Transverse Strength of Polymethylmethacrylate Reinforced with Different Forms and Concentrations of E-Glass Fibres

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Abstract

Aims: The aim of the study was to determine the reinforcing effect of different types and concentrations of E-glass fibres on the transverse strength of denture base material. ***Methods:*** Ninety-one specimens of a heat-cured acrylic resin (65 mm x 10 mm x 2.5 mm) were prepared by modifying the polymethyl methacrylate (PMMA) with the addition of different concentrations (2.5%, 3%, 4%, and 5%) of three types of E-glass fibres (chopped strand mat, woven, and continuous fibres). Transverse strength testing was performed using a three-point bending test machine. For statistical analysis, the Kruskal-Wallis test followed by Dunn's multiple comparison test were used. ***Results:*** Mean transverse strength of control specimens was 90.71±2.73 MPa. The addition of 5% chopped strand mat glass fibre showed the highest mean transverse strength (131.17±8.23 MPa). Transverse strength values of continuous glass fibre-added groups at all concentrations were higher than that of control group. However, the difference was not statistically significant. ***Conclusions:*** The addition of chopped strand mat glass fibre was the most effective method to improve transverse strength of PMMA denture base resin.

Key Words: Transverse Strength, Acrylic Resin, Denture Base Materials, Glass Fibre

Introduction

The material most commonly used for the fabrication of removable dentures is polymethyl methacrylate (PMMA) resin [1]. The clinical performance and success of PMMA resin is dependent upon the mechanical and physical properties of the material. However, the primary concern is the denture base's poor strength characteristics, which are the low transverse strength and impact strength [2,3]. In the evaluation of denture plastics, transverse strength measurements are used to a greater extent than those of either tensile or compressive strength, because this test more closely represents the type of loading *in vivo* [4].

Different types of fibres have been used to reinforce dentures: glass fibres, ultra-high molecular weight polyethylene (UHMWP) fibres, carbon/graphite fibres, and aramide fibres [5-8]. Among these fibres, glass fibres have gained popularity because of their good aesthetic qualities and good bonding to polymers [5,9]. Glass fibres also have been shown to improve the mechanical properties of acrylic resin, especially fatigue resistance, impact strength, and flexural strength [5,6,10-12]. In addition, factors that relate to the strength of the fibre PMMA composite are quantity of fibres in polymer matrix, type and orientation of fibres, and adhesion of fibres to polymer matrix [1].

Aim

The aim of the study was to evaluate the effect of three different forms and four concentrations of E-glass fibres on the transverse strength of denture base PMMA.

Materials and Method

This investigation was conducted by means of fabricating a total of 91 heat-polymerised denture base PMMA resin (Meliodent, Heraeus Kulzer GmbH, Hanau, Germany) specimens divided into 13 groups, each consisting of seven specimens. The unreinforced specimens were the control. The spec-

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imens' dimensions were 65 mm x 10 mm x 2.5 mm [13]. Three different forms of E-glass fibres (Vetrotex International, Chambéry, France) were selected for the reinforcement of acrylic denture PMMA: chopped strand mat (CSM), woven (W) and continuous unidirectional (CU). Fibre concentrations in the test groups were 2.5%, 3%, 4%, and 5% by volume.

Physical properties of E-glass fibres used in this study were as follows:

- CSM, which consists of randomly oriented chopped E-glass fibres approximately 50 mm long and 12 μm diameter.
- W, which consists of randomly oriented fibres laid plainly, approximately 150 mm long and 5.5 μm diameter.
- CU, which consists of continuous fibres, approximately 12 μm in diameter.

Control group specimens were prepared in powder/liquid (P/L) ratio of 10 ml/23.4 g according to the manufacturer's recommendations. The glass fibres were soaked in monomer-polymer mixture (10 ml/8 g ratio) for 10 minutes to ensure better impregnation of E-glass fibres into PMMA material.

CSM, W, and CU glass fibres were cut and shaped to fit the rectangular form of the specimens and were horizontally embedded into the centre of the acrylic resin dough. After polymerisation procedure, the specimens were ground with 600-grit silicon carbide paper to remove excess materials. The specimens were then stored in water at 37°C for 48 hours prior to testing.

Transverse strength testing was performed using a three point bending test machine (Instron 4411 Servohydrolic Testing Machine, Instron Corp, Norwood MA, USA), whereby the simple specimen beam was centrally loaded at a crosshead speed of 5 mm/min over a two-point support span set at 50 mm. The specimens were deflected until rupture occurred. The transverse strength (MPa) of each specimen was determined with the following formula [4]:

$$S= 3.P.L/ 2.b.d^2$$

where S is considered as transverse strength (MPa), P the maximum load applied (N), L the span between the two supports (mm), b the width of the specimen (mm), and d the thickness of the specimen (mm).

Statistical analysis

Statistical analysis was performed with GraphPad Prism V.3 program for Windows (GraphPad Software, La Jolla CA, USA). The mean transverse strength values and standard deviations were calculated for each group and the data were analysed using the Kruskal-Wallis test, which was suitable for the number and the distributions of samples in each group, followed by *post-hoc* Dunn's multiple comparison test at $P<0.05$ level. The sample size of test could not be detected previously and the power was above 75%.

Results

The means and SDs of transverse strength and Kruskal-Wallis test results are presented in *Table 1.*

The 5% CSM glass fibre-added test group showed the highest mean transverse strength value (131.17±8.23 MPa). Transverse strength values of CSM glass fibre-added groups at all concentrations were higher than that of the control group ($P<0.001$). The lowest mean transverse strength value belonged to 2.5% CU fibre-containing group (92.81±5.21 MPa). The differences between the transverse strength values of the control group and those of all concentrations of CU fibre-containing group were not statistically significant *(Tables 1 and 2).*

Table 1. *The Mean Transverse Strength Values (MPa) and Standard Deviation of all Groups*

Fibre concentrations	**Control (no fibre)**	**CSM**	**CU**	**W**	**KW**	***P***
2.5%	90.71±2.73	113.88±4.11	92.81±5.21	103.95±6.73	21.08	0.0001
3%		117.17±4.28	106.64±5,38	106.74±6.42	21.06	0.0001
4%		125.63±7,9	108.28±7.04	118.46±6.08	20.73	0.0001
5%		131.17±8.23	117.59±5.85	123.71±7.15	20.10	0.0001
KW		15.54	19.01	18.55		
P		0.001	0.001	0.0001		

Table 2. *The Result of Post-Hoc Dunn's Multiple Comparison Test With Regard to Fibre Forms. The Groups With Different Fibres are Compared With the Control Group and With Each Other*

Dunn's Multiple Comparison Test	**2.5%**	**3%**	**4%**	**5%**
Control/CSM	***P*<0.001**	***P*<0.001**	***P*<0.001**	***P*<0.001**
Control/CU	*P*>0.05	*P*>0.05	*P*>0.05	*P*>0.05
Control/W	***P*<0.05**	*P*>0.05	***P*<0.01**	***P*<0.05**
CSM/CU	***P*<0.01**	*P*>0.05	*P*>0.05	*P*>0.05
CSM/W	*P*>0.05	*P*>0.05	*P*>0.05	*P*>0.05
CU/W	*P*>0.05	*P*>0.05	*P*>0.05	*P*>0.05

Table 3. *The Result of Post-Hoc Dunn's Multiple Comparison Test With Regard to Concentrations. The Concentration of Fibres is Compared Within Each Fibre Type*

Dunn's multiple comparison test	**CSM**	**CU**	**W**
2.5%/3%	*P*>0.05	*P*>0.05	*P*>0.05
2.5%/4%	*P*>0.05	*P*>0.05	***P*<0.05**
2.5%/5%	***P*<0.01**	***P*<0.001**	***P*<0.01**
3%/4%	*P*>0.05	*P*>0.05	*P*>0.05
3%/5%	*P*>0.05	*P*>0.05	***P*<0.01**
4%/5%	*P*>0.05	*P*>0.05	*P*>0.05

Comparison of fibre concentration showed that a statistically significant difference existed between 2.5% and 5% in all test groups (*P*<0.01) (*Table 3).*

Discussion

Denture fracture in clinical use occurs from a large transitory force caused by an accident or a small force during repeated chewing. The transverse strength test, impact test, and flexural fatigue test were employed to examine these forces [4,14]. The transverse strength test, one of the mechanical strength tests, is especially useful in comparing denture base materials in which a stress of this type is applied to the denture during mastication [4].

To improve the mechanical properties of acrylic resin, different types of fibres have been used [5-8]. Among the many types of fibres, glass fibres are considered to be suitable for strengthening dentures [12,15,16]. In addition, the translucency of glass fibres provides aesthetically pleasing dentures. More importantly, they have an excellent adhesion to the PMMA resin matrix and, consequently, an outstanding ability to increase mechanical properties [12]. Several factors — such as orientation and quantity of fibres [1,7,17-20], impregnation of fibres with the matrix, and fibre adhesion to the polymer matrix — have an impact on the mechanical strength of PMMA resin [17,18]. Therefore, this study investigated the effects of different forms and concentrations of glass fibres on the transverse strength of denture base resin. In the present study, the addition of glass fibre in the PMMA enhanced the transverse strength of the heat-cured PMMA. This finding is in agreement with previously reported studies [1,12,15,21,22]. The one factor that is related to the strength of the fibre composite is the quantity of fibres in polymer matrix [1,7,19,20]. One study [1] reported that the transverse strength was significantly influenced by the glass fibre percentage treatments. In the current study, when the concentration of fibre was increased, the transverse strength values also increased. Of all the groups used, regardless of the fibre forms, the 5% glass fibre content revealed the most favourable effect.

In the present study, the test groups that included untreated glass fibres used in chopped form (CSM) at all concentrations showed the highest mean transverse strength value. Similarly, in a previous study [23], the results indicated that glass fibres, in chopped form, significantly increased the mean transverse strength of the Lucitone 199, Meliodent and Impact denture-base resins, compared with the other group that contained no fibres. These results are in agreement with the findings reported by Valittu *et al.* (1994) [20] and Stipho (1998) [24].

The transverse strength value of specimens reinforced with woven fibres was significantly higher than that of continuous unidirectional glass fibres. This finding was contrary to Vojdani and Khaledi's 2006 study [22]. In this study, woven fibre reinforcement increased transverse strength by 30%, and reinforcing with continuous fibre increased the transverse strength by up to 50%.

Reinforcing PMMA resin denture base material with glass fibres significantly improves the transverse strength, consequently increasing the lifespan of the prosthesis during clinical use.

Conclusion

Within the limitation of the current study, the following conclusions can be made:

1. The transverse strength of heat-polymerised resin was enhanced by the addition of glass fibres.
2. Increased fibre concentration caused a higher transverse strength of the PMMA.
3. The chopped strand mat glass fibre-added test group showed the highest transverse strength value. The addition of chopped strand mat glass fibre was a more effective method of improving the transverse strength of PMMA denture base resin than the others.

References

1. Stipho HD. Effect of glass fiber reinforcement on some mechanical properties of autopolymerizing polymethyl methacrylate. *Journal of Prosthetic Dentistry* 1998; **79:** 580-584.

2. Loncar A, Vojvodiæ D, Matejicek F, Jerolimov V. Flexural strength of denture base materials. *Acta Stomatologica Croatia* 2006; **40:** 151-161.

3. Lung CYK, El-Sheikh MA, Al-Zahrani BS. Causes of denture fracture: A survey. *Saudi Dental Journal,* 2006; **18:** 149-154.

4. Craig RG. *Restorative Dental Materials.* 11th ed. St Louis: Mosby; 2002: pp 643, 87-88.

5. Valittu PK. A review of fiber-reinforced denture base resins. *Journal of Prosthodontics* 1996; **5:** 270-276.

6. Valittu PK. Comparison of the *in vitro* fatigue resistance of an acrylic resin removable partial denture reinforced with continuous glass fibers or metals wires. *Journal of Prosthodontics* 1996; **5:** 115-121.

7. Ekstrand K, Ruyter UE, Wellendorf H. Carbon/graphite fiber reinforced poly(methylmethacrylate): Properties under dry and wet conditions. *Journal of Biomedical Material Research* 1987; **21:** 1065-1080.

8. Ladizesky NH, Ho CF, Chow TW. Reinforcement of complete denture bases with continuous high performance polyethylene fibers. *Journal of Prosthetic Dentistry* 1992; **68:** 934-939.

9. Vallittu PK. Curing of a silane coupling agent and its effect on the transverse strength of autopolymerizing polymethyl methacrylate-glass fiber composite. *Journal of Oral Rehabilitation* 1997; **24:** 124-130.

10. Valittu PK. Effect of void space and polymerization time on transverse strength of on the acrylic-glass fiber composite. *Journal of Oral Rehabilitation* 1995; **22:** 257-261.

11. Valittu PK, Vojtkova H, Lassila VP. Impact strength of denture polymethyl methacrylate reinforced with continuous glass fibers or metal wire. *Acta Odontologica Scaninavia* 1995; **53:** 392-396.

12. Valittu PK. Flexural properties of acrylic polymers reinforced with unidirectional and woven glass fibers. *Journal of Prosthetic Dentistry* 1999, **81:** 318-326.

13. American National Standard. *Specification No. 12 for Denture Base Polymers*. Chicago: American Dental Association; 1975 (Reaffirmed, 1999).

14. Kanie T, Fujii K, Arikawa H, Inoue K. Flexural properties and impact strength of denture base polymer reinforced with woven glass fibers. *Dental Materials* 2000; **16:** 150-158.

15. Aydin C, Yilmaz H, Caglar A. Effect of glass fiber reinforcement on the flexural strength of different denture base resin. *Quintessence International* 2002; **33:** 457-463.

16. Kim SH, Watts DC. The effect of reinforcement with woven E-glass fibers on the impact strength of complete denture fabricated with high-impact acrylic resin. *Journal of Prosthetic Dentistry* 2004; **91:** 274-280.

17. Narva KK, Vallittu PK, Helenius H, Yli-Urpo A. Clinical survey of acrylic resin removable denture repairs with glass-fiber reinforcement. *International Journal of Prosthodontics* 2001; **14:** 219-224.

18. Vallittu PK, Ruyter IE, Ekstrand K. Effect of water storage on the flexural properties of E-glass and silica fiber acrylic resin composite. *International Journal of Prosthodontics* 1998; **11:** 340-350.

19. Yazdanie N, Mahood M. Carbon fiber acrylic resin composite: an investigation of transverse strength. *Journal of Prosthetic Dentistry* 1985; **54:** 543-547.

20. Vallittu PK, Lassila VP, Lappalainen R. Acrylic resin-fiber composite-Part I: The effect of fiber concentration on fracture resistance. *Journal of Prosthetic Dentistry* 1994; **71:** 607-612.

21. Ozdemir AK, Polat NT. The effect of glass fiber distribution on the transverse strength and surface smoothness of two denture resins. *Dental Material Journal* 2003; **22:** 600-609.

22. Vojdani M, Khaledi AAR. Transverse strength of reinforced denture base resin with metal wire and E-glass fibers. *Journal of Dentistry* 2006; **4:** 167-172.

23. Keyf F, Uzun G. The effect of glass fibre-reinforcement on the transverse strength, deflection and modulus of elasticity of repaired acrylic resins. *International Dental Journal* 2000; **50:** 93-97.

24. Stipho HD. Repair of acrylic resin denture base reinforced with glass fibre. *Journal of Prosthetic Dentistry* 1998; **82:** 546-550.