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A Comparison of the Flexural Strength and Modulus of Elasticity of Different Resin Composites

Farklı Rezin Kompozitlerin Esneme Dayanıklılığı ve Elastisite Modülünün Karşılaştırılması

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ABSTRACT

Introduction: Resin composites have become a popular alternative material to the amalgam restoration in stress-bearing posterior teeth.
Aim: The aim of this study was to evaluate the flexural strength and modulus of elasticity of different resin composites (Admira, Alert, Artemis, Clearfil Photo Posterior, Supreme (Dentin and Body) and TPH). This study also evaluated the influence of aging in water on these properties.
Materials and Methods: Standard mechanical testing of 25x2x2 mm bar specimens was carried out at 24 hours and 1 month. Data was analyzed using ANOVA and Duncan's multiple range tests ($p<0.05$).
Results: Except for Clearfil Photo Posterior, the packable composites exhibited flexural strength values that are not substantially better than those of conventional hybrid composite (TPH). The packable composites, Clearfil Photo Posterior and Alert had the highest modulus of elasticity due to their high filler load than the other restorative materials. The ormocer composite Admira had the lowest values in regard to flexural strength and modulus of elasticity.
Conclusion: The effect of aging in water on the flexural strength and modulus of elasticity was material dependent.

KEYWORDS

Composite, Flexural strength, Elastic modulus

ÖZET

Giriş: Rezin kompozitler stres altındaki posterior dişlerde amalgam restorasyonlara popüler alternatif seçenek haline gelmişlerdir.
Amaç: Bu çalışmanın amacı farklı rezin kompozitlerin (Admira, Alert, Artemis, Clearfil Photo Posterior, Supreme (Dentin and Body) and TPH) esneme dayanıklılığı ve elastisite modülünün değerlendirilmesidir. Aynı zamanda bu çalışmada suda bekletmenin bu özelliklere etkileri değerlendirildi.
Gereçler ve Yöntemler: 25x2x2mmlik çubuk örneklerin standart mekanik testi 24 saat ve 1 ayda yürütüldü. Sonuçlar ANOVA ve Duncan's Multiple Range Testi ile değerlendirildi ($p <0.05$).
Bulgular: Clearfil Photo Posterior hariç kondanse edilebilen kompozitler geleneksel hibrit kompozite (TPH) göre esneme dayanıklılığı değerleri olarak daha iyi sonuçlar göstermemişlerdir. Kondanse edilebilen kompozitler Clearfil Photo Posterior ve Alert yüksek doldurucu içeriği nedeniyle diğer restorative materyallere göre en yüksek elastisite modülüne sahipti. Ormoser kompozit Admira esneme dayanıklılığı ve elastisite modülüne bağlı olarak değerlendirildiğinde en düşük değerlere sahipti.
Sonuç: Suda bekletmenin esneme dayanıklılığı ve elastisite modülüne etkisi materyal bağımlıdır.

ANAHTAR KELİMELER

Kompozit, Esneme dayanıklılığı, Elastisite modülü

INTRODUCTION

Within the last decades, modern resin composites have been developed with a focus on amalgam-like mechanical properties, excellent aesthetics and biocompatibility[1]. All these factors affect the clinical success of dental resin composites. Since the first composites were developed, many efforts to improve their clinical performance have been undertaken. Research on the resin matrix is mainly based on the development of new monomers[2,3] while studies on the filler content focus on loading, particle size, silanation[4] and on the development of new particles[5]. Such studies are of high importance because the mechanical properties of resin composites depend highly on the concentration and particle size of the filler. The flexural strength, compressive strength and elastic modulus increase with the amount of inorganic fraction while the polymerization shrinkage is said to decrease[4].

Packable composites have been introduced in the market with high expectations as an alternative to amalgam[6]. Packable composites have a high filler load, improved filler technology and modifications in the organic matrices compared to traditional hybrid composites, which enable establishing excellent interproximal contacts and original occlusal anatomy in posterior restorations by condensing the material into the cavity preparations [6-8]. Since they are non-sticky, they can be used with conventional amalgam instruments as well as with metal matrix bands and wooden wedges[6-8].

Recently, a new brand of resin composites called as “nanofilled composites” has been introduced to the dental market, which has been produced with nanofiller technology and formulated with nanomer and nanocluster filler particles. Nanomers are discrete nanoagglomerated particles of 20-75 nm in size, and nanoclusters are loosely bound agglomerates of nano-sized particles. The manufacturer suggests that the combination of nanomer-sized particles and nanocluster formulations reduces the interstitial spacing of the filler particles and, therefore, provides increased filler loading, better physical properties and improved polish retention[9].

Besides the improvements in the filler technology, research has been conducted to change the monomer systems of the composite resins. The new packable composites based on the organically modified ceramic (ormocer) technology were developed. The traditional monomer systems, Bis-GMA, UDMA and TEGDMA are replaced with multifunctional urethane-and thioether(-meth)acrylate alkoxysilanes as sol-gel precursors for the synthesis of inorganic-organic copolymer ormocer composites. The alkoxysilyl groups of the silane allow the formation of an inorganic Si-O-si network by hydrolysis and polycondensation reactions, whereas the (meth)acrylate groups photochemically induce the organic polymerization[10-12].

Although many new materials have been developed, the major drawback of the posterior composite restorations commonly encountered in the dental practice is the fracture within the body or at the margins of the restorations[13-16]. Flexural strength and modulus of elasticity are the parameters used to evaluate the elasticity and degradation of the materials under stress[17].

The flexural strength (transverse strength, modulus of rupture) of a material is measured with a three-point bending test, in which the load is applied in the middle of a simple beam which is supported at each end. Flexural strength of a material is tested to determine both the strength of the material and the amount of the distortion expected. The modulus of elasticity (elastic modulus, Young’s modulus) of a material demonstrates the stiffness within the elastic range. It describes the stress-strain relationship of a material under load. The interatomic and intermolecular forces of the material determine the modulus of elasticity of a material. As the attraction forces increase, the modulus of elasticity and the rigidity of the material increase. Therefore, modulus of elasticity is quite dependent on the composition of the material[17].

The objective of this study was to evaluate the flexural strength and modulus of elasticity of two packable (Alert, Clearfil Photo Posterior), one nanofilled (Supreme (Dentin and Body)), one ormocer (Admira) and two hybrid composites (Artemis, TPH). This study also evaluated the influence of aging in water on these properties.

MATERIALS AND METHODS

The materials used in the study are listed in Table 1. Flexural strength testing was conducted according to International Standard Organization for Standardization (ISO), Standard 4049[18]. The materials were placed in a mould (measuring 25x 2x 2mm), which was positioned on a glass slide. Another glass slide was then placed on top of the mould to remove the excess of the material from the mould. Each specimen was light cured from top and bottom surfaces with a visible light source (Hilux Expert, Benlioğlu Dental Turkey) in 4 overlapping positions of 40 seconds each, along the length of the mould. Output of the curing light was verified to ensure light output above 500mW/cm^2, using a Hilux curing light meter. 7 bar specimens of each material were stored in distilled water at 37^0 C for 24 hours and 7 were stored under the same conditions for 1 month. Before loading, height and width of the specimens were measured using a digital micrometer (Digimatic, Mitutoyo Corp, Tokyo, Japan) at an accuracy of 0.01 mm at 3 locations along the specimen. The mean of these 3 measurements was used to calculate the flexural strength and modulus of elasticity. The specimens were subjected to a 3-point bend test on an Instron (Llyod Instruments, Ltd, LR 30K, UK) uniaxial servo-mechanical testing machine at a crosshead speed of 1 mm/min. The maximum load supported by the specimen before failure was captured electronically. Flexural strength (F, in megapascals) was calculated according to the following formula:

$$F= 3P_fL/2WH^2$$

TABLE I

Restorative materials used in the study

Type	Commercial name	Manufacturer	Batch number	Filler weight	Average filler size (μm)
Packable composite	Clearfil Photo Posterior	Kuraray Dental, Japan	D0102C	86%	4 μm
Packable composite	Alert	Jeneric/Pentron, Wallingford CT, USA	64463	84%	0.7 μm
Nanofilled composite	Supreme (Dentin)	3M ESPE Dental Products, St Paul, MN, USA	2AC	78.5%	20nm (silica) 5-20nm (zirconia/silica)
Nanofilled composite	Supreme (Body)	3M ESPE Dental Products, St Paul, MN, USA	3AK	78.5%	20nm (silica) 5-20nm (zirconia/silica)
Hybrid composite	TPH	Dentsply Caulk, Milford, DE, USA	010705	77%	below 1 μm
Hybrid composite	Artemis (Dentin)	Ivoclar Vivadent AG, Schaan, Liechtenstein	#573491AN	75-77%	0.6 μm
Ormocer composite	Admira	Voco, Cuxhaven, Germany	331113	78%	0.7 μm

Where P_f is the maximum load measured at the time of failure (in newtons), L is the distance between the supports (20mm), W is the mean specimen width and H is the mean specimen height (in milimeters) between the tension and compression surfaces.

Modulus of elasticity was also determined according to ISO Standard 4049 (ISO, 2000). The modulus of elasticity (E, in gigapascals) was determined from the load deformation profiles generated previously during the 3-point bend flexural testing according to the following formula:

$E= \Delta F/\Delta Y x L^3/4WH^3$

Where $\Delta F/\Delta Y$ is the change in force (ΔF) per unit change in deflection (ΔY) of the center of the specimen, L is the distance between the supports on the tension surface (20mm), W is the mean specimen width and H is the mean specimen height (in mm) between the tension and compression surfaces. The slope in newtons per millimeter was measured in the initial straight-line portion of the load deflection graph.

The 24 hours and 1 month data were subjected to statistical analyses with ANOVA and Duncan's multiple range tests ($p<0.05$).

RESULTS

Flexural Strength

The mean flexural strengths of the materials is shown in Table IIA,B, b and Figure 1. Mean flexural strength ranged from 78.95 to 130.83 at 24 hours. The ranking of the flexure strengths from lowest to highest was as follows:

Admira< Supreme Dentin< Artemis< Alert< Supreme body< TPH< Clearfil Photo Posterior.

At 1 month, mean flexural strength ranged from 66.06 to 137.09. Ranking of the flexural strengths was similar to the exception of the change in ranking between Supreme Body and Alert (Supreme Body< Alert).

Of the packable composites, Clearfil Photo Posterior, had the highest flexural strength at 24 hours ($p<0.05$) but no statistically significant difference was found from that of TPH at 1 month ($p=0.05$). The ormocer composite, Admira, exhibited the lowest flexural strength values but no statistically significant differences were found from those of Supreme Dentin, Artemis and Alert at 24 hours and those of Supreme Dentin and Artemis at 1 month ($p=0.05$).

TABLE II A

*Mean flexural strength values of the materials at 24 hours**

Test material	Mean flexural strength ± SD
Admira	78.95 ± 10.59 [a]
Supreme (Dentin)	80.88 ± 14.67 [a]
Artemis	88.10 ± 6.69 [ab]
Alert	90.08 ± 10.09 [ab]
Supreme (Body)	96.16 ± 10.62 [bc]
TPH	106.94 ± 7.91 [c]
Clearfil Photo Posterior	130.83 ± 11.65 [d]

F= 18.29, p<0.001

SD= Standard deviation

** Superscript letters indicate statistically homogeneous subsets (p>0.05)*

TABLE II B

*Mean flexural strength values of the materials at 1 month**

Test material	Mean flexural strength ± SD
Admira	66.06 ± 11.60 [a]
Supreme (Dentin)	68.11 ± 14.43 [a]
Artemis	70.77 ± 4.32 [a]
Supreme (Body)	92.75 ± 11.52 [b]
Alert	99.91 ± 14.10 [b]
TPH	127.69 ± 14.08 [c]
Clearfil Photo Posterior	137.09 ± 9.00 [c]

F= 40.67, p<0.001

SD= Standard deviation

** Superscript letters indicate statistically homogeneous subsets (p>0.05)*

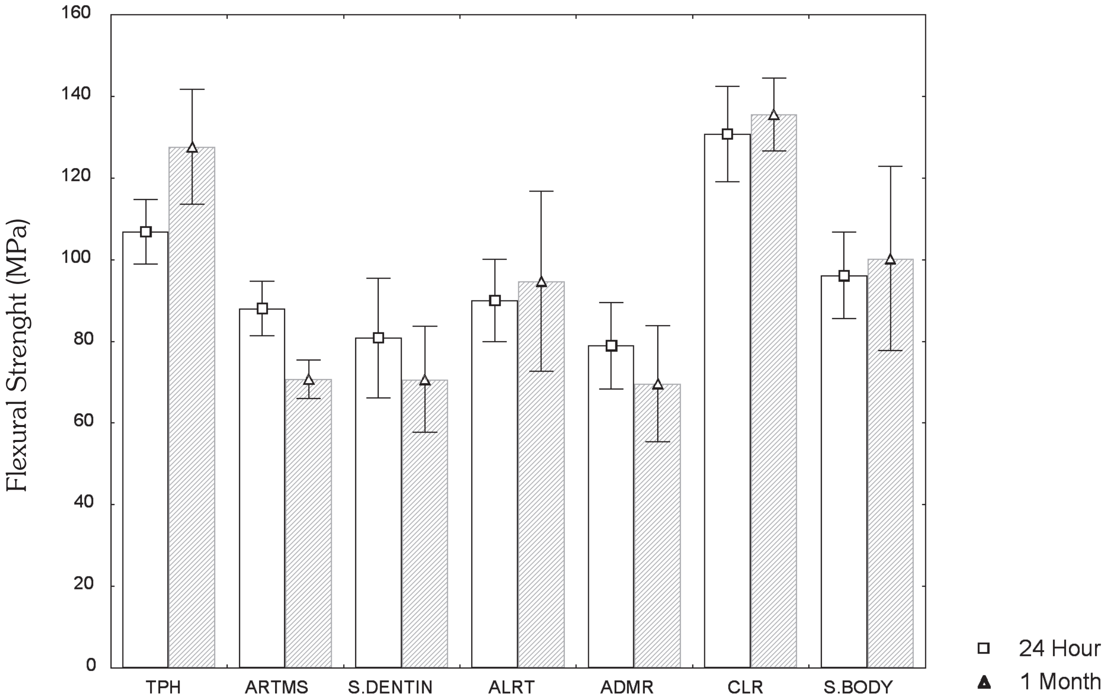

FIGURE 1

Flexural strength (MPa) of the materials used in the study. ARTMS= Artemis, S. DENTIN= Supreme Dentin, ALRT= Alert, ADMR= Admira, CLR= Clearfil Photo Posterior, S.BODY= Supreme Body

The nanofilled composite, Supreme Body, had statistically higher flexural strength values than those of Supreme Dentin at 24 hours and 1 month. Of the control hybrid composites, TPH, exhibited statistically higher flexural strength values than the other control composite, Artemis, at both times ($p<0.05$).

For most materials flexural strength did not change after aging in water for 1 month ($p=0.05$). The flexural strength of Artemis decreased whereas flexural strength of TPH increased significantly by aging ($p<0.05$).

Modulus of Elasticity

The mean modulus of elasticity of the materials are shown in Table IIIA,B and Figure 2. At 24 hours, mean modulus of elasticity ranged from 5.53 to 13.39. The ranking of elastic modulus from lowest to highest was as follows:

Artemis< Supreme Dentin< Admira< Supreme Body< TPH< Alert< Clearfil Photo Posterior.

At 1 month, mean modulus of elasticity ranged from 4.57 to 12.16. The ranking of modulus of elasticity was as follows:

TABLE III A

*Mean modulus of elasticity values of the materials at 24 hours**

Test material	Mean modulus of elasticity ± SD
Artemis	5.53 ± 0.50 [a]
Supreme (Dentin)	5.71 ± 0.92 [ab]
Admira	6.31 ± 0.43 [abc]
Supreme (Body)	6.54 ± 0.75 [bc]
TPH	6.90 ± 0.46 [c]
Alert	8.19 0.92 [d]
Clearfil Photo Posterior	13.39 1.37 [e]

F= 68.20, p<0.001

SD= Standard deviation

** Superscript letters indicate statistically homogeneous subsets (p>0.05)*

TABLE III B

*Mean modulus of elasticity values of the materials at 1 month**

Test material	Mean modulus of elasticity ± SD
Admira	4.57 ± 0.28 [a]
Artemis	4.65 ± 0.38 [a]
Supreme (Dentin)	5.95 ± 0.56 [b]
TPH	6.65 ± 0.92 [bc]
Supreme (Body)	7.22 ± 0.52 [c]
Alert	8.69 ± 0.69 [d]
Clearfil Photo Posterior	12.16 ± 0.87 [e]

F= 110.74, p<0.001

SD= Standard deviation

** Superscript letters indicate statistically homogeneous subsets (p>0.05)*

Admira< Artemis< Supreme Dentin< TPH< Supreme Body< Alert< Clearfil Photo Posterior

The two packable composites, Alert and Clearfil Photo Posterior exhibited higher modulus of elasticity values at 24 hours and 1 month. However, similar to the results of the flexural strength test, Clearfil Photo Posterior demonstrated the highest values among the other materials ($p<0.05$). Also as in flexural strength results, Supreme Body exhibited higher modulus of elasticity values than Supreme Dentin ($p<0.05$) and TPH exhibited higher modulus of elasticity values than Artemis ($p<0.05$). Although the lowest modulus of elasticity value was that of Artemis at 24 hours and of Admira at 1 month, no statistically significant difference was found between the two materials ($p=0.05$).

For most materials modulus of elasticity did not change after aging in water for 1 month ($p=0.05$). The modulus of elasticity of Artemis and Admira decreased significantly by aging ($p<0.05$).

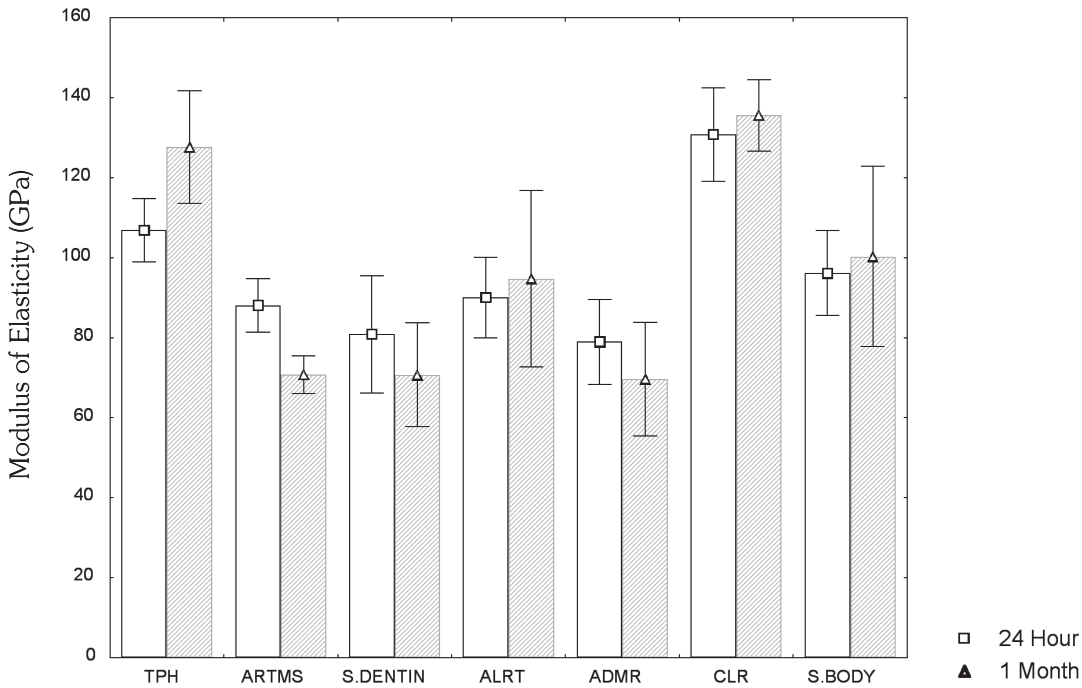

FIGURE 2

Modulus of elasticity (GPa) of materials used in the study. ARTMS= Artemis, S. DENTIN= Supreme Dentin, ALRT= Alert, ADMR= Admira, CLR= Clearfil Photo Posterior, S.BODY= Supreme Body

DISCUSSION

There has been a growing demand for esthetic restorative materials in posterior teeth[19]. The high filler loaded composites were developed in order to show better clinical performance when used as posterior restorative materials[5,20]. The packable, nanofilled and ormocer composites have all been developed with claims to offer better placement techniques as well as improved physical and mechanical properties than traditional hybrid composite resins by their manufacturers. However, no consistently better results were reported from in vitro studies regarding the superiority of these materials over hybrid composites[21-23].

In the present study, however, the packable composite resin Clearfil Photo Posterior exhibited the highest mean values for both flexural strength and modulus of elasticity, which seems to be the result of the highest filler load level (86% wt) and the largest average particle size (4 µm) of the material than those of the other materials used in the study.

The other packable composite, Alert, exhibited modulus of elasticity values close to those of Clearfil Photo Posterior. The higher modulus of elasticity of Alert was reported by other in vitro studies, and this was attributed to the high filler load level (84% wt) of the material[4,5,11,21]. In these studies, the flexural strength values of Alert were found to be statistically lower or equal to those of conventional hybrid composites[11,21]. Similarly, in the present study, the modulus of elasticity values of Alert was higher but flexural strength values were lower than those of the hybrid composite, TPH. This result is consistent with that of Cobb et al [22], who found the flexural strength of Alert statistically lower than that of TPH.

TPH, exhibited similar flexural strength values to those of Clearfil Photo Posterior at both time periods. However, the other control composite, Artemis, exhibited lower values in regard to flexural strength and modulus of elasticity than those of TPH. It is a well-known fact that the type, size, distribution and the amount of fillers influence the properties of composite resins[4,5,13,24-26]. However, Ikejima et al[4] found that the flexural strength of hybrid composites increased with increasing filler volume fraction between 0-52.2 vol% but did not increase further between 52.2-61.7 vol%. They concluded that flexural strength was correlated with filler fraction up to 60 vol%. Since the volume fraction of the two hybrid composites were similar (55-58%, 57% for Artemis and TPH, respectively) the lower values of Artemis were likely to be related to its smaller particle size than TPH (mean particle size 0.6 µm for Artemis and approximately 1µm for TPH). The authors also found that the modulus of elasticity of composites increased with and correlated with increasing filler volume fraction[4]. This finding is consistent with the results of this study, in which the two packable composites, Clearfil Photo Posterior and Alert, had the higher modulus of elasticity values than the other materials used in the study.

It was suggested that the composition of the resin matrix also influenced the mechanical and physical characteristics of composite resins[2,3]. The ormocer composite, Admira, exhibited the lowest flexural strength values at 24 hours and 1 month. The moduli of elasticity of the material were lower than those of the packable composites and TPH. Flexural strength and modulus of elasticity of ormocers statistically equal to or lower than those of hybrid composites were reported in the literature[11,23,27]. Moreover, Abe et al[28] reported lower modulus of elasticity values of Admira than those of Alert, as in the present study. These results confirm the suggestion that filler load level, fillers themselves and filler-matrix interactions rather than the composition of the organic matrix have an important effect on the mechanical and physical properties of composite resins[4,5,11].

The nanofilled composite resins are claimed to combine the strength of a hybrid and polish of a microfilled composite[9]. Supreme Body exhibited better flexural strength and modulus of elasticity values than those of Supreme Dentin. Differences in flexural strength and modulus of elasticity were reported between different shades of the same products due to the varying filler content and filler particle size[29]. However, no difference is mentioned in regard to filler load and composition between the two types of the material by the manufacturer. Therefore, the significantly high values of Supreme Body are of concern.

Flexure strength and elastic modulus tests based on ISO 4049 have been commonly employed in order to rank the restorative materials comparatively. In these studies, the effect of aging in water on the flexure strength and elastic modulus of restorative materials have been evaluated with varying time periods[28,30-32]. Musanje et al[33] suggested the use of artificial saliva rather than water. They also suggested that although there was no universally accepted time for testing the specimens, multiple testing at longer time periods having been included since early times might not reflect the later behavior of the materials. However, it was also stated that aging had little effect after 30 days and a little long term effect on the strength[34,35]. Therefore, in the present study, the aging period of the specimens was selected as 1 month.

The effects of aging in water on flexural strength and modulus of elasticity were found to be material dependent and were influenced by the balance between composite post-cure and the degradation by water[35,36]. Thus, in this study, the decrease in the flexural strength and modulus of elasticity of Artemis and modulus of elasticity of Admira by aging in water may be attributed to the water sorption effects, which cause the straining of the Si-O-Si bonds in the fillers and result in the complete or partial filler debonding[35,37,38]. There have been controversial reports regarding the effect of aging in water on the flexural properties of hybrid composites[29,35]. In contrast to the decreased modulus of elasticity and flexural strength of Artemis, an increase in flexural strength of TPH was observed in the present study. The different responses of the two hybrid composites to water aging may be related to the differences in the resin compositions and filler types. The increased flexure strength of TPH is consistent with that of Munksgaard[23], who also reported an increase in both flexural strength and modulus of elasticity of TPH by time and explained the situation by the continuous, albeit declining, conversion of vinyl groups.

In the present study there were no statistically significant differences in the flexural strength and modulus of elasticity of other materials. According to Munksgaard [23], water uptake might not have the same detrimental effect on the elastic modulus and on the flexural strength of materials. Moreover, the compensating effect of water uptake reduces the flexure strength and elastic modulus whiles the continuous, although declining, conversion of vinyl groups tends to increase the values.

Flexural strength test, in fact, is a combination of both compressive and tensile strength tests. While the stresses on the upper surface of the beam are compressive, the ones on the lower surface are tensile[17]. Flexural strength test is reported to be more discriminating and sensitive to subtle changes of the materials than compressive strength tests[39]. The major advantage of flexural strength and modulus of elasticity tests is that both the compressive and tensile strength and deformation can be assessed together[40].

Modulus of elasticity is an important parameter to determine a material's stiffness. A material with a low modulus of elasticity tends to display momentary displacements and micromovements under chewing forces. This condition results in the breakdown of the bond between the tooth structure and the restoration as well as fractures of the restorations[21, 41-43].

Tooth flexure occurs during function and parafunction which facilitates the initiation and progression of non-carious cervical tooth loss or lesions[40]. Restorative materials with lower modulus of elasticity are suitable for restoration of Class V cavity preparations since they flex in response to cervical deformation[44]. In the stress bearing Class I, II and IV cavity preparations a material with a high flexural strength is required to withstand the masticatory forces. Moreover, a high modulus of elasticity is necessary to maintain its shape under load[40].

The ISO has set 80 MPa as the minimum flexural strength for polymer-based filling and restorative materials claimed suitable for restorations involving the outer occlusal surfaces. All of the materials tested exceeded or came very close to fulfilling this requirement. However, among the materials tested in the study, the packable composite, Clearfil Photo Posterior, exhibited the highest flexural strength and modulus of elasticity values. Therefore, it would be the material of choice in situations in which the restoration is subjected to occlusal forces. Further long-term clinical studies need to be conducted.

CONCLUSIONS

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

1. Except for Clearfil Photo Posterior, the packable composites exhibited flexural strength values that are not substantially better than those of conventional hybrid composite, TPH.

2. The packable composites, Clearfil Photo Posterior and Alert had the highest modulus of elasticity owing to their high filler load than the other restorative materials.

3. The ormocer composite, Admira had the lowest values in regard to flexural strength and modulus of elasticity.

4. Supreme Body, had the higher flexural strength and modulus of elasticity than Supreme Dentin although no difference was reported in regard to filler load and composition between the two types of the same nanofilled composite by the manufacturer.

5. The effect of aging in water on the flexural strength and modulus of elasticity was material dependent. Although many of the materials were not influenced, aging in water significantly decreased the modulus of elasticity of the ormocer composite, Admira. The modulus of elasticity and flexural strength of Artemis decreased, whereas flexural strength of TPH increased significantly by aging.

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