; for example, high-impact strength resin has poor flexural strength compared to conventional acrylic resins (14). On the other hand, metal and glass fibers exhibit different mechanical properties, high elasticity and lack of resilience (15). Fibers have been demonstrated to be more effective than metal glass, where their lower modulus of elasticity compared to metals provides more favorable stress distribution pattern (15).

The physical and mechanical properties of acrylic resins have been improved by reinforcing them with several types of fibers such as carbon fibers, which increase flexural and impact strength, prevent fatigue fracture and increase fatigue resistance. However, these fibers have an undesirable dark color (16). Aramid fibers are resistant to chemicals, have a high thermal and mechanical stability and increase the impact strength (16, 17), but these are also unaesthetic and their use is limited to certain intraoral applications (16). Although they need a long time for preparation (18, 19), polyethylene fibers increase the flexural and impact strength, modulus of elasticity and are almost invisible in the acrylic denture base (16). Nylon fibers are polyamide fibers that are resistant to shock and repeated stress. However, their mechanical properties are affected by water absorption (16).

Reinforcement of acrylic resin with glass fibers results in good adhesion to dental fibers, with good aesthetic results and acceptable cost. Compared to metal, glass fibers are light, easy-to-prepare and nontoxic, leading to their widespread use (20). These fibers are available in three forms: continuous parallel, chopped and woven (16, 21) and have been introduced as a substitute for metals when high mechanical stresses are expected (22). Several factors influence the effectiveness of fiber reinforcement, including the quantity of fibers, their length, direction, form, position, adhesion to the polymer matrix, impregnation with the resin and type of resin (15). The greater the quantity of fibers, the greater the reinforcement effect that can be gained. If the fibers are located in the prosthesis tensile stress zone, compressive stresses may develop during compression at occlusal contact points and tensile stresses may develop on the opposite side next to the alveolar ridges, where a neutral stress zone results between these two stresses (23, 24).

Because the use of IOD improves the patients' quality of life, the way to overcome the fracture of acrylic overdentures in the area covering their abutments was the research problem of the present study. Therefore, it aimed to evaluate the effect of reinforcing the acrylic resin with glass fibers on the fracture strength around a simulated IOD abutment.

2. Methods

2.1. Study design and models

Thirty models (50-mm long × 12-mm wide × 1.5-mm thick) (22, 25) were fabricated with Vertex TM Modelling Wax Hard(Vertex-Dental, Zeist, The Netherlands), and square pieces were fabricated with base plate wax (12 mm long × 4 mm thick) and placed in the center of the models while being warm. Metal cylinders of 4 mm diameter and 15 mm length were placed over the models for 4 mm depth to create an in vitro model simulating the clinical situation observed with IOD. The ISO 2008 standard was modified to simulate the clinical situation of acrylic resin denture over an implant assembly (22, 23, 26, 27).

The wax of the models was then isolated with Renfert® Picosep (Alphabond Dental, Hilzingen, Germany) before their placement into Elite® dental stones (Zhermack SpA, Badia Polesine, Italy), which filled the lower half of the denture flask. Then, a half of the wax models were coated with the stone, and the metal cylinder was in the top half of the flask. After the stone had set, the exposed stone was coated with a separating fluid (Ivoclar Vivadent, Schaan, Liechtenstein). Then, the upper half of the flask was filled with the dental stone and allowed to set for three hours. After submerging the flasks in boiling water for five minutes, the wax was brushed manually with a detergent solution and rinsed with clean boiling water. The exposed stone surfaces were then recoated with the separating fluid.

Woven glass fibers (Vectris®, Ivoclar Vivadent AG, Liechtenstein) were cut into pieces of 50-mm length and 10-mm width according to the manufacturer's instructions. These pieces were then cured by a light curing device (Megadenta, Dentalprodukte, Germany). Thereafter, a 0.5-mm-thick polymethyl methacrylate (PMMA) strip was compressed on the lower half of the flask, and one or two layers of glass fibers were placed over the PMMA of the models of experimental groups I and II (ten models each), respectively. However, the ten models of the Control Group were left without glass fibers. Then, an additional amount of PMMA was added to the desired thickness (1.5 mm).

Heat polymerized denture base RESPAL NF resin (Salmoiraghi Produzione Dentaria S.R.L., Mulazzano, Italy) was used to pack the flasks according to the manufacturer's instructions. After that, the flasks were closed with a hydraulic pressure of up to 1500 psi. Excess acrylic was then removed and reclosed with a hydraulic pressure of up to 3500 psi. Flasks were processed in water bath at 63-75oC and 100oC for 1.5 hours and half an hour, respectively, and were then allowed to cool at room temperature for four hours. Finally, the models were finished, polished and stored in water at room temperature for 50 hours according to standard procedures (23, 26, 27).

2.2. Fracture strength testing

The models were subjected to three-point bending test in a universal testing machine (Instron®, Canton, Massachusetts, USA) at a cross-head speed of 2 mm/min. (23). The models were supported at two points 44 mm apart as shown in Figure (1), and the load was applied on the simulated abutment. Because the standard flexure strength method could not be applied as a result of the irregular geometry of the models, the ultimate loads at fracture in Newton (N) were used as the outcome measure (22).

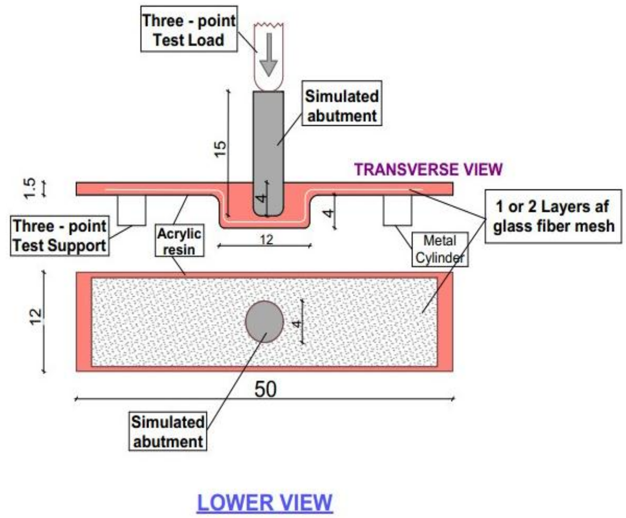

Figure 1. A schematic model of specimens. All dimensions are in millimeters.

2.3. Statistical analysis

Data were analyzed using the Statistical Packages for Social Sciences (SPSS) software, version 20.0 (IBM Corp., New York, USA). The normality of outcome distribution was checked using Kolmogorov-Smirnov, and differences in load fractures were then analyzed using one-way analysis of variance (ANOVA) followed by Bonferroni post-hoc pairwise comparisons. Differences were considered statistically significant at *P*-values <0.05.

3. Results

3.1. Fracture strength of the simulated IOD models reinforced with glass fibers

Table (1) shows that the group reinforced with two layers of glass fibers (experimental group II) had a mean ultimate load at fracture of 48.69 ± 3.71 N compared to mean loads of 32.78 ± 2.41 N and 24.42 ± 2.73 N for the models reinforced with one layer (experimental group I) and non-reinforced with glass fibers (control group), respectively. ANOVA showed a statistically significant difference among the three groups regarding the mean ultimate load at fracture.

Table 1. Fracture strength of the simulated IOD models reinforced with glass fibers as indicated by the ultimate load at fracture

Group	Ultimate load at fracture (N)			F statistic	*P*-value
	Mean ± SD	Minimum	Maximum		
Control	24.42 ± 2.73	18.51	28.64	168.934	<0.001
Experimental I	32.78 ± 2.41	29.32	40.41		
Experimental II	48.69 ± 3.71	36.45	52.71		

IOD, Implant-supported overdenture; N, Newton; SD, standard deviation

Bonferroni post-hoc test showed statistically significant differences between both experimental groups and the control group as well as between experimental group I and experimental group II (Table 2).

Table 2. Bonferroni pairwise comparisons among the control and experimental groups regarding the ultimate load at fracture

Number of layers (I)	Number of layers (J)	Mean difference (I-J)*	SE	*P*-value
Control group	Experimental group I	-8.35	1.34	< 0.001
	Experimental group II	-24.26	1.34	< 0.001
Experimental group 1	Experimental group II	-15.91	1.34	< 0.001

SE, Standard error; *, The negative sign of the mean difference indicates that the value of the mean ultimate load of the control group was less than that of each reinforced group.

4. Discussion

The present study tested the fracture strength of two types of simulated models reinforced with one or two layers of glass fibers in comparison to a non-reinforced model. The thickness of the conventional denture base ranged from 1to 4 mm, while the thickness of the models was 1.5mm (28). Furthermore, the abutments of the overdentures were covered with at least 2-mm layer of acrylic resin to prevent complications (29). The thickness of the study models was adopted as reported in a previous study (22), considering that the remaining distance for the acrylic due to the implant components is less than 2 mm was due to the implant components.

Glass fibers are preferred for reinforcement of IODs due to their unique characteristics in comparison to other types of fibers, including their aesthetic appearance, good mechanical characteristics and biocompatibility (20). The acrylic resin impregnated with fibers provides a better reinforcement than non-reinforced ones. Clinically, readymade pre-impregnated fibers are more efficient and have less technical problems (30). Therefore, pre-impregnated fibers had been chosen. Moreover, woven glass fibers were used because of their easier processing and shearing in comparison to the continuous parallel ones (28, 29). These fibers had been positioned in the tensile stress zone, which is in the lower third of the models and on the side opposite to the applied force due to the effect of their position on the results, where glass fibers must be placed in the area upon which greater tension can be applied (23). As a role, the fibers must be perpendicular to the applied forces to produce the best resistance (29, 31).

The present study showed that adding glass fibers to the acrylic resin in simulated IOD abutments had resulted in a significant increase in the fracture strength. This finding is in agreement with those reported in previous studies (32–34). In contrast, it disagrees with that by

Uzun et al. (35), who found no effect on the fracture strength of acrylic resin reinforced with glass fibers. This might be due to the position of fibers in the center of models in their samples, while the fibers were positioned in the tensile stress zone in the present study. In addition, the present study is inconsistent with that conducted by Minami et al. (36), who found no improvement in the fracture strength during their study of the repairing of heat-polymerized acrylic by reinforced self-polymerized acrylic with glass fibers. However, Fonseca et al. (15) reported that there was an improvement in the fracture strength by adding glass fibers, whether in heat- or self-polymerized acrylic. The disagreement between the results of the present study and those reported by Minami et al. (36) could be attributed to the difference in the position of fibers in the center of models in the former study.

The present study showed that the number of glass fiber layers affects the fracture strength. Therefore, the higher the number of fiber layers added in the tensile stress zone, the more the fracture strength of the IOD. This is in line with the findings by Dyer et al. (37) and Agha et al. (38) regarding the quantity of fibers added to the tensile stress zone of prostheses. However, it disagrees with the finding by Kanie et al. (23), who found that the increase in the number of fiber layers does not increase the fracture strength. This might be due to the distribution of fibers in the center and sides of the models of their study, while the fibers were distributed in the tensile stress zone in the present study.

The present study is limited by the fact that the tested in vitro model may not duplicate the stress environment seen clinically. Because the acrylic resin fracture of IOD occurs by an accumulative effect in clinical situations, acyclic loading may provide additional valuable data (39).

5. Conclusions

Fracture strength of acrylic resins in the tensile stress zones of IODs can be increased by the addition of pre-impregnated woven glass fibers. Moreover, it can be further improved by using two glass fiber layers. Further studies mimicking the oral condition are recommended to represent the clinical scenario.

Acknowledgments

The authors thank the staff of the Prosthodontics Department at the faculties of Dentistry of Hama and Damascus universities as well as the staff of Mechanical Engineering Department at Damascus University, who helped them during the study.

Authors' contributions

HMM designed the study, performed experiments, interpreted data and wrote the initial draft. IT and KD supervised the work and helped in editing the manuscript. All authors read and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests associated with this article.

Ethical approval

Not required.

References

1. Anonymous. The glossary of prosthodontic terms. J Prosthet Dent 2005; 94: 10–92. PubMed
2. Ledger E. On preparing the mouth for the reception of a full set of artificial teeth. Br J Dent Sci 1856; 1: 90. Google Scholar
3. Gargari M, Prete V, Pujia M, Ceruso FM. Development of patient-based questionnaire about aesthetic and functional differences between overdentures implant-supported and overdentures tooth-supported. Study of 43 patients with a follow up of 1 year. Oral Implantol 2013; 5: 86–91. PubMed ● Google Scholar
4. Mericske-Stern R, Steinlin Schaffner T, Marti P, Geering AH. Peri-implant mucosal aspects of ITI implants supporting overdentures. A five-year longitudinal study. Clin Oral Implants Res 1994; 5: 9–18. DOI ● PubMed ● Google Scholar
5. Morais J, Heydecke G, Pawliuk J, Lund JP, Feine JS. The effects of mandibular two-implant overdentures on nutrition in elderly edentulous individuals. J Dent Res 2003. 82: 53–8. PubMed ● Google Scholar
6. Shah FK, Gebreel A, Elshokouki AH, Habib AA, Porwal A. Comparison of immediate complete denture, tooth and implant-supported overdenture on vertical dimension and muscle activity. J Adv Prosthodont 2012; 4: 61–71. DOI ● PubMed ● Google Scholar

7. Mahoorkar S, Bhat S, Kant R. Single implant supported mandibular overdenture: a literature review. 2016; 16: 75–82. DOI ● PubMed ● Google Scholar
8. Fueki, K, Kimoto K, Ogawa T, Garrett NR. Effect of implant-supported or retained dentures on masticatory performance: a systematic review. J Prosthet Dent 2007; 98: 470–7. DOI ● PubMed ● Google Scholar
9. Goodacre CJ, Bernal G, Rungcharassaeng K, Kan JY. Clinical complications with implants and implant prostheses. J Prosthet Dent 2003; 90: 121–32. DOI ● PubMed ● Google Scholar
10. Misch CE. Dental implant prosthetics. 2nd ed. Philadelphia, Elsevier Health Sciences; 2014. Google Scholar
11. Rodrigues AH. Metal reinforcement for implant-supported mandibular overdentures. J Prosthet Dent 2000; 83: 511–3. DOI ● PubMed ● Google Scholar
12. Prasad AH, Kalavathy, Mohammed HS.Effect of glass fiber and silane treated glass fiber reinforcement on impact strength of maxillary complete denture. Ann Essences Dent 2011; 3: 7–12. DOI ● Google Scholar
13. Hirajima Y, Takahashi H, Minakuchi S. Influence of a denture strengthener on the deformation of a maxillary complete denture. Dent Mater J 2009; 28: 507–12. DOI ● PubMed ● Google Scholar
14. Alla RK, Sajjan S, Alluri VR, Ginjupalli K, Upadhya N. Influence of fiber reinforcement on the properties of denture base resins. J Biomater Nanobiotechnol 2013; 4: 91–7. DOI ● Google Scholar
15. Fonseca RB, Kasuya AV, Favarão IN, Naves LZ, Hoeppner MG.The influence of polymerization type and reinforcement method on flexural strength of acrylic resin. ScientificWorldJournal, 2015; 2015: 919142. DOI ● PubMed ● Google Scholar
16. Tandon R, Gupta S, Agarwal SK. Denturebase materials: From past to future. Indian J Dent Sci 2010; 2: 33–9. Google Scholar
17. Berrong JM, Weed RM, Young JM. Fracture resistance of Kevlar-reinforced poly (methyl methacrylate) resin: a preliminary study. Int J Prosthodont 1990; 3: 391–5. PubMed ● Google Scholar
18. Dixon DL, Breeding LC. The transverse strengths of three denture base resins reinforced with polyethylene fibers. J Prosthet Dent 1992; 67: 417–9. DOI ● PubMed ● Google Scholar
19. Van Noort R. Introduction to Dental Materials. Elsevier Health Sciences; 2013. Google Scholar
20. Goguta L, Marsavina L, Bratu D, Topala F. Impact strength of acrylic heat curing denture base resin reinforced with E-glass fibers. Timisoara Med J 2006; 56: 88–91. Google Scholar
21. Nakamura M, Takahashi H, Hayakawa I. Reinforcement of denture base resin with short-rod glass fiber. Dent Mater J 2007; 26: 733–8. DOI ● PubMed ● Google Scholar
22. Fajardo RS, Pruitt LA, Finzen FC, Marshall GW, Singh S, Curtis DA. 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. DOI ● PubMed ● Google Scholar
23. Kanie T, Fujii K, Arikawa H, Inoue K. Flexural properties and impact strength of denture base polymer reinforced with woven glass fibers. Dent Mater 2000; 16: 150–8. DOI ● PubMed ● Google Scholar
24. Hamza TA, Rosenstiel SF, El-Hosary MM, Ibraheem RM. Fracture resistance of fiber-reinforced PMMA interim fixed partial dentures. J Prosthodontic 2006; 15: 223–8. DOI ● PubMed ● Google Scholar
25. International Organization for Standardization. ISO 20795-1: 2008 dentistry base polymers - part 1: denture base polymers. Available from: https://www.iso.org/standard/39740.html.
26. Bertassoni LE, Marshall GW, de Souza EM, Rached RN. Effect of pre-and postpolymerization on flexural strength and elastic modulus of impregnated, fiber-reinforced denture base acrylic resins. J Prosthet Dent 2008; 100: 449–57. DOI ● PubMed ● Google Scholar
27. Vallittu PK. Flexural properties of acrylic resin polymers reinforced with unidirectional and woven glass fibers. J Prosthet Dent 1999; 81: 318–26. DOI ● PubMed ● Google Scholar
28. Kanie T, Arikawa H, Fujii K, Ban S. Flexural properties of denture base polymers reinforced with a glass cloth–urethane polymer composite. Dent Mater 2004; 20: 709–16. DOI ● PubMed ● Google Scholar
29. 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. DOI ● PubMed ● Google Scholar
30. Narva KK, Lassila LV, Vallittu PK. The static strength and modulus of fiber reinforced denture base polymer. Dent Mater 2005; 21: 421–8. DOI ● PubMed ● Google Scholar
31. Dyer SR, Lassila LV, Jokinen M, Vallittu PK. Effect of fiber position and orientation on fracture load of fiber-reinforced composite. Dent Mater 2004; 20: 947–55. DOI ● PubMed ● Google Scholar
32. Marei MK. Reinforcement of denture base resin with glass fillers. J Prosthodont 1999; 8: 18–26. DOI ● PubMed ● Google Scholar
33. John J, Gangadhar SA, Shah I. Flexural strength of heat-polymerized polymethyl methacrylate denture resin reinforced with glass, aramid, or nylon fibers. J Prosthet Dent 2001; 86: 424–7. DOI ● PubMed ● Google Scholar
34. Basant G, Reddy Y. The effect of incorporation, orientation and silane treatment of glass fibers on the fracture resistance of interim fixed partial dentures. J Indian Prosthodont Soc 2011; 11: 45–51. DOI ● PubMed ● Google Scholar
35. Uzun G, Hersek N, Tincer T. Effect of five woven fiber reinforcements on the impact and transverse strength of a denture base resin. J Prosthet Dent 1999; 81: 616–20. DOI ● PubMed ● Google Scholar
36. Minami H, Suzuki S, Kurashige H, Minesaki Y, Tanaka T. Flexural strengths of denture base resin repaired with autopolymerizing resin and reinforcements after thermocycle stressing. J Prosthodont 2005; 14: 12–8. DOI ● PubMed ● Google Scholar
37. Dyer SR, Sorensen JA, Lassila LV, Vallittu PK. Damage mechanics and load failure of fiber-reinforced composite fixed partial dentures. Dent Mater 2005; 21: 1104–10. DOI ● PubMed ● Google Scholar
38. 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. DOI ● PubMed ● Google Scholar
39. Nedir R, Bischof M, Szmukler-Moncler S, Belser UC, Samson J. Prosthetic complications with dental implants: from an up-to-8-year experience in private practice. Int J Oral Maxillofac Implants 2006; 21: 919–28. PubMed ● Google Scholar