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Effect of an Increase in Nano-Filler Content on the Mechanical Properties of High-Leucite Composite Resins Useable in Dentistry

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Abstract

Objective: Currently, a large number of studies are under way on the technologies used to prepare fillers and improve composite resins. The aim of the present study was to evaluate the physical properties of dental composite resins after incorporation of ceramic nano-fillers.

Materials and Methods: In the present study, high-leucite nano-fillers were incorporated into dental composite resins (a mixture of Bis-GMA [70%] and TEGDMA [30%]) at different concentrations. Then the mechanical properties of the resultant composite resins, including tensile and flexural strengths, were evaluated. The tensile and flexural strengths of the samples were measured with the use of a universal testing machine. Data were analyzed with *t* test, using SPSS 20.

Results: The results showed that the flexural strength in 10% nano-filler-reinforced composite resin group was significantly higher (56.05 ± 90.75 MPa) than that in the conventional composite resin group (51.4 ± 59.08 MPa) ($P < 0.05$). In addition, the tensile strength in the 10% nano-filler-reinforced composite resin group (48.3±43.03 MPa) was significantly higher than that in the conventional composite resin group (39.3 ± 27.83 MPa) ($P < 0.05$).

Conclusion: Based on the results of the present study, in composite resins containing 10 wt% of nano-fillers, the tensile and flexural strengths increased significantly.

Keywords: Composite resin, High-leucite, Tensile strength, Flexural strength

Introduction

Dental composite resins generally consist of 4 parts: an organic resin matrix, inorganic reinforcing fillers, a coupling agent and an activating agent. In general, the resin forms the matrix of composite resin and connects the filler particles through the coupling agent, keeping them together (1, 2).

In the majority of the composite resins, glass and glass compounds are used as fillers. Despite all the advances, it is still necessary to further evaluate the mechanical properties of dental composite resins, including strength, resistance and stability, for their use in areas with high tension. The fillers used in the manufacture of composite resins are predominantly silicate glass, and dental ceramics are seldom used. However, these glass fillers have a limited role in strengthening dental composite resins due to their low strength and the brittle nature of their structure (3).

Ellakwa et al evaluated the effect of polyethylene fibers on the flexural strength of composite resins and reported that the type and composition of the covering composite might have a more important role in determining the flexural properties of fiber-reinforced composite resins, and they might even be more effective than fibers in some cases (4).

Bae et al carried out a study on the effects of reinforcing fibers on the mechanical properties of dental composites. The results showed that the flexural strength of composites with lithium disilicate fillers was significantly higher than that of composites with leucite crystals and the flexural strength of composites with leucite fillers was significantly higher than that of composites containing glass fillers. There were no significant differences in the tensile strengths between the three groups (5).

In addition, Elsaka et al evaluated the effect of incorporation of titanium dioxide nanoparticles into glass-ionomer on its mechanical and antibacterial properties. In that study, 3, 5 and 7 wt% of titanium dioxide nanoparticles were incorporated into glass-ionomer. The results showed that incorporation of 3 and 5 wt% of titanium dioxide resulted in increases in compressive and flexural strengths of glass-ionomer; however, incorporation of 7 wt% of these nanoparticles resulted in a decrease in the mechanical properties mentioned above (6).

Foroutan et al evaluated the properties of composite resins reinforced with Al_2O_3 nanoparticle fillers and reported that samples with nano-fillers exhibited a 100% increase in flexural strength and an 80% increase in tensile strength (7).

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Sodagar et al (2012) evaluated the effect of incorporation of silver nanoparticles on the flexural strength of acrylic resins. They added the liquid of the acrylic resin with 0.05% and 0.2% concentrations of silver nanoparticles to 2 types of acrylic resin powder (Selecta Plus and Rapid Repair). The control groups consisted of acrylic resins without silver nanoparticles. The flexural strength in each group, consisting of 15 blocks of acrylic resin, was evaluated using the three-point bending technique. The results showed the highest flexural strength in the Rapid Repair group with no silver nanoparticles. Incorporation of 0.05% concentration of silver nanoparticles into Rapid Repair acrylic resin resulted in a significant decrease in flexural strength. However, incorporation of a higher concentration of silver nanoparticles up to 0.2% resulted in an increase in its flexural strength up to the baseline values. In contrast, incorporation of silver nanoparticles to Select Plus acrylic resin resulted in an increase in flexural strength; however, incorporation of 0.05% concentration of silver nanoparticles was more effective than incorporation of 0.2% concentration (8).

Mollazadeh et al showed during the synthesis and characterization of dental composites reinforced with ceramic glass particles (fluoroapatite–mullite) that the flexural strength was profoundly dependent on the composition of their particles; however, the diametral tensile strength and hardness were less sensitive to the composition of filler particles (9). Tavassoli Hojati et al studied the effect of incorporating Zinc oxide (ZnO) nanoparticles into flowable composite resins on their physical and mechanical properties and showed a significant increase in the compressive strength of these composite resins (10).

The aim of the present study was to evaluate the effect of high-leucite nano-fillers, which were produced by microabrasion of commercial IPS Empresses ceramic glass blocks, on the mechanical properties of dental composite resins.

Materials and Methods

In the present study, the tensile and flexural strengths of a conventional composite resin and composite resins reinforced with high-leucite nano-fillers were evaluated. For each test (tensile and flexural strength tests) a total of 35 samples (a total of 70 samples) were evaluated.

The resin was a mixture of Bis-GMA (70%) (Rohm-Degussa Huls Group Co., Germany) and TEGDMA (30%) with 1, 5, 10 and 20 wt% of nano-fillers. The materials were mixed manually. A mixture of 0.5 wt% of camphorquinone (CQ) (Fluka Co., Germany) and 0.05 wt% of amine (3-N-dimethy amino diethyl methacrylate) (Aldrich Co., Germany) was added to the composite as a photoinitiator. The filler was $KA_1Si_2O_6$ (high leucite) with a mean particle size of 5 µm, produced by microabrasion of IPS Empress ceramic blocks (with the trade name of Ivoclar-Vivadent). The fillers were dried in an oven at 80°C for 3 hours. Then the fillers were stored at room temperature (37°C) for 20 days to dry completely. High-leucite filler was added to the resin matrix at 1, 5, 10 and 20 wt% and then mixed. Then a photoinitiator was added to the paste. The composites were manufactured by dispersing the particles within the resin with the use of a solvent. The composite resins were mixed with different weight percentages of filler nanoparticles mentioned above and transferred into an ultrasonic homogenizer (Ultrasonic Sonopuls 2200, Germany) in order to achieve a properly homogeneous mix. Then the shapes of the samples (tensile and flexural) were determined based on ISO 1567 for the evaluation of each mechanical variable (11).

The flexural strength was determined with the use of a universal testing machine (Hounsfield, England) based on ISO 4049 (12).

Statistical Analysis

Data on tensile and flexural strengths of the samples were analyzed with *t* test, using SPSS 20.

Results

Flexural Strength

In this study, flexural strength values in the conventional composite resin group and the groups with composite resins reinforced with nanoparticles at 1%, 5%, 10% and 20% concentrations were 51.4 ± 59.08, 52.4 ± 85.08, 52.1 ± 11.77, 56.5 ± 90.75 and 58.5 ± 15.75 MPa, respectively. The most important consideration in relation to the material strength is the fact that the strength is not an inherent property of a material, i.e. the material strength depends on the material status and the technique used to determine its strength. In addition, the discrepancy between the results of studies might be attributed to various factors, including the preparation technique, the composite resin type and the amount and size of nanoparticles incorporated into the material. In fact, in the present study, as it was expected the ceramic fillers were more resistant to the tensions applied and overall they resulted in an increase in the flexural strength of composite resins Figure 1 and Table 1.

This might be explained by the fact that an increase in the weight percentage of filler results in an increase in the flexural strength of composite resin because a higher filler content gives rise to greater resistance to crack formation. In this context, micro-cracks in composite resins decrease

Table 1. The Means and Standard Deviations of Flexural Strength Values in Conventional Composite Resin and Composite Resins Reinforced With High-Leucite Fillers[a]

Group	No.	Mean	SD
Conventional composite	7	51.5914	4.08397
Composite with 1% filler	7	52.8554	4.08359
Composite with 5% filler	7	52.1110	1.77171
Composite with 10% filler	7	56.9069	5.75350
Composite with 20% filler	7	58.1529	5.75350

[a] One-way ANOVA: $F = 3.05$, P value = 0.032.

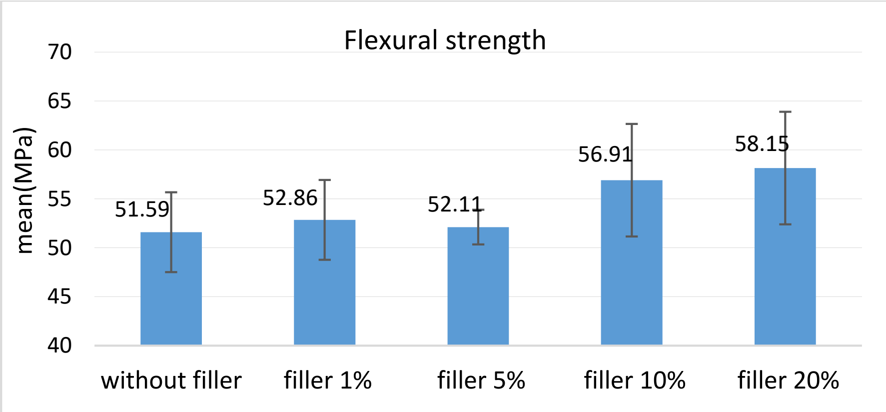

Figure 1. Comparison of Flexural Strengths Between Conventional Composite Resin and Composite Resins Reinforced With High-Leucite Fillers.

strength; therefore, a better bond between the resin and filler and silanization of the filler particles result in better conduction of tensions between the matrix and filler. On the other hand, since the flexural module of a composite depends on the ratio of filler module/matrix module and since the filler module is higher than the resin matrix module, an increase in filler content increases this properly of composite resin, resulting in an increase in the flexural strength of composite resin.

Table 2 presents two-by-two comparisons of composite resin groups in terms of flexural strength based on post hoc Tukey tests.

According to Table 2, conventional composite resin (with no filler) exhibited no significant different in flexural strength from composite resins containing 1% (P=0.606) and 5% filler (P=0.832); conventional composite resin exhibited significantly lower flexural strength compared to composite resins containing fillers at concentrations of 10% (P=0.036) and 20% (P=0.011). In addition, there was no significant difference in flexural strength between composite resins with 10% and 20% filler contents (P=0.611). The lowest flexural strength was recorded in conventional composite resin and composite resins with 1% and 5% filler contents; in this context, the highest flexural strength was recorded in composite resins with 10% and 20% filler contents. A lack of significant differences in flexural strength between conventional composite resin and composite resin with 1% and 5% filler contents showed that increasing the filler content up to 5% had no effect on the flexural strength of composite resins. In composite resins with 10% filler content, the flexural strength increased significantly; however, increasing the filler content up to 20% did not result in a significant increase in flexural strength. Since the flexural strength in composite resins with 10% and 20% filler contents was similar, composite resins with 10% filler content are recommended to prevent problems such as composite resin discoloration and changes in other physical and chemical properties of composite resins.

Tensile Strength

Table 3 and Figure 2 present the means and standard deviations of tensile strength values in conventional composite resin and composite resins reinforced with high-leucite fillers at different percentages.

Based on Figure 2, the tensile strengths in conventional composite resin and composite resins with 1%, 5%, 10% and 20% nano-filler contents were 39.3±27.83,

Table 2. The Results of Tukey Post Hoc Tests for Two-by-Two Comparisons of the Groups in Terms of Flexural Strength

(I)	(J)	Mean Difference (I-J)	P Value	95% CI	
				Lower Bound	Upper Bound
Without filler	1%	-1.2639	0.606	-6.2114	3.6834
Without filler	5%	-.51957	0.832	-5.4670	4.4278
Without filler	10%	-5.3154*	0.036	-10.2628	-0.3680
Without filler	20%	-6.5614*	0.011	-11.5088	-1.6140
1%	5%	.74441	0.761	-4.2030	5.6918
1%	10%	-4.0514	0.105	-8.9988	0.8960
1%	20%	-5.2974*	0.037	-10.2448	-0.3500
5%	10%	-4.7958	0.057	-9.7433	0.1515
5%	20%	-6.0418*	0.018	-10.9893	-1.0945
10%	20%	-1.246	.611	-6.1934	3.7014

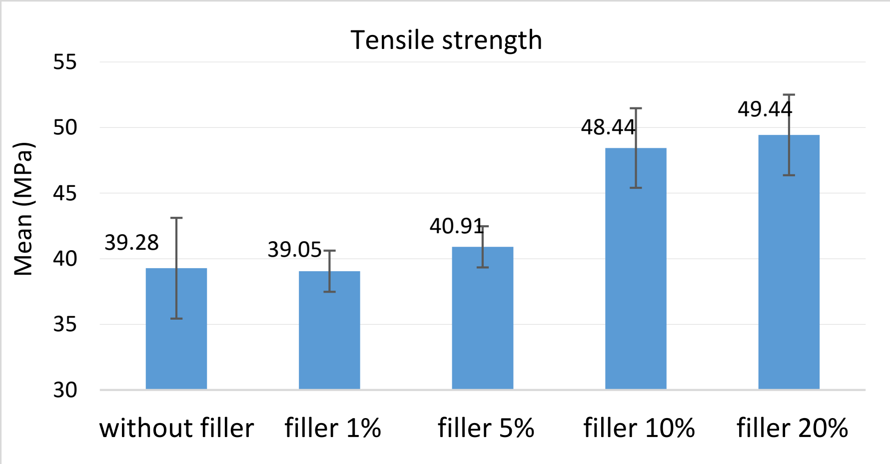

Figure 2. Comparison of Tensile Strengths Between Conventional Composite Resin and Composite Resins Reinforced With High-Leucite Fillers.

Table 3. The Means and Standard Deviations of Tensile Strength Values in Conventional Composite Resin and Composite Resins Reinforced With High-Leucite Fillers

Group	No.	Mean	SD
Conventional composite	7	39.2771	3.83881
Composite with 1% filler	7	39.0543	1.56950
Composite with 5% filler	7	40.9063	1.56950
Composite with 10% filler	7	48.4389	3.03773
Composite with 20% filler	7	49.4386	3.06950

[a] One-way ANOVA: F = 23.74, P value = 0.01.

39.1±50.56, 40.1±90.56, 48.3±43.03 and 49.3±43.06 MPa, respectively.

This might be explained by the fact that an increase in filler content results in an increase in its concentration in volume unit, decreasing the distance between the filler particles and reinforcing the bond between the filler and non-organic phase; therefore, there is an increase in adhesion and an improvement in composite resin bonding increases its tensile strength. On the other hand, an increase in filler content decreases displacements within the matrix phase, which in itself decreases the material's mechanical strength; therefore, it leads to an increase in the tensile strength of composite resin. Table 4 presents the results of two-by-two comparisons of composite resin groups in terms of tensile strength with post hoc Tukey tests.

The results showed that conventional composite resin (with no filler content) did not exhibit any significant differences in tensile strength from composite resins with 1% (P=0.415) and 5% (P=0.280) filler contents. The tensile strength of conventional composite resin was significantly less than that of composite resins with 10% (P=0.000) and 20% (P=0.000) filler contents. In addition, the tensile strengths of composite resins with 10% and 20% filler contents did not exhibit any significant difference (P=0.504). The lowest tensile strength was recorded in conventional composite resin and those with 1% and 5% filler contents. The highest tensile strength was recorded in composite resins with 10% and 20% filler contents. Since the tensile strengths in composite resins with 10% and 20% filler contents were similar, composite resins with 10% filler content are recommended to prevent problems such as composite resin discoloration and changes in other

Table 4. The Results of Tukey Post Hoc Tests for Two-by-Two Comparisons of the Groups in Terms of Tensile Strength

(I)	(J)	Mean Difference (I-J)	*P* Value	95% CI	
				Lower Bound	Upper Bound
Without filler	1%	1.2228	0.415	-1.798	4.244
Without filler	5%	-1.629	0.280	-4.651	1.392
Without filler	10%	-9.1617*	0.000	-12.183	-6.139
Without filler	20%	-10.1614*	0.000	-13.183	-7.139
1%	5%	-2.8520	0.063	-5.873	.1698
1%	10%	-10.3845*	0.000	-13.406	-7.362
1%	20%	-11.3843*	0.000	-14.406	-8.362
5%	10%	-7.5325*	0.000	-10.554	-4.511
5%	20%	-8.5323*	0.000	-11.554	-5.510
10%	20%	-0.9997	0.504	-4.0215	2.022

physical and chemical properties of composite resins.

Discussion

Studies have shown that strength is not an inherent property of a material; this means the strength is a function of the status of the material and the technique used to test its strength. In addition, the discrepancies between the results of studies might be attributed to several factors, including the preparation technique, the composite resin type and the amount and sizes of nanoparticles incorporated into the material (13). Foroutan et al reported a 100% increase in the flexural strength of composite resins reinforced with Al_2O_3 nanoparticles, consistent with the results of the present study (7). On the other hand, Sodagar et al reported that the effect of incorporating silver nanoparticles on the flexural strength of acrylic resins depends on various factors, including the type of the acrylic resin and the concentration of silver nanoparticles incorporated (8). The results of the present study showed that ceramic fillers were more resistant to mechanical stresses and in general they increased the flexural strength of composite resins; in this context, the least flexural strength was recorded in conventional composites and in those reinforced with 1% and 5% nanoparticles, and the highest flexural strengths were recorded in composite resins reinforced with 10% and 20% nano-fillers. It appears an increase in the weight percentage of nano-fillers results in greater resistance to micro-crack formation, increasing the flexural strength of composite rein; however, in conventional composite resins it decreases the flexural strength. In relation to the tensile strength, Foroutan et al reported an 80% increase in the tensile strength of composite resins reinforced with Al_2O_3 nanoparticle fillers (7). Nam et al reported that an increase in the amount of silver nanoparticles in the acrylic resin resulted in an improvement in its mechanical properties (13). The flexural strength is an indication of the restoration's longevity and durability (14). In the present study, the results of tensile strength test showed that this mechanical property was more favorable in ceramic fillers; in this context, the least tensile strength was recorded in conventional composite resin and in those reinforced with 1% and 5% nano-fillers, and the highest was recorded in composite resins reinforced with 10% and 20% nano-fillers. It appears incorporation of nano-fillers into the resin results in an increase in concentration in volume unit, decreases the distances between the particles, results in a decrease in displacements within the matrix and increases bonding between the nano-fillers and the inorganic phase, finally increasing the tensile strength of composite resin.

Conclusion

Based on the results, it appears incorporation of nano-fillers into high-leucite dental composite resins changes their mechanical properties. Incorporation of 5 wt% of nano-fillers into conventional composite resins did not result in any changes in their flexural and tensile strengths; however, when this amount increased to 10%, the tensile and flexural strengths increased. It should be pointed out that such an increase up to 20 wt% did not have any effect on the mechanical properties of composite resins. Therefore, it is suggested that composite resins with 10 wt% of nano-fillers be used in order to prevent problems such as discoloration of composite resin or other possible changes in other physical and chemical properties.

Ethical Issues

Not applicable.

Conflict of Interests

None to be declared.

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