THE FLEXURAL STRENGTHS OF FIVE COMMERCIALLY AVAILABLE TOOTH-COLOURED RESTORATIVE MATERIALS

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Original Article

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ABSTRACT

Purpose of the study: The objective of this study was to investigate the flexural strengths of five commercially available tooth-coloured restorative materials – Alpha-Dent (composite resin, Dental Technologies Inc.), Solare Anterior (composite resin, GC), F2000 (polyacid-modified composite resin, 3M), Beautifil (giomer, Shofu) and Fuji II LC (resin-modified glass ionomer cement, GC] using the ISO 4049 specifications.

Materials and Method: Ten specimens of (25±0.2)mm x (2±0.1)mm x (2±0.1)mm from each material were prepared at 22-23ºC using a customized metal mould. After light polymerization, the specimens were stored in distilled water at 37ºC for 24 hours. The specimens were subsequently blotted dry, measured and subjected to flexural testing using an Instron Universal Testing Machine with a crosshead speed of 0.5mm/min. The flexural strengths were calculated from the maximum load exerted on the specimens. Data were analysed using one way ANOVA and scheffe's post-hoc multiple comparison tests at a significance level of 0.05.

Results: The results showed that the mean flexural strengths of Beautifil, Solare Anterior and Alpha-Dent were above 80 MPa and those of F2000 and Fuji II LC were below 80 MPa. The results of one-way ANOVA and Scheffe's post-host tests demonstrated that Beautifil had significantly higher mean flexural strength compared to Fuji II LC, F2000 and Alpha-Dent ($P<0.05$). Both Solare Anterior and Alpha-Dent showed significantly higher mean flexural strengths than Fuji II LC and F2000 ($P<0.05$). The mean flexural strengths between Beautifil and Solare Anterior, between Alpha-Dent and Solare Anterior and between F2000 and Fuji II LC were not significantly different.

Conclusions: Under the experimental conditions, Beautifil (BF) showed significantly higher mean flexural strength compared to Fuji II LC (FL), F2000 (F2) and Alpha-Dent (AD) (BF>FL, F2, AD). The mean flexural strengths of Beautifil, Solare Anterior and Alpha-Dent were above the minimum requirement of ISO 4049 for occlusal fillings (80 MPa), therefore can be used in stress-bearing areas. The mean flexural strengths of Fuji II LC and F2000 did not meet the minimum requirement of ISO 4049 for occlusal fillings, therefore should not be used in stress-bearing areas.

Key words: flexural strength; tooth-coloured restorative materials

INTRODUCTION

Marked changes in the use of dental restorative materials have occurred during the past 10 to 20 years with the introduction of tooth-coloured materials as aesthetic consideration is becoming important in the restoration of teeth. These materials include composite resins, glass ionomer cements (GIC), resin-modified glass ionomer cements (RMGICs), polyacid-modified composite resins (compomers) and more recently giomers.

However, not all tooth-coloured dental restorative materials can be indicated for stress-bearing areas such as in Class I, Class II and Class IV restorations. There is a limit to the value of applied force to which a restoration can withstand without fracturing. Strength values such as tensile, shear, compressive and flexural strength are usually used as indicators of structural performances for brittle materials including resin-based filling materials (1-8).

Test methods to investigate some of the physical properties of dental materials are described in ISO 4049 for polymer-based filling materials (9). This study only considers the flexural strength as this is one of the parameters used to characterise resistance of a filling material against occlusal loading and thus is clinically relevant (10). ISO 4049 (9) classifies light-curing direct filling resins into two main types based on its flexural strength:

Table 1. The list of tooth-coloured restorative materials evaluated in this study

Materials	Category	Manufacturer	Batch number	Shade Curing time
Alpha-Dent	Micro-filled hybrid composite	Dental Technologies Hamlin Ave.	0400315	A3 40 seconds
Solare anterior	Micro-filled hybrid composite	GC Dental Products Corporation, Japan	0412152	A3 40 seconds
Beautifil	Giomer	Shofu Dental Corporation, Osaka Japan	060515	A3 40 seconds
F2000	Compomer	3M Dental Products St.Paul, USA.	20040503	A3 40 seconds
Fuji II LC	Resin-modified glass ionomer cement	GC Corporation,Tokyo Japan	0411245	A3 40 seconds

Type 1: Fillings for the occlusal areas, flexural strength ≥80 MPa

Type 2: Fillings for other indications, flexural strength ≥50 MPa

Flexural strength of a material is its ability to bend before it breaks. A high flexural strength is desired under the masticatory forces that might induce permanent deformation of the dental materials. Yap and Teoh (8) demonstrated that composite resins with high flexural strength are less prone to bulk and marginal fracture.

Previous studies have shown that flexural strengths of composite resins fall in the range of 58 MPa to 126.3 MPa (4,10,11). Attin et al. (12) demonstrated that hybrid composite resins exhibited the highest flexural strength compared to resin-modified glass ionomer cement (RMGIC) Fuji II LC, and polyacid-modified composite resins.

Generally, the strength properties (compressive strength, flexural strength, modulus of elasticity and surface microhardness) of RMGICs were inferior to those of hybrid composite resins (12). The flexural strength of RMGICs falls in the range of 26 MPa to 80 MPa (2,4,11,13).

Giomers are a relatively new generation of light-cured fluoride releasing aesthetic dental restorative materials. They contain pre-reacted glass-ionomer (PRG) fillers in a resin matrix. These fillers are made of fluorosilicate glasses that have been pre-reacted with polyacrylic acid to form a glass-ionomer matrix structure and then blended into the resin (14,15). Beautifil is one of the giomers that utilizes the surface pre-reacted glass ionomer (S-PRG) technology. A clinical trial that was carried out showed that the success rate for cervical Beautifil restorations after two years was 80%, while occlusal Beautifil had a 100% success rate (16).

To date little published research is available on the mechanical properties or performance of giomers. Therefore the aim of this study is to evaluate and compare the flexural strength of a giomer with other tooth-coloured, resin-based dental restorative materials.

MATERIALS AND METHOD

Materials used in this study were listed in Table 1.

Specimen Preparation

All the materials were manipulated according to manufacturers' instructions. Alpha-Dent, Solare Anterior, Beautifil and F2000 were directly dispensed from their respective syringe for specimen preparations.

For Fuji II LC, the capsule was first activated using a capsule applier and then mixed for 10 seconds using a capsule mixer, HSM 1. The material was then dispensed using the same capsule applier.

The preparation of the specimens was done according to the ISO 4049 specifications. From each material, ten bars measuring (25±0.2) mm × (2±0.1) mm × (2±0.1) mm were prepared at 22-23ºC (room temperature) and in a relative humidity of 50% using a customized split stainless steel mould as shown in Figure 1.

The base of the mould was first coated with vaseline to facilitate removal of the specimens and then covered with cellulose strip for isolation. The

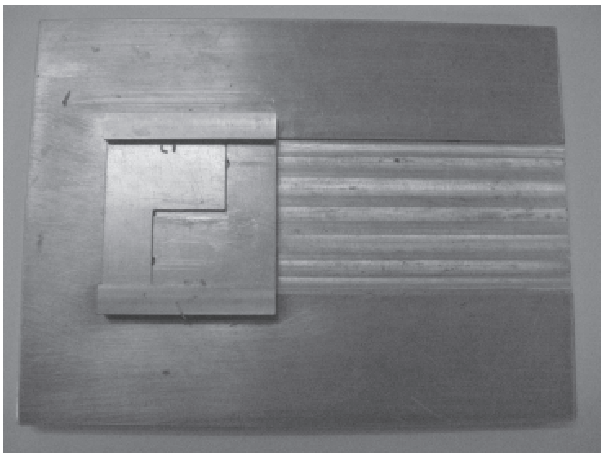

Figure 1: The split stainless steel mould used to fabricate the specimens.

test materials were carefully packed into the mould without voids and were covered again with cellulose strip on its top surface. A glass slide was placed on top of the mould and gentle pressure was applied to extrude excess material.

The top surfaces of the specimens were then light-polymerized using Coltulux 3 Coltene (Dentsply). Prior to the use of the light curing unit and after the curing of each series of 10 specimens, the output of the curing device was tested with a radiometer (Caulk, Dentsply). Light densities between 410 and 420 mW/cm^2 were measured and no decrease in the output could be observed. The centre section of the specimens was irradiated first for 40 seconds. For additional curing, the edge of specimens on each end was irradiated again for 40 seconds. The specimens were then removed from the mould and turned over to allow the curing sequence repeated. The curing sequence resulted in a total of three curing cycles of 40 seconds each on both side of the test specimen (6 in total).

All the test specimens were polished with a wet silicone carbide paper of 600 and 1000 grit size at a speed of 150 rpm using a grinding machine (Metasserv, Buehler UK Ltd, Coventry, England). The dimensions of the specimens were then measured with an electronic digital caliper (Mitutoyo, Japan) to an accuracy of ±0.01mm. The specimens were stored in distilled water in a sealed container at 37 °C for 24 hours.

Testing Procedure

The specimen was removed from the storage container, wiped dried, mounted in a specially designed jig and subjected to a 3-point-bending test using an Instron Testing Machine ((Instron 4302, Instron Corporation, England) as shown in Figure 2 at a crosshead speed of 0.5 mm/min until the specimen fractured. A simplified diagram of the 3-point-bending test is illustrated in Figure 3.

The maximum load exerted on each specimen was recorded and the flexural strength, σ, was calculated in MPa from the following equation:

$$\sigma = \frac{3FL}{2BH^2}$$

F is the maximum load, in newtons, exerted on the specimen; L is the distance, in milimeters, between the supports; B is the width, in milimeters, of the specimen measured immediately prior to testing and H is the height of the specimen, in milimeters measured immediately prior to testing.

Statistical Method

The results of flexural strength were analyzed using one-way analysis of variance (ANOVA) followed by Scheffe's post-hoc multiple pair-wise comparison test to evaluate differences in the mean flexural strengths between the tooth-coloured restorative materials tested. Differences were accepted as statistically significant at a 95% confidence level (p<0.05). All statistical tests were performed with the statistic software SPSS 14.0 for Windows.

Figure 2: The Universal Instron Testing Machine (Instron 4302, Instron Corporation) used for flexural testing in this study.

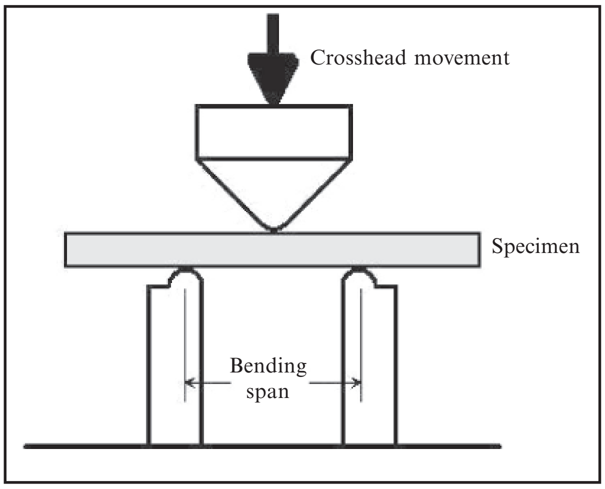

Figure 3: A simplified diagram of the 3-point-bending test.

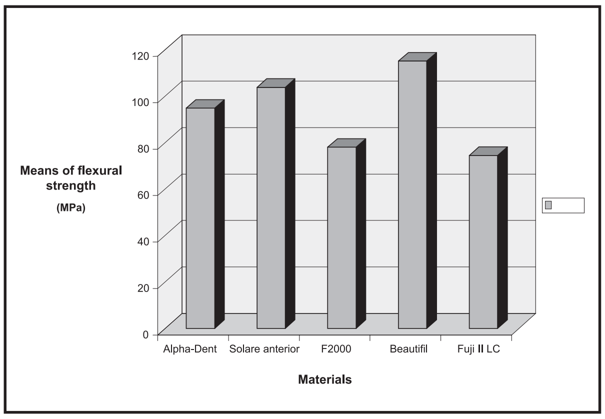

Figure 4: The mean flexural strengths of the materials tested.

Table 2. Comparison of the mean flexural strengths (MPa) of the materials tested

Materials	n	Flexural strength	95% Confidence Interval for Mean		F Statistic[a] (df)	P-value[a]
		Mean (SD)	Lower Bound	Upper Bound		
Alpha-dent	10	94.83 (10.55)	87.28	102.38	40.31	< 0.001
Solare Anterior	10	103.86 (7.32)	98.63	109.10	(4)	
F2000	10	78.08 (7.40)	72.78	83.37		
Beautifil	10	115.18 (10.15)	107.92	122.44		
Fuji II LC	10	74.51 (6.51)	69.85	79.17		

[a]One-way ANOVA test (P <0.05)

Table 3. Pairwise multiple comparisons of the mean difference of the flexural strengths (MPa) of the materials tested

Pairwise comparison of materials tested			Mean difference	*P*-value[a]	95% Confidence Interval	
					Lower bound	Upper bound
Alpha-dent	vs	Solare Anterior	-9.03	0.251	-21.30	3.24
		F2000	16.76*	0.003	4.48	29.03
		Beautifil	-20.34*	0.000	-32.62	-8.07
		Fuji II LC	20.32*	0.000	8.05	32.60
Solare Anterior	vs	F2000	28.79*	0.000	13.51	38.06
		Beautifil	-11.31	0.085	-23.59	0.96
		Fuji II LC	29.35*	0.000	17.09	41.63
F2000	vs	Beaufiil	-37.10*	0.000	-49.38	-24.83
		Fuji II LC	3.56	0.927	-8.71	15.84
Beautifil	vs	Fuji II LC	40.67*	0.000	28.39	52.94

[a] Scheffe's post-hoc test
* The mean difference is significant at $P < 0.05$

RESULTS

The mean flexural strengths for the materials tested in this study are presented in Table 2 and Figure 4. The mean flexural strengths of Beautifil, Solare Anterior and Alpha-dent were above 80 MPa, the minimum requirement of ISO 4049 for occlusal fillings. The results also showed that the mean flexural strengths of polyacid-modified composite resin F2000 and resin-modified glass ionomer cement Fuji II LC were below 80 MPa.

The results of one-way analysis of variance (ANOVA) test are shown in Table 2. The results indicated that significant differences in the mean flexural strength ($P<0.001$) existed between the five different tooth-coloured restorative materials tested.

The results of multiple pairwise comparisons using Scheffe's post-host test are shown in Table 3. The results demonstrated that Beautifil (BF) had significantly higher mean flexural strength ($P<0.05$) compared to Fuji II LC (FL), F2000 (F2) and Alpha-Dent (AD) (BF>FL, F2, AD). Both Solare Anterior (SL) and Alpha-Dent showed significantly higher flexural strengths ($P<0.05$) than Fuji II LC and F2000 (SA, AD>FL, F2). However, the mean differences in flexural strength between Beautifil and Solare anterior and between Alpha-Dent and Solare anterior were not significant. The mean flexural strengths between F2000 and Fuji II LC were also not significantly different.

DISCUSSION

Previous studies (1,2,5-7,17) have shown that the flexural strengths of dental materials generally followed a trend; the resin-modified GICs have the lowest values, followed by poly-acid modified composite resins (intermediate) and composite resins have the highest values. In our study, Beautifil (Giomer), a new hybrid aesthetic restorative material revealed higher mean flexural strength than those of hybrid micro-filled composite resins (Alpha-Dent and Solare Anterior) tested. Despite numerous laboratories testing on giomers, minimal amount of research has been published in relation to the mechanical properties of these materials such as flexural strength. Flexural strength of a material is particularly dependent upon the volume fraction of the reinforcing phase, the filler content. The significantly greater flexural strength values of giomer Beautifil compared to composite resin

Alpha-Dent could be attributed to its high filler content (81.5% weight). In addition, Beautifil does not contain hydroxyl ethyl methacrylate (HEMA) and is a surface-reacted giomer. Therefore, there is less water absorption and less expansion (16). Excessive water absorption can adversely affect mechanical properties. Water can act as a plasticizer to the resin and hydrolytic damage to both filler and silane can result (18). Consequently, the flexural strength of the restorative material is decreased.

The higher mean flexural strengths of hybrid micro-filled composite resins (Solare Anterior and Alpha-Dent) compared to those of F2000 and Fuji II LC, as expected are due to their higher filler content. Micro-hybrid composite resins can contain between 77% to 84% filler by weight. Furthermore, the role of the filler particles in composite resins is somewhat different compared with that in resin-modified glass ionomer cements and polyacid-modified composite resins. In composite resins, the filler particles are treated, during manufacturing, with a silane coupling agent to bond the filler chemically to the resin matrix. Thus, when a stress is applied to the set composite resin, it can be transferred from one strong filler particle to another. Therefore, the flexural strength of composites is further enhanced by this coupling agent (11).

On the other hand polyacid-modified composite resin F2000 contains GDMA (glyceryl methacrylate) which is chemically and functionally similar to HEMA (hydroxyethyl methacrylate) and like HEMA, it has hydroxyl functionality, which makes it hydrophilic. Thus, the absorption of water by GDMA may account for the lower flexural strength observed with F2000 after conditioning in distilled water. Polyacid-modified composite resins have decreased water sensitivity during clinical placement and improved resistance to desiccation but swell with water absorption (1). Our study showed that although poly-acid modified composite resin F2000 demonstrated higher mean flexural strength than resin-modified glass ionomer cement Fuji II LC, their mean difference was not significant. F2000 was also significantly inferior to composite resins Alpha-dent and Solare anterior and giomer Beautifil. These findings are in agreement with the findings by Burgess et al. (17) and Meyer et al. (19). In addition, the mean flexural strength of polyacid-modified composite resin F2000 were below 80 MPa and therefore, did not meet the limit of ISO 4049 for occlusal fillings.

Our results showed that the mean flexural strength of resin-modified glass ionomer cement (RMGIC) Fuji II LC was significantly lower than giomer Beautifil and composite resins Solare Anterior and Alpha-Dent. These are in agreement with Li et al. (13). The low flexural strength of RMGIC Fuji II LC can be attributed to water absorption by its resin component. Since RMGICs use mainly HEMA or modified HEMA monomers, the organic structure formed after the setting reactions will contain a higher proportion of hydrophilic functional groups (20). Therefore in aqueous environment, RMGICs may absorb greater amount of water and swell. They consequently become plastic and are thus mechanically less resistant to fracture (1). However, Yap and his co-workers (4) have showed that an increase in powder weight significantly improved flexural strength of Fuji II LC. The higher powder-liquid ratio results in a higher amount of unreacted glass per unit volume of cement. The latter acts as fillers that can retard crack growth and propagation during flexural strength testing, resulting in higher flexural strength.

Clinical implications

Ideally, the properties of dental restorative materials should be very similar in every aspect to those of the tooth tissue being replaced. Physical properties are usually referred to as indicators of structural performance for brittle dental materials including resin-based restorative materials (1-8).

Clinically, composite restorations can be subjected to undesirable flexural stresses in both anterior and posterior area. Characterization of flexural strength is thus crucial to dental practitioners and material scientists. In stress-bearing area (Class I, Class II and IV restorations) a high flexural strength is required to withstand forces and load when biting without fracture. Thus, the use of Alpha-dent, Solare anterior and Beautifil with higher flexural strength can be considered in these situations.

Beautifil (Giomer), a relatively new hybrid dental restorative material has the advantage of fluoride release and recharge properties (21,22) along with good aesthetics, easy polishing and strength comparable to composite resins (23,24). Thus, it can replace conventional glass ionomer cement or compomer at cervical restorations. Our study shows that Beautifil has the highest flexural strength, thus can be used in stress bearing areas or as alternatives to composite resins. Fuji II LC is usually indicated in a limited range of clinical treatments such as in the cervical and labial restorations which are not subjected to excessive occlusal or external forces (cervical, root, deciduous teeth, and small class III cavity) and in cases where fluoride release is desired. The flexural strength of F2000 (polyacid-modified composite resin) falls between composite resins and Fuji II LC (resin-modified glass ionomer cement) as in agreement with other studies (1,17). Although poly-acid modified composite resins (compomers) have gained acceptance among practitioners due to their handling properties, aesthetics and fluoride release, their use should be limited to non-stress-bearing areas.

The results of this study must be interpreted with caution in predicting the clinical performance of the materials tested. This is because the relative flexural strength of dental materials in clinical situation may differ significantly from that predicted from mechanical properties evaluated in vitro (25).

CONCLUSIONS

Within the limitations of this study, the following conclusions were made:

1. Beautifil (BF) had significantly higher mean flexural strength compared to Fuji II LC (FL), F2000 (F2) and Alpha-Dent (AD) (BF>FL, F2, AD).
2. Both Solare Anterior (SL) and Alpha-Dent showed significantly higher mean flexural strengths than Fuji II LC and F2000 (SA, AD>FL, F2).
3. There were no significant differences in the mean flexural strengths between Beautifil and Solare Anterior, between Solare Anterior and Alpha-Dent and between F2000 and Fuji II LC.
4. The mean flexural strengths of Beautifil, Solare Anterior and Alpha-dent were above the minimum requirement of ISO 4049 for occlusal fillings (80 MPa), therefore can be used in stress-bearing areas as suggested by their manufacturers.
5. The mean flexural strengths of Fuji II LC and F2000 did not meet the minimum requirement of ISO 4049 for occlusal fillings (80 MPa), therefore should not be used in stress-bearing areas.

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