

## Article

# Effect of Additional Dry Heat Curing on Microflexural Strength in Three Types of Resin Composite: An In Vitro Study

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**Abstract:** Aim: Additional dry heat curing is a method that favorably influences the mechanical properties of an indirect resin composite restoration. Microflexural strength is a property currently applied for the evaluation of indirect resin composite restorations. The aim of the present study was to assess the effect of additional dry heat curing on microflexural strength in three types of direct-use resin composites. Materials and Methods: This in vitro study consisted of 70 resin composites samples made with a 6 × 2 × 1 mm metal matrix and divided into seven experimental groups, which included Gr1a: Tetric N-Ceram without additional dry heat curing (n = 10); Gr1b: Tetric N-Ceram with additional dry heat curing (n = 10); Gr 2a: Filtek Z350 XT without additional dry heat curing (n = 10); Gr2b: Filtek Z350 XT with additional dry heat curing (n = 10); Gr3a: Filtek Z250 without additional dry heat curing (n = 10); Gr3b: Filtek Z250 with additional dry heat curing (n = 10); and Gr4: SR Nexco Paste (control) without additional dry heat curing (n = 10). The samples were stored in distilled water at 37 °C for 24 h. A universal testing machine with a 2000 N load cell at a speed of 1 mm/min was used to assess flexural strength. The data were analyzed with a parametric ANOVA test with Tukey’s post hoc intergroup factor (for groups without heat treatment) and a nonparametric Kruskal Wallis test with Bonferroni’s post hoc (for groups with heat treatment). In addition, the comparison of independent groups in each resin composite type with and without heat treatment was performed with a Mann Whitney U test. A significance level of  $p < 0.05$  was considered. Results: The Filtek Z250 resin composite with and without additional dry heat curing presented the highest microflexural strength values with  $137.27 \pm 24.43$  MPa and  $121.32 \pm 9.74$  MPa, respectively, while the SR Nexco Paste (control) resin composite presented the lowest microflexural strength values with  $86.06 \pm 14.34$  MPa compared to all the resin composites with additional dry heat curing. The Filtek Z250 and Filtek Z350XT resin composites with and without additional dry heat curing presented significantly higher microflexural strength versus the SR Nexco ( $p < 0.05$ ) and Tetric N-Ceram ( $p < 0.05$ ) resin composites. In addition, the Filtek Z350XT and Tetric N-Ceram resin composites with additional dry heat curing showed significantly higher microflexural strength ( $p < 0.05$ ) compared to those without additional dry heat curing. Conclusions: The Filtek Z250 and Z350XT resin composites had significantly higher microflexural strength values with and without additional dry heat curing. In addition, the Filtek Z350XT and Tetric N-Ceram resin composites subjected to additional dry heat curing showed significantly higher microflexural strength compared to when they did not receive the same procedure, a situation that did not occur with the Filtek Z250 resin composite.

**Keywords:** resin composite; microflexural strength; dentistry; complementary polymerization; mechanical properties; heat treatment

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## 1. Introduction

Resin composites, introduced by Bowen in the 1960s [1–3], are the most commonly used material for direct restorations with esthetic compromise. In clinical situations with considerable loss of tooth structure due to caries, wall and/or cusp fracture, or occlusal surface wear, direct resin composite restorations are overdemanding and challenging [4–6]. To solve these situations, indirect restorative techniques are used to achieve better interproximal contacts, less polymerization shrinkage, and a better marginal seal due to the polymerization process [7], since they are made outside the oral cavity in the dental clinic by professionals or can also be worked on in a dental laboratory [4,6,7].

Indirect inlays restorations based on a resin composite have gained importance due to the simplicity of their preparation, their good mechanical properties against wear and fracture, their favorable finishing and polishing capabilities [8], and their evolution in using new additives in their components, such as zirconia ( $ZrO_2$ ) and silica nanoparticles that enhance the behavior and longevity of restorations [4,5,9,10].

In order to enhance the resin composite properties as an indirect material and to counteract some problems (polymerization shrinkage, complete or partial fracture of restoration margins, and color changes), this material presents new techniques that are proposed after light curing [10–13]. Monteza [4], Grazioli [14], and other authors [15–17] have proposed subjecting resin composites to complementary heat curing processes; thus, this increases their conversion degree and generates greater rigidity and resistance to color changes and fractures [18,19].

Different methods of extraoral additional activation, including activation by dry heat and autoclaving, were proposed to improve physical and mechanical properties, and enable the use of direct-use composite resins in indirect restorations [14–19]. For Grazioli [14], Lepequeur [20], and Leao [21], dry heat is a technique that provides excellent results on microflexural strength of a resin composite for indirect use. Microflexural strength is understood as the mechanical property that allows determining the flexural deformation degree that a material can have, being of consideration in indirect resin composite restorations, since this property confers resistance to different occlusal loads [4,22–27].

Therefore, the aim of the present study was to assess the effect of additional dry heat curing on microflexural strength in three types of direct-use resin composites.

## 2. Materials and Methods

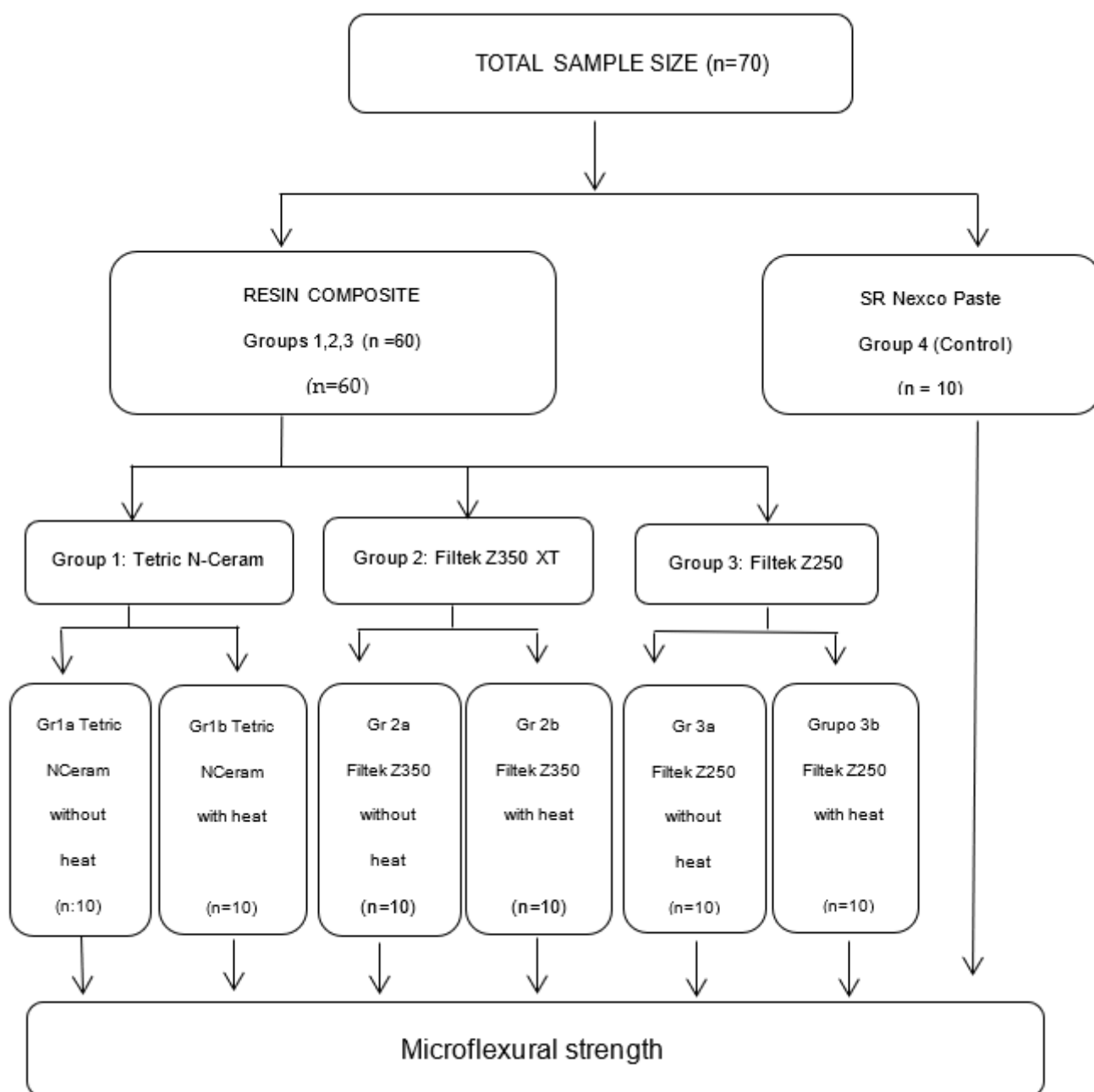
### 2.1. Type of Study and Delimitation

This *in vitro*, randomized, controlled, experimental study was conducted at the Faculty of Dentistry of Universidad Nacional Federico Villarreal and in the High Technology Laboratory Certificate (ISO/IEC Standard: 17025), Lima, Peru, from August to October 2021, with approval letter No.001-2021-COVID-19-FO-UNFV. The present study considered the CRIS Guidelines (Checklist for Reporting In-vitro Studies) [28].

### 2.2. Sample Calculation and Selection

A total sample of 70 resin composites blocks was prepared and standardized. The sample size per group was 10 resin composite blocks ( $n = 10$ ) and was calculated based on a one-way analysis of variance in G\*Power statistical software version 3.1.9.7; this was made possible by data obtained in a previous pilot study with 7 groups and 5 sample units per group, considering a significance level ( $\alpha$ ) = 0.05, a statistical power ( $1 - \beta$ ) = 0.80, and an effect size of 0.48. Finally, the 70 sample units were equally distributed in a simple

randomized manner without replacement in seven groups according to treatment and control (Figure 1).



**Figure 1.** Random distribution of groups according to the sample size.

### 2.3. Variables

The variables included in the present study were dry heat treatment, resin composites, and microflexural strength.

### 2.4. Sample Characteristics and Preparation

Samples of the Filtek Z350XT (3M ESPE, Maplewood, MN, USA) and Tetric N-Ceram (Ivoclar Vivadent, Schaan, Liechtenstein) direct-use nanohybrid composite resins, as well as samples of the Filtek Z250 (3M ESPE, Maplewood, MN, USA) direct-use microhybrid composite resins, were used for the present study. Samples of the SR Nexco ceromer (Ivoclar Vivadent, Schaan, Liechtenstein) were used as controls (Table 1). All the samples used

were of A2 color. These were prepared with standardized molds that were 6 mm long, 1 mm deep, and 2 mm wide [24,25,27]. The resin composite was applied inside the standardized mold (on a glass microscope slide) with a Teflon spatula. When filling was completed, it was covered with a polyester strip and light pressure was applied with another glass microscope slide to obtain a smooth surface and remove excess. The resin composite was then light cured at two points equidistant from the center and ends with a 3rd generation light emitting diode (LED) light-curing lamp (Valo—Ultradent, South Jordan, UT, USA) in contact with the polyester strip (0.05 mm thick) at a distance of 2 mm between the tip of the light guide and the surface of the resin composite at an angle of 90° for 20 s, and at a light intensity of 1000 mW/cm<sup>2</sup>. The samples were measured with a digital Vernier (Mitutoyo, Kawasaki, Kanagawa, Japan) and then distributed for each type of resin composite in two groups, applying only to one group the additional dry heat curing in an oven at 170 °C for 5 min. The control group with the SR Nexco paste did not receive dry heat as an additional technique.

**Table 1.** Description of the resin composites used in this study.

Resin Composite	Descriptions	Compositions	Photoinitiator System	Manufacturer
Filtek Z250	Microhybrid, methacrylate-based resin composite	<p><b>Matrix:</b> bisphenol A glycol dimethacrylate (Bis-GMA), bisphenol A ethoxylated, methacrylate (Bis-EMA), urethane dimethacrylate (UDMA), triethylene glycol dimethacrylate (TEGDMA), and polyethylene glycol dimethacrylate (PEGDMA).</p> <p><b>Fillers:</b> 1. Surface-modified zirconia/silica with a particle size of 0.1–10 microns (median approximately 3 microns or less). 2. Nonagglomerated/non-aggregated 20 nanometer surface-modified silica particles. The filler loading is 81.8% by weight (67.8% by volume).</p>	CQ (camphorquinone)	3M ESPE Dental Products, St Paul, MN, USA
Filtek Z350 XT	Nanohybrid, methacrylate-based resin composite	<p><b>Matrix:</b> Bis-GMA, UDMA, Bis-EMA, PEGDMA, and TEGDMA resins.</p> <p><b>Fillers:</b> a combination of non-agglomerated/non-aggregated 20 nm silica filler, non-agglomerated/non-aggregated 4 to 11 nm zirconia filler, and aggregated zirconia/silica cluster filler (comprised of 20 nm silica and 4 to 11 nm zirconia particles). The inorganic filler loading is about 72.5–87.5 wt%.</p>	CQ (camphorquinone)	3M ESPE Dental Products, St Paul, MN, USA
Tetric N-Ceram	Nanohybrid, methacrylate-based resin composite	<p><b>Matrix:</b> Bis-GMA, UDMA, Bis-EMA, PEGDMA, and TEGDMA resins.</p> <p><b>Fillers:</b> a combination of non-agglomerated/non-aggregated 20 nm</p>	CQ (camphorquinone and TPO) diphenyl (2,4,6-trimethylbenzoyl) phosphine oxide	Ivoclar-Vivadent, AG, 9494 Schaan/Liechtenstein

		silica filler, non-agglomerated/non-aggregated 4 to 11 nm zirconia filler, and aggregated zirconia/silica cluster filler (comprised of 20 nm silica and 4 to 11 nm zirconia particles). The inorganic filler loading is about 56 wt%		
		<b>Matrix:</b> UDMA, Aliphatic Dimethacrylate (16.9%wt)		
SR Nexco paste	Nanohybrid	<b>Fillers:</b> silicon dioxide (19.8%wt) prepolymer and co-polymer, which consists of pre-polymerised ground up UDMA matrix and inorganic microfiller particles (62.9%wt.)	CQ (camphorquinone)	Ivoclar Vivadent, Schaan, Liechtenstein

The indirectly applied SR Nexco laboratory composite resin was light-cured for 20 s, then received its conventional additional treatment in the Lumamat 100 chamber (Ivoclar Vivadent, Schaan, Liechtenstein) for 25 min [15].

Subsequently, all the samples were stored for 24 h in open glass containers with distilled water at 37 °C.

### 2.5. Microflexural Strength Test

After the storage time, the 70 samples were subjected to microflexural strength evaluation using the three-point method on a universal testing machine (CMT-5L, 7419 series, Liangong Group, Liaocheng, Shandong, China) [27], with a cell load of 2000 N at a speed of 1 mm/min and a distance of 4 mm between supports (Figure 2). Once the data in Kg/N (maximum load applied to the samples) was obtained, a formula was applied to determine the microflexural strength of the resin composites blocks in Megapascals (MPa). The formula for calculating the microflexural strength was:

$$\sigma_u = \frac{3Fl}{2bh^2}$$

where:

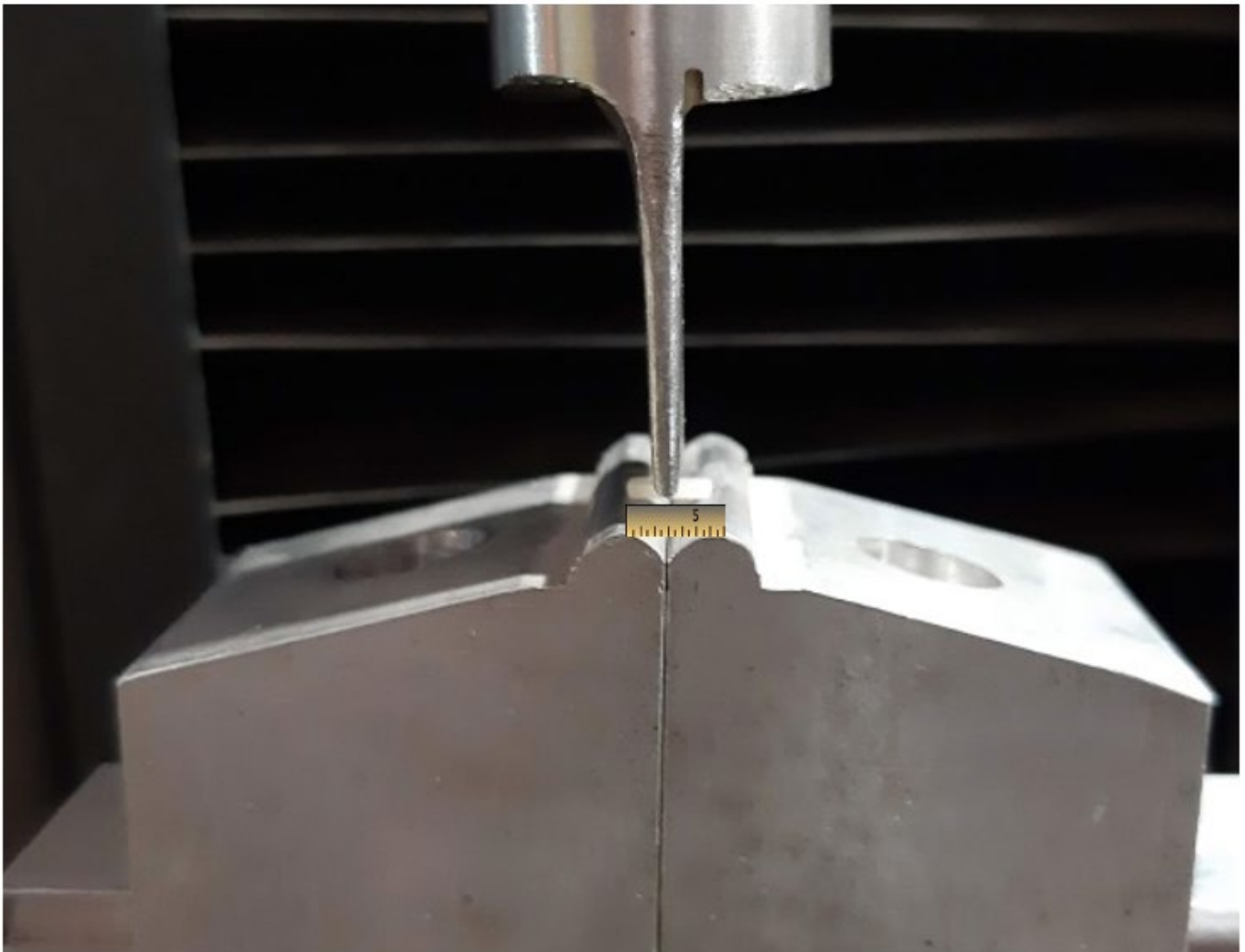
$\sigma_u$  = microflexural strength (MPa)

$l$  = distance between supports (mm)

$F$  = maximum load (N)

$b$  = width of the specimen (mm)

$h$  = height of the specimen (mm)



**Figure 2.** Measurement of microflexural strength with the universal testing machine. The dimensions of the resin composite block were as follows: 6 mm long, 1 mm deep, and 2 mm wide.

### 2.6. Statistical Analysis

The data were entered into a Microsoft Excel 2019® spreadsheet and imported by SPSS (Statistical Package for the Social Sciences Inc. IBM, New York, NY, USA) version 24.0. For descriptive analysis, measures of central tendency and dispersion such as mean and standard deviation were used. To test the hypothesis, statistical assumptions of the variable of interest were previously verified by the Shapiro Wilk normality test, Levene's homoscedasticity test, and the randomization test by Wald-Wolfowitz. Depending on the fulfillment of assumptions, the decision was taken to apply the parametric ANOVA test with an intergroup factor and Tukey's post hoc (for groups without heat treatment) and the nonparametric Kruskal Wallis test with Bonferroni's post hoc (for groups with heat treatment). In addition, for the comparison of independent groups in each type of composite resin with and without heat treatment, the Mann Whitney U test was used. A significance level of  $p < 0.05$  was considered for all comparisons.

### 3. Results

When comparing the microflexural strength values between the Filtek Z350, Tetric N-Ceram, and Filtek Z250 resin composites without additional dry heat curing, significant differences can be observed between the groups ( $p < 0.001$ ), including the control group. In addition, it could be seen that the average obtained in all the resin composites of direct

use was higher than the control group; the Filtek Z250 obtained the highest values of microflexural strength (Table 2).

**Table 2.** Comparison of microflexural strength without additional dry heat curing, according to the type of resin composite.

Type of Resin Composite	n	Mean	SD	SE	95% CI		Mín	Máx	p-Value <sup>c</sup>	p-Value <sup>b</sup>	p-Value <sup>a</sup>
					LL	UL					
Tetric N-Ceram	10	88.17	6.06	1.92	83.83	92.51	80.22	100.97	0.549		
Filtek Z250	10	121.32	9.74	3.08	114.35	128.29	104.96	136.22	0.972		
Filtek Z350 XT	10	111.62	12.45	3.94	102.71	120.52	92.39	135.93	0.924	0.062	<0.001 *
SR Nexco Paste (control)	10	86.06	14.34	4.54	75.80	96.32	68.41	109.19	0.339		

n: sample; SD: standard deviation; SE: standard error; 95% CI: 95% confidence interval; LL: lower limit; UL: upper limit; Min: minimum value; Max: maximum value; a: one-factor inter-subject ANOVA test (\*  $p < 0.05$ : significant differences); b: Test de Levene ( $p > 0.05$ , homogeneous variances); and c: Test de Shapiro Wilk ( $p > 0.05$ , normal distribution).

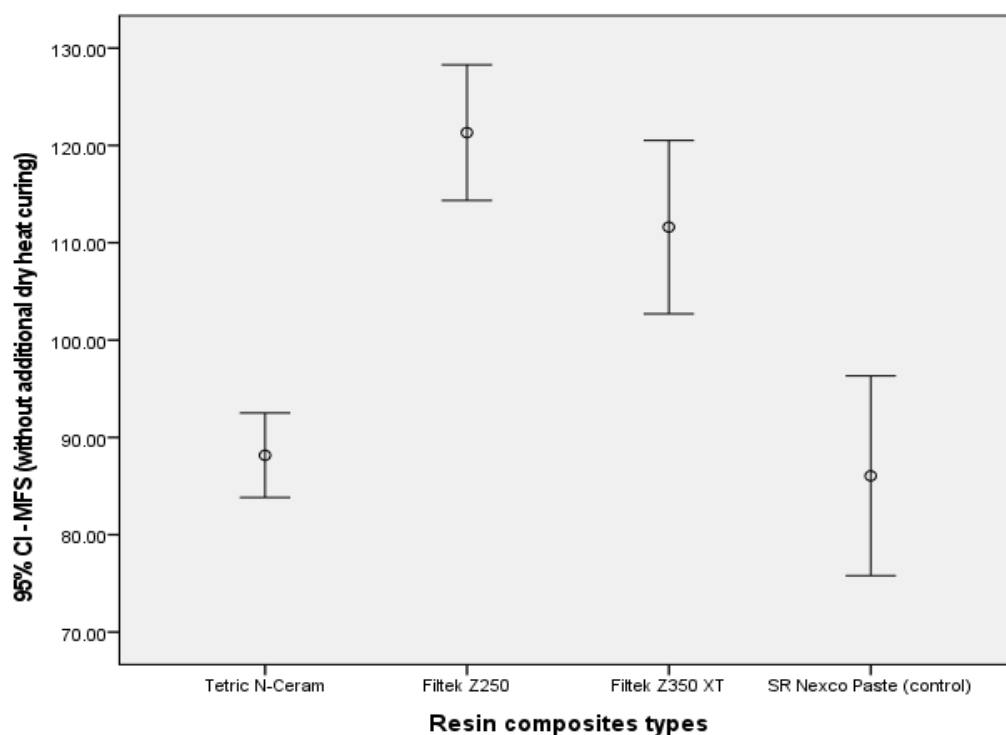
When multiple comparisons were made between the resin composite groups and the control group, both without additional dry heat curing, significant differences were observed between the Tetric N-Ceram with the Filtek Z250 ( $p < 0.001$ ) and the Filtek Z350 XT ( $p < 0.001$ ). In the same way, significant differences could be observed between the control group with the Filtek Z250 ( $p < 0.001$ ) and the Filtek Z350 XT ( $p < 0.001$ ). There were no significant differences between the Tetric N-Ceram and the control group (Table 3).

**Table 3.** Multiple comparisons between the resin composite types without additional dry heat curing, according to Tukey's post hoc test.

Tukey's Test	Filtek Z250	Filtek Z350 XT	SR Nexco Paste (Control)
Tetric N-Ceram	<0.001 *	<0.001 *	0.974
Filtek Z250	-	0.223	<0.001 *
Filtek Z350 XT	0.223	-	<0.001 *

\*  $p < 0.05$ : significant differences.

Figure 3 shows that the Filtek Z250 and Filtek Z350 XT resin composites had significantly higher microflexural strength than the Tetric N-Ceram resin composite and the control group.



**Figure 3.** Multiple comparisons of the mean (with a 95% confidence interval) of microflexural strength (MFS) between the resin composite types without additional dry heat curing.

When comparing the microflexural strength values presented by the Filtek Z350, Tetric N-Ceram, and Filtek Z250 resin composites, all with additional dry heat curing, significant differences were observed between the groups ( $p < 0.001$ ), including the control group. In addition, it could be seen that the average obtained by all direct-use resin composites was higher than the control group, with the Filtek Z250 obtaining the highest values of microflexural strength ( $p < 0.001$ ) (Table 4).

**Table 4.** Comparison of microflexural strength with additional dry heat curing, according to the type of resin composite.

Type of Resin Composite	n	Median	IQR	Mean	SD	Min	Max	$p$ -Value <sup>c</sup>	$p$ -Value <sup>b</sup>	$p$ -Value <sup>a</sup>
Tetric N-Ceram	10	95.86	10.94	95.06	6.78	80.78	101.75	0.188		
Filtek Z250	10	143.36	39.77	137.27	24.43	103.18	181.73	0.604		
Filtek Z350 XT	10	136.55	13.34	134.85	13.99	104.33	152.81	0.293	0.006	<0.001 *
SR Nexco Paste (control)	10	81.11	24.47	86.06	14.34	68.41	109.19	0.339		

n: sample; IQR: interquartile range (P75–P25); SD: standard deviation; SE: standard error; 95% CI: 95% confidence interval; LL: lower limit; UL: upper limit; Min: minimum value; Max: maximum value; a: Kruskal-Wallis H-test ( $* p < 0.05$ : significant differences); b: Levene's test ( $p > 0.05$ , homogeneous variances); and c: Shapiro Wilk test ( $p > 0.05$ , normal distribution).

When multiple comparisons were made between the groups of direct resin composites with additional dry heat curing and the control group, significant differences were observed between the Tetric N-Ceram with the Filtek Z250 ( $p = 0.003$ ) and the Filtek Z350 XT ( $p = 0.006$ ). Similarly, significant differences could be observed between the control group with the Filtek Z250 ( $p < 0.001$ ) and the Filtek Z350 XT ( $p < 0.001$ ) resin composite. In addition, the Tetric N-Ceram resin composite did not show significant differences with the control group (Table 5).



**Table 5.** Multiple comparisons between the types of additional dry heat curing resin composites, according to the post hoc test with Bonferroni correction.

Post Hoc Test	Filtek Z250	Filtek Z350 XT	SR Nexco Paste (Control)
Tetric N-Ceram	0.003 *	0.006 *	1.000
Filtek Z250	-	1.000	<0.001 *
Filtek Z350 XT	1.000	-	<0.001 *

\*  $p < 0.05$ : significant differences.

When performing individual analysis between the resin composite groups, without and with additional dry heat curing, it was observed that the nanohybrid resin composites Tetric N-Ceram and Filtek Z350XT presented significant differences in their microflexural strength ( $p = 0.023$  and  $p = 0.004$ , respectively) (Table 6).

**Table 6.** Comparison of microflexural strength, with and without additional dry heat curing, according to the type of resin composite.

Type of Resin Composite	Heat Treatment	n	Median	IQR	Z	U	$p$ -Value <sup>a</sup>
Tetric N-Ceram	Without	10	86.59	8.22	−2.269	20.00	0.023 *
	With	10	95.86	10.94			
Filtek Z250	Without	10	120.84	14.85	−1.361	32.00	0.174
	With	10	143.36	39.77			
Filtek Z350 XT	Without	10	111.00	15.45	−2.873	12.00	0.004 *
	With	10	136.55	13.34			

n: sample; IQR: interquartile range; Z: approximation to normal distribution; and U: Mann Whitney U test (\*  $p < 0.05$ : significant differences). Note: the control group was not compared since SR Nexco Paste is only used with heat treatment.

#### 4. Discussion

Several studies [4,29–32] have assessed the flexural strength of direct-use resin composites following the guidelines of the International Organization for Standardization (ISO) 4049–2019 [23], which suggests a geometric dimension with a unit of analysis (resin bar) that does not adjust to the clinical reality; thus, this may generate some controversy in respect of results. Yap et al., concluded in their study that microflexural tests on resin composites gave higher values than flexural tests regardless of the conditioning medium, either air or artificial saliva. Therefore, the use of microflexural testing shows promise as a replacement for flexural testing in view of its significant correlation, clinical relevance, and higher efficiency [26].

In the present study as well as in other studies, good results have been found when evaluating microflexural strength using a smaller size resin composite block with dimensions of  $6 \times 1 \times 2$  mm [24–26], being closer to the measurements of an inlay preparation. These dimensions allow light curing at a single time, compared to the blocks used for flexural strength testing ( $25 \times 2 \times 2$  mm) recommended by ISO 4049–2019 [23], which need to be light cured in multiple cycles; this results in certain areas receiving greater irradiation, which can affect the uniformity of light curing and, thus, bias the results [23–26]. This is in agreement with Askary et al., who reported that sample size and curing distance significantly affect flexural strength values, as samples larger than the lamp tip require multiple shots to light cure [33].

Microflexural strength can be changed not only by the type of test used but also by other external and internal factors that affect the effectiveness of light curing [26]. External factors related to operator technique include light curing time, exposure to elevated temperature after light curing, and characteristics of the light-curing unit, including the distance between the tip of the light guide and the surface of the restoration [24,25]. Internal factors affecting light-curing efficiency are related to resin properties and composition,

such as the monomer, photoinitiator system, concentration levels, filler type and size, as well as the shade and pigments [25,26,33].

In their study, Al Zain et al., assessed the light-curing distance factor on the microflexural strength of the Filtek Z250 and Tetric Evoceram resin composites, the latter having very similar characteristics to the Tetric N-Ceram. It was concluded that light curing at distances of 2 or 8 mm from the resin composite surface did not significantly affect microflexural strength; thus, the 1 mm thick samples may have allowed light to reach the bottom of each resin composite block, which resulted in favorable strength. Therefore, this could indirectly indicate satisfactory light curing [34]. On the other hand, the distance at 0 mm is generally not clinically achievable, since the distance between the lamp tip and the gingival floor of a proximal box can reach up to 8 mm of distance; thus, the distance of 0 mm is not clinically relevant [25]. Because of these findings, it was decided in the present study to light cure at a distance of 2 mm.

It has been reported that the exposure of composite restoration to additional heat-curing methods by dry or moist heat allows for increased microhardness efficiency, flexural strength, fracture toughness, wear resistance, increased tensile strength, and increased color stability in the restorative treatment [4,14,20,22]. Furthermore, additional heat curing results in the increased conversion of monomers into stable polymer chains [24,25].

It should be pointed out that in the present study, additional dry heat curing at 170 °C for 5 min was used instead of the wet heat autoclave method, since according to Monteza et al. [4] and Oskar et al. [35], water decreased the properties of the Filtek Z350XT resin composite by up to 36.4%. This could be because when immersing the resin composite in water to undergo the heat-curing process, its properties are affected by the correlation of absorption and solubility that its organic matrix possesses [36]. Another reason that reinforced the idea of using oven dry heat for additional heat curing was that such equipment is usually present in dental offices and offers cost advantages compared to processing indirect restorations [11,15]. In addition, exposure of a resin composite to dry heat has been reported to have positive effects by increasing the internal temperature of the material to above 100 °C, improving its physical and mechanical properties due to the increased mobility of unreacted monomers in the polymeric network [15,16]. This leads to a higher degree of matrix conversion (from 80 to 85%) [17] and a higher crosslink density of the network, including some degree of relaxation of the polymerization stress; this is because some of the unreacted monomers volatilize during the heating process, favoring a higher stability and toughness of the resin composite [14,17].

When comparing the resin composite groups, it was observed that the microhybrid Z250 and the nanohybrid Filtek Z350XT significantly increased their microflexural strength values when additional dry heat curing was applied; this is in agreement with the results obtained by Grazioli et al., Almeida et al., and Ferreira et al. [14,15,18]. The presence of zirconia and silica particles found in the content of such resin composites make it possible to improve their mechanical properties [25]. The effect of additional thermal activation on microflexural strength depends mainly on the composition, since the Bis-GMA (bisphenol glycidyl methacrylate) present in Filtek Z250 and Filtek Z350 has a low degree of conversion due to its high molecular weight, high viscosity, and low flexibility characteristics. However, the addition of diluent monomers with higher flexibility, such as EGDMA (ethylene glycol dimethylacrylate) or TEGDMA (triethylene glycol dimethacrylate), improves the mobility of Bis-GMA and its polymerization conversion rate [17]. Another alternative to Bis-GMA is the monomer UDMA (urethane dimethacrylate) included in Filtek Z250 and Filtek Z350XT, which has a similar molecular weight, but a lower viscosity than Bis-GMA [15–17]. The choice of these resin composites Z250 and Z350 XT is based on the fact that they are very frequently selected refractory restorative materials in scientific article methodologies. Their particle size and distribution, the type of filler particles, and the shape and silanization of the matrix in their composition make it

possible to obtain optimum results of microhardness or other mechanical properties [14–16].

In addition, the present study used SR Nexco as a control group because it is a laboratory resin composite widely used in inlays and onlays; it is necessary to know if it presents a lower or higher microflexural strength and, thus, confirm whether the resin composites of indirect laboratory processing are the gold standard or the first choice because of their good clinical performance [36–39]. It is also known that the SR Nexco paste has a lower degree of conversion due to the presence of a tetraacrylate monomer in the material formulation [40]. Acrylates are known for their high reactivity and the presence of many functional groups, which can lead to vitrification of the polymer and the onset of self-deceleration of polymerization; this could explain the low microflexural strength observed, compared to direct-use resin composites [15,40,41].

Third-generation LED lamps are light-curing devices with light intensity that can vary from 800 to 1500 mW/cm<sup>2</sup> with a wavelength range from 395 to 515 nm [42,43]. The difference in intensity and wavelength can be key to achieving optimal polymerization as the complete activation of photoinitiators in the deepest part of a restoration depends on it [43]. In the present study, the resin composites were photopolymerized with a third generation Valo<sup>®</sup> LED lamp (average light intensity: 1000 mW/cm<sup>2</sup>; wavelength: 395 to 480 nm) for 20 s at a distance of 2 mm [44]; this is so because it has been reported that this type of lamp allows the activation of photoinitiators such as camphorquinone (CQ) contained in Filtek Z250 and Filtek Z350 XT, and Lucirin TPO (monoacylphosphine oxide) included in Tetric N-Ceram [24,45,46]. Al-Zain and Marghalani [24,25], attributed as influencing factors to the photoinitiator system, argued that CQ is activated with exposure to longer blue light wavelengths, and TPO is highly reactive with high absorption and is activated with exposure to shorter violet light wavelengths. When TPO is activated, free radical growth centers are generated and form a polymer network at a faster rate compared to CQ. However, due to the high reactivity of TPO, more free radicals may occur within the polymer network compared to CQ, which affects the quality of curing. This may explain the significant differences in microflexural strength between the Filtek Z250 and Z350XT resin composites versus the Tetric N-Ceram. Another factor to consider regarding Tetric N-Ceram would be its filler type based on barium glass, ytterbium trifluoride, and pre-polymeric mixed oxides; as radiopaque agents and in high concentrations, they decrease the microflexural strength [24]. Since the manufacturer has not yet disclosed the concentration of its components, it can be assumed that the radiopaque agents are in high concentrations; this could have partially contributed to the lower microflexural strength of the Tetric N-Ceram versus the Filtek Z250 and Z350XT. The presence of zirconia and silica particles may improve the mechanical properties of the material, which may explain the significantly higher microflexural strength for the Filtek Z250 and Z350XT [24,25].

The present study is important because it provides an alternative to increase the microflexural strength of nanohybrid resin composites through the use of dry heat, since these resins significantly improved their microflexural strength when subjected to additional dry heat curing. More studies are needed to compare other nanohybrid resin composites with additional heat curing, taking into account other mechanical properties such as microhardness and surface roughness [6,47]. In addition, it would be advisable to perform thermogravimetric analysis (TGA/DSC) of resin composites just before additional dry heat curing at 170 °C; this should be conducted in order to verify if this additional procedure changes the composite weight, optimizing its mechanical properties [48,49]. It is also recommended to assess the effects of additional heat treatments on different resin composites, taking into account important parameters such as water absorption, moisture retention, differential scanning calorimetry, and Young's modulus.

Among the limitations of the present study, it is important to recognize that the data obtained should be taken with caution, since an *in vitro* study cannot be extrapolated to the clinical field. However, this lays the foundation for future randomized controlled

clinical trials to evaluate the mechanical properties of nanohybrid resin composites used in indirect restorations after being subjected to additional dry heat curing.

## 5. Conclusions

In summary, with all the limitations of the present in vitro study, it can be concluded that the Filtek Z250 and Z350XT resin composites exhibited significantly higher microflexural strength values than the Tetric N-Ceram resin composite, with and without additional dry heat curing. In addition, the Filtek Z350XT and Tetric N-Ceram resin composites subjected to additional dry heat curing showed significantly higher microflexural strength compared to when they did not receive the same procedure, a situation that did not occur with the Filtek Z250 resin composite.

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## References

1. Nakanishi, L.; Kaizer, M.R.; Brandeburski, S.; Cava, S.S.; Della Bona, A.; Zhang, Y.; Moraes, R.R. Non-silicate nanoparticles for improved nanohybrid resin composites. *Dent. Mater.* **2020**, *36*, 1314–1321. <https://doi.org/10.1016/j.dental.2020.07.001>.
2. Cayo, C.; Llancari, L.; Mendoza, R.; Cervantes, L. Marginal filling and adhesive resistance of bulk fill resin applying 18% edta gel compared with 37% phosphoric acid gel in vitro dental conditioning. *J. Oral Res.* **2019**, *8*, 228–235.
3. Raju, R.; Rajan, G.; Farrar, P.; Prusty, B.G. Dimensional stability of short fibre reinforced flowable dental composites. *Sci. Rep.* **2021**, *11*, 4697. <https://doi.org/10.1038/s41598-021-83947-x>.
4. Monteza, S.; Loyola, P. Flexural Strength of a Nanohybrid Composite Resin Subjected to Additional Thermopolymerization Techniques. *Pol. Con.* **2020**, *6*, 1667–1681. <https://doi.org/10.23857/pc.v6i11.3353>.
5. Cayo, C.; Carrillo, A. Marginal sealing applying sodium hypochlorite versus phosphoric acid as dental conditioner. *Rev. Cubana Estomatol.* **2020**, *57*, e2872.
6. Ramírez-Vargas, G.G.; Medina y Mendoza, J.E.; Aliaga-Mariñas, A.S.; Ladera-Castañeda, M.I.; Cervantes-Ganoza, L.A.; Cayo-Rojas, C.F. Effect of polishing on the surface microhardness of nanohybrid composite resins subjected to 35% hydrogen peroxide: An in vitro study. *J. Int. Soc. Prevent Communit. Dent.* **2021**, *11*, 216–221.
7. Baldi, A.; Comba, A.; Tempesta, R.M.; Carossa, M.; Pereira, G.K.R.; Valandro, L.F.; Paolone, G.; Vichi, A.; Goracci, C.; Scotti, N. External Marginal Gap Variation and Residual Fracture Resistance of Composite and Lithium-Silicate CAD/CAM Overlays after Cyclic Fatigue over Endodontically-Treated Molars. *Polymers* **2021**, *13*, 3002. <https://doi.org/10.3390/polym13173002>.
8. Paolone, G.; Moratti, E.; Goracci, C.; Gherlone, E.; Vichi, A. Effect of Finishing Systems on Surface Roughness and Gloss of Full-Body Bulk-Fill Resin Composites. *Materials* **2020**, *13*, 5657. <https://doi.org/10.3390/ma13245657>.
9. Galiatsatos, A.; Galiatsatos, P.; Bergou, D. Clinical Longevity of Indirect Composite Resin Inlays and Onlays: An Up to 9-Year Prospective Study. *Eur. J. Dent.* **2022**, *16*, 202–208. <https://doi.org/10.1055/s-0041-1735420>.
10. Van Dijken, J.W. Direct resin composite inlays/onlays: An 11 years follow-up. *J. Dent.* **2000**, *28*, 299–306. [https://doi.org/10.1016/s0300-5712\(00\)00010-5](https://doi.org/10.1016/s0300-5712(00)00010-5).
11. Da Silva, D.; Ceballos, L.; Fuentes, M.V. Influence of the adhesive strategy in the sealing ability of resin composite inlays after deep margin elevation. *J. Clin. Exp. Dent.* **2021**, *13*, 886–893. <https://doi.org/10.4317/jced.58689>.

12. Bustamante-Hernández, N.; Montiel-Company, J.M.; Bellot-Arcís, C.; Mañes-Ferrer, J.F.; Solá-Ruíz, M.F.; Agustín-Panadero, R.; Fernández-Estevan, L. Clinical Behavior of Ceramic, Hybrid and Composite Onlays. A Systematic Review and Meta-Analysis. *Int. J. Environ. Res. Public Health* **2020**, *17*, 7582. <https://doi.org/10.3390/ijerph17207582>.
13. Vervack, V.; De Coster, P.; Vandeweghe, S. Clinical Evaluation of Resin Composite CAD/CAM Restorations Placed by Undergraduate Students. *J. Clin. Med.* **2021**, *10*, 3269. <https://doi.org/10.3390/jcm10153269>.
14. Grazioli, G.; Francia, A.; Cuevas-Suárez, C.E.; Zanchi, C.H.; Moraes, R.R.D. Simple and Low-Cost Thermal Treatments on Direct Resin Composites for Indirect Use. *Braz. Dent. J.* **2019**, *30*, 279–284.
15. Almeida-Chetti, V.A.; Macchi, R.L.; Iglesias, M.E. Effect of post-curing treatment on mechanical properties of composite resins. *Acta Odontol. Latinoam.* **2014**, *27*, 72–76. <https://doi.org/10.1590/S1852-48342014000200005>.
16. Santana, I.L.; Lodovici, E.; Matos, J.R.; Medeiros, I.S.; Miyazaki, C.L.; Rodrigues-Filho, L.E. Effect of experimental heat treatment on mechanical properties of resin composites. *Braz. Dent. J.* **2009**, *20*, 205–210. <https://doi.org/10.1590/s0103-64402009000300006>.
17. Ribeiro, A.; Tupinamba, C.; Carvalho, C.; Moreira, L.; Souza, P. Influence of two methods of additional activation on composite resins surface hardness. *Braz. J. Oral Sci.* **2012**, *11*, 396–400.
18. Dias, M.F.; Espíndola-Castro, L.F.; Lins-Filho, P.C.; Teixeira, H.M.; Silva, C.H.; Guimarães, R.P. Influence of different thermopolymerization methods on composite resin microhardness. *J. Clin. Exp. Dent.* **2020**, *12*, 335–341. <https://doi.org/10.4317/jced.56772>.
19. De Souza, L.; Oro, A.; Consani, S.; Ferraz, M.; Galafassi, D.; Carlini, B. Influência do tempo de fotoativação na resistência à flexão de compósitos restauradores. *RFO* **2008**, *13*, 56–60.
20. Lapesqueur, M.; Surriaga, P.; Masache, M.E.; Vásquez, B.; Peña, M.; Gómez, O.M.M.; Domínguez, J.A. Efectos sobre microdureza y grado de conversión de dos tipos de resinas sometidas a tratamientos de pospolimerización. *Rev. Nac. Odontol.* **2015**, *11*, 1–14. <https://doi.org/10.16925/od.v11i21.947>.
21. Leao, G.H.; Carvalho, C.; Galhano, G.; Gueira, L.; Pavanelli, C. Influencia de la polimerización adicional en la microdureza de las resinas compuestas directas. *Cienc. Odontol.* **2007**, *10*, 10–15.
22. Cruz, F.; Carvalho, R.; Henrique, C.; Siqueira, H.; Queiroz, J.R.C.; Leite, F.P.P. Efecto del tratamiento térmico y de fibras de polietileno en la resistencia a la flexión de resinas compuestas. *Acta Odontol. Venez.* **2014**, *52*, 1–8.
23. ISO 4049:2019; Dentistry—Polymer-Based Restorative Materials. ISO: Geneva, Switzerland, 2019. Available online: <https://www.iso.org/standard/67596.html> (accessed on 23 February 2022).
24. Al-Zain, A.O.; Platt, J.A. Effect of light-curing distance and curing time on composite microflexural strength. *Dent. Mater. J.* **2021**, *40*, 202–208. <https://doi.org/10.4012/dmj.2020-002>.
25. Al-Zain, A.O.; Marghalani, H.Y. Influence of Light-curing Distances on Microflexural Strength of Two Resin-based Composites. *Oper. Dent.* **2020**, *45*, 297–305. <https://doi.org/10.2341/19-001-L>.
26. Yap, A.U.; Eweis, A.H.; Yahya, N.A. Dynamic and Static Flexural Appraisal of Resin-based Composites: Comparison of the ISO and Mini-flexural Tests. *Oper. Dent.* **2018**, *43*, E223–E231. <https://doi.org/10.2341/17-224-L>.
27. Chung, S.M.; Yap, A.U.; Chandra, S.P.; Lim, C.T. Flexural strength of dental composite restoratives: Comparison of biaxial and three-point bending test. *J. Biomed. Mater. Res. B Appl. Biomater.* **2004**, *71*, 278–283. <https://doi.org/10.1002/jbm.b.30103>.
28. Krithikadatta, J.; Gopikrishna, V.; Datta, M. CRIS Guidelines (Checklist for Reporting In-vitro Studies): A concept note on the need for standardized guidelines for improving quality and transparency in reporting in-vitro studies in experimental dental research. *J. Conserv. Dent.* **2014**, *17*, 301–304. <https://doi.org/10.4103/0972-0707.136338>.
29. Loyola-García, P.; Díaz-López, C.; Castillo-Guarnizo, Z.; Riofrío-Herrera, J.; Monteza-Iñiguez, S. Comparative study of the flexural strength of two materials used for the reconstruction of stumps. *Pol. Con.* **2019**, *4*, 40–58. <https://doi.org/10.23857/pc.v4i1.851>.
30. Sezin, M.; Lutri, M.P.; Mirotti, G.; Kraemer, M.E.; Monserrat, N.; Piconi, M.C.; Caballero, A.L.; Crohare, L. Flexural strength and elastic modulus of high, medium and low density resins. *Rev. Fac. Odont.* **2018**, *28*, 14–21.
31. Bonilla, E.; Aguilar Padilla, A.V.; Flores, P.M.; Sandoval, Z.; Cavazos, E.; Torres, P. Flexural strength assessment for three dental resin composites. *ROBYD* **2017**, *1*, 33–36.
32. Bahari, M.; Kahnamoui, M.A.; Chaharom, M.E.E.; Kimyai, S.; Sattari, Z. Effect of curing method and thermocycling on flexural strength and microhardness of a new composite resin with alkaline filler. *Dent. Res. J.* **2021**, *18*, 96. <https://doi.org/10.4103/1735-3327.330877>.
33. El-Askary, F.S.; Botros, S.A.; Nassif, M.S.A.; Ozcan, M. Flexural strength of nano-hybrid resin composite as a function of light attenuation distance and specimen dimension. *J. Adhes. Sci. Technol.* **2017**, *31*, 520–529. <https://doi.org/10.1080/01694243.2016.1221251>.
34. Eshawi, Y.T.; Al-Zain, A.O.; Eckert, G.J.; Platt, J.A. Variation in composite degree of conversion and microflexural strength for different curing lights and surface locations. *J. Am. Dent. Assoc.* **2018**, *149*, 893–902. <https://doi.org/10.1016/j.adaj.2018.06.004>.
35. Bunz, O.; Benz, C.I.; Arnold, W.H.; Piwowarczyk, A. Shear bond strength of veneering composite to high performance polymers. *Dent. Mater. J.* **2021**, *40*, 304–311. <https://doi.org/10.4012/dmj.2019-3005>.
36. Sharafeddin, F.; Motamed, M.; Fattah, Z. Effect of Preheating and Precooling on the Flexural Strength and Modulus of Elasticity of Nanohybrid and Silorane-based Composite. *J. Dent.* **2015**, *16*, 224–229.
37. Stawarczyk, B.; Brauneis, M.; Langwieder, B.; Spintzyk, S.; Eichberger, M.; Liebermann, A. Mechanical and optical properties of indirect veneering resin composites after different aging regimes. *Dent. Mater. J.* **2021**, *40*, 279–287. <https://doi.org/10.4012/dmj.2019-307>.

38. Mayinger, F.; Reymus, M.; Liebermann, A.; Richter, M.; Kubryk, P.; Großekappenberg, H.; Stawarczyk, B. Impact of polymerization and storage on the degree of conversion and mechanical properties of veneering resin composites. *Dent. Mater. J.* **2021**, *40*, 487–497. <https://doi.org/10.4012/dmj.2019-394>.
39. Visuttiwattanakorn, P.; Suputtamongkol, K.; Angkoonisit, D.; Kaewthong, S.; Charoonanan, P. Microtensile bond strength of repaired indirect resin composite. *J. Adv. Prosthodont.* **2017**, *9*, 38–44. <https://doi.org/10.4047/jap.2017.9.1.38>.
40. Schwantz, J.K.; Oliveira-Ogliari, A.; Meereis, C.T.; Leal, F.B.; Ogliari, F.A.; Moraes, R.R. Characterization of Bis-Acryl Composite Resins for Provisional Restorations. *Braz. Dent. J.* **2017**, *28*, 354–361. <https://doi.org/10.1590/0103-6440201601418>.
41. Salgado, V.E.; Cavalcante, L.M.; Moraes, R.R.; Davis, H.B.; Ferracane, J.L.; Schneider, L.F. Degradation of optical and surface properties of resin-based composites with distinct nanoparticle sizes but equivalent surface area. *J. Dent.* **2017**, *59*, 48–53. <https://doi.org/10.1016/j.jdent.2017.02.008>.
42. Omid, B.-R.; Gosili, A.; Jaber-Ansari, M.; Mahdikhah, A. Intensity output and effectiveness of light curing units in dental offices. *J. Clin. Exp. Dent.* **2018**, *10*, 555–560. Available online: <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6012498/> (accessed on 25 May 2022).
43. Kumar, S.R.; Luddin, N.; Mohammad, Z.K.M.; Alam, M.K. The Effect of Microleakage on Composite Resin Restorations Cured by Different Light Curing Units (LCU). *Int. Med. J.* **2014**, *21*, 101–105. Available online: [https://www.researchgate.net/profile/Mohammad\\_Alam10/publication/260790411\\_The\\_Effect\\_of\\_Microleakage\\_on\\_Composite\\_Resin\\_Restorations\\_Cured\\_by\\_Different\\_Light\\_Curing\\_Units\\_LCU/links/004635323cf701bab5000000.pdf](https://www.researchgate.net/profile/Mohammad_Alam10/publication/260790411_The_Effect_of_Microleakage_on_Composite_Resin_Restorations_Cured_by_Different_Light_Curing_Units_LCU/links/004635323cf701bab5000000.pdf) (accessed on 13 May 2022).
44. Behnaz, E.; Hengameh, S.; Assila, V. Hardness Evaluation of Composite Resins Cured with QTH and LED. *J. Dent. Res. Dent. Clin. Dent. Prospect.* **2014**, *8*, 40–44. Available online: [https://joddd.tbzmed.ac.ir/Article/JODDD\\_181\\_20140618111657](https://joddd.tbzmed.ac.ir/Article/JODDD_181_20140618111657) (accessed on 13 May 2022).
45. Meléndez, D.; Delgado, L.; Tay, L. The science behind led light curing units. *ROBYD* **2021**, *10*, 1–18.
46. Cayo-Rojas, C.F.; Hernández-Caba, K.K.; Aliaga-Mariñas, A.S.; Ladera-Castañeda, M.I.; Cervantes-Ganoza, L.A. Microleakage in class II restorations of two bulk fill resin composites and a conventional nanohybrid resin composite: An in vitro study at 10,000 thermocycles. *BMC Oral Health* **2021**, *21*, 619. <https://doi.org/10.1186/s12903-021-01942-0>.
47. Gaviria-Martinez, A.; Castro-Ramirez, L.; Ladera-Castañeda, M.; Cervantes-Ganoza, L.; Cachay-Criado, H.; Alvino-Vales, M.; Garcia-Luna, G.; López-Gurreonero, C.; Cornejo-Pinto, A.; Cayo-Rojas, C.F. Surface roughness and oxygen inhibited layer control in bulk-fill and conventional nanohybrid resin composites with and without polishing: In vitro study. *BMC Oral Health* **2022**, *22*, 258. <https://doi.org/10.1186/s12903-022-02297-w>.
48. Voronova, M.; Rubleva, N.; Kochkina, N.; Afineevskii, A.; Zakharov, A.; Surov, O. Preparation and Characterization of Polyvinylpyrrolidone/Cellulose Nanocrystals Composites. *Nanomaterials* **2018**, *8*, 1011. <https://doi.org/10.3390/nano8121011>.
49. Farmer, T.J.; Castle, R.L.; Clark, J.H.; Macquarrie, D.J. Synthesis of Unsaturated Polyester Resins from Various Bio-Derived Platform Molecules. *Int. J. Mol. Sci.* **2015**, *16*, 14912–14932. <https://doi.org/10.3390/ijms160714912>.