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Comparative Evaluation Of Flexural Strength Of Different Composites In Response To Temperature Variations: An In Vitro Study

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Abstract

Background: Thermal fluctuations caused by the consumption of hot and cold beverages may affect the mechanical properties of resin-based composite restorations. This in vitro study compared the flexural strength of a nanoceramic composite and an ormocer-based composite following thermocycling and immersion in different beverage media.

Methods: Sixty standardized bar-shaped specimens (25 × 2 × 2 mm) were prepared using a nanoceramic composite (n = 30) and an ormocer-based composite (n = 30). Each material was divided into three subgroups (n = 10) and immersed in hot coffee (55°C), a cold carbonated beverage (4°C), or distilled water after 500 thermocycles. Flexural strength was evaluated using a three-point bending test. Data were analyzed using an independent *t*-test, one-way ANOVA, and Tukey's post hoc test ($p < 0.05$).

Results: The nanoceramic composite exhibited significantly higher flexural strength than the ormocer-based composite (30.09 ± 5.92 MPa vs. 19.66 ± 9.47 MPa; $p < 0.001$). Among the immersion media, the cold carbonated beverage group demonstrated the highest flexural strength, whereas distilled water showed the lowest values. Significant differences were observed among the experimental groups ($p < 0.001$) and immersion media ($p = 0.003$).

Conclusions: The nanoceramic composite demonstrated superior flexural strength compared with the ormocer-based composite following thermocycling and beverage immersion. Cold beverage exposure produced the highest flexural strength, whereas distilled water resulted in the lowest values, indicating that both restorative material and temperature conditions significantly influence flexural performance.

Keywords: Flexural strength; nanoceramic composite; ORMOCER; resin-based composites; thermocycling; temperature variation; dental restorative materials

Introduction

Resin-based composite restorations have become the material of choice for direct esthetic restorations because of their favorable esthetics, adhesive bonding capability, conservative tooth preparation, and continuous advancements in material science. Improvements in resin chemistry and filler technology have enhanced the mechanical properties and clinical performance of composite resins, enabling their successful use in both anterior and posterior stress-bearing restorations [1]. A systematic review by Opdam et al. further demonstrated the favorable long-term survival of posterior composite restorations, supporting their reliability in contemporary restorative dentistry [2].

Despite these advances, the longevity of composite restorations depends on their ability to withstand the complex oral environment. Restorative materials are routinely exposed to cyclic occlusal loading, moisture, pH fluctuations, and repeated thermal changes associated with the consumption of hot and cold foods and beverages. These thermal variations may induce repeated expansion and contraction of the resin matrix and filler particles, generating internal stresses that contribute to degradation of the filler-matrix interface and deterioration of mechanical properties over time [3]. Ayatollahi et al. reported that temperature changes and beverage exposure significantly influenced the mechanical behavior of resin-based composites, emphasizing the importance of evaluating restorative materials under simulated oral conditions [4].

Among the mechanical properties of restorative materials, flexural strength is considered one of the most clinically relevant because restorations are subjected to tensile, compressive, and shear stresses during mastication. Adequate flexural strength is essential to resist fracture and maintain the structural integrity of restorations under functional loading. Rodrigues Junior et al. demonstrated significant differences in the flexural strength of various resin-based composites, indicating that material composition plays an important role in mechanical performance [5]. Accordingly, the International Organization for Standardization (ISO 4049) recommends the three-point bending test as the standard method for evaluating the flexural strength of polymer-based restorative materials [6].

Recent developments in restorative dentistry have led to the introduction of nanoceramic and ormocer-based composites. Nanoceramic composites incorporate nanosized ceramic fillers that improve filler distribution, stress transfer, and overall mechanical performance, whereas ormocer-based composites utilize an organically modified ceramic matrix designed to reduce polymerization shrinkage and enhance dimensional stability [7,8]. Although both materials have demonstrated favorable physical properties, exposure to beverages of varying temperatures may influence their mechanical behavior. Previous studies have reported that hot and cold beverages can significantly affect the flexural strength of resin-based composites, suggesting that restorative materials respond differently to thermal challenges depending on their composition [10,11].

Although several studies have evaluated the influence of thermal aging or beverages on individual restorative materials, direct comparisons between nanoceramic and ormocer-based composites under standardized thermocycling and beverage immersion conditions remain limited. Therefore, the present in vitro study compared the flexural strength of a nanoceramic composite and an ormocer-based composite following thermocycling and immersion in hot coffee, a cold carbonated beverage, and distilled water. The null hypothesis was that no statistically significant difference would exist in the flexural strength of the two restorative materials following thermocycling and immersion in different media.

Materials And Methods

This in vitro study was conducted in the Department of Conservative Dentistry and Endodontics, Chadalawada Krishna Srinivasa (CKS) Teja Institute of Dental Sciences and Research, Tirupati, India, after obtaining approval from the Institutional Ethics Committee (Approval No. CKS/ENDO/23-24/04). A total of 60 standardized bar-shaped specimens were prepared following the recommendations of ISO 4049 for polymer-based restorative materials. Thirty specimens were fabricated using a nanoceramic composite (Magma NT, Prevest DenPro Pvt. Ltd., Jammu, India), and 30 specimens were prepared using an ormocer-based composite (Admira Fusion, VOCO GmbH, Cuxhaven, Germany). The restorative materials were packed into customized silicone molds measuring 25 × 2 × 2 mm, covered with Mylar strips and glass slides to obtain a smooth surface, and light-cured according to the manufacturers' instructions using an LED curing unit. The cured specimens were removed from the molds and inspected for voids or surface defects. Any defective specimen was discarded and replaced to ensure uniformity.

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The specimens were randomly allocated into two experimental groups (n = 30) according to the restorative material. Each group was further subdivided into three subgroups (n = 10) based on the immersion medium. Subgroups A1 and B1 were immersed in hot coffee maintained at 55°C, subgroups A2 and B2 were immersed in a cold carbonated beverage maintained at 4°C, and subgroups A3 and B3 were immersed in distilled water at room temperature. Before immersion, all specimens underwent 500 thermocycles between 5°C and 55°C to simulate thermal changes encountered in the oral environment. Following thermocycling, the specimens were immersed in their respective media for seven consecutive days, and the immersion solutions were replaced every 24 hours to maintain consistent exposure conditions.

After the immersion period, the specimens were rinsed with distilled water, blot dried, and subjected to flexural strength testing using a universal testing machine. A three-point bending test was performed with a support span of 20 mm at a crosshead speed of 0.5 mm/min until fracture occurred. The maximum fracture load (N) was recorded, and flexural strength (MPa) was calculated using the ISO 4049 equation: $\boldsymbol{\sigma = 3FL/2BH^2}$, where F represents the maximum fracture load (N), L is the support span (mm), B is the specimen width (mm), and H is the specimen thickness (mm).

Statistical Analysis

Statistical analysis was performed using IBM SPSS Statistics version 25.0 (IBM Corp., Armonk, NY, USA). Data were expressed as mean ± standard deviation. The overall flexural strength of the nanoceramic and ormocer-based composites was compared using an independent samples *t*-test. Differences among the six experimental groups and among the immersion media were analyzed using one-way analysis of variance (ANOVA), followed by Tukey's post hoc test for multiple pairwise comparisons. Statistical significance was established at $p < 0.05$.

Results

The descriptive statistics of flexural strength for the six experimental groups are presented in Table 1. Among all groups, the nanoceramic composite immersed in the cold carbonated beverage demonstrated the highest mean flexural strength (32.84 ± 3.75 MPa), followed by the nanoceramic composite immersed in the hot beverage (31.37 ± 6.71 MPa). The lowest mean flexural strength was observed in the ormocer-based composite immersed in distilled water (13.20 ± 5.98 MPa). In both restorative materials, specimens immersed in the cold carbonated beverage exhibited higher flexural strength than those immersed in hot coffee or distilled water. Overall, the nanoceramic composite demonstrated higher mean flexural strength than the ormocer-based composite across all immersion media

Table 1: Descriptive Statistics of Flexural Strength Among Study Groups

Group	n	Mean (MPa)	Standard Deviation	Minimum	Maximum
Nanoceramic Hot Beverage	10	31.37	6.71	21.29	42.15
Nanoceramic Cold Beverage	10	32.84	3.75	27.60	38.48
Nanoceramic Distilled Water	10	26.05	5.75	18.90	34.50
Ormocer Hot Beverage	10	19.99	10.70	8.50	35.20
Ormocer Cold Beverage	10	25.79	9.16	14.80	39.10
Ormocer Distilled Water	10	13.20	5.98	5.50	22.40

The overall comparison of flexural strength between the two restorative materials is presented in Table 2. The nanoceramic composite demonstrated a significantly higher mean flexural strength than the ormocer-based composite (30.09 ± 5.92 MPa vs. 19.66 ± 9.47 MPa). Independent samples *t*-test revealed that this difference

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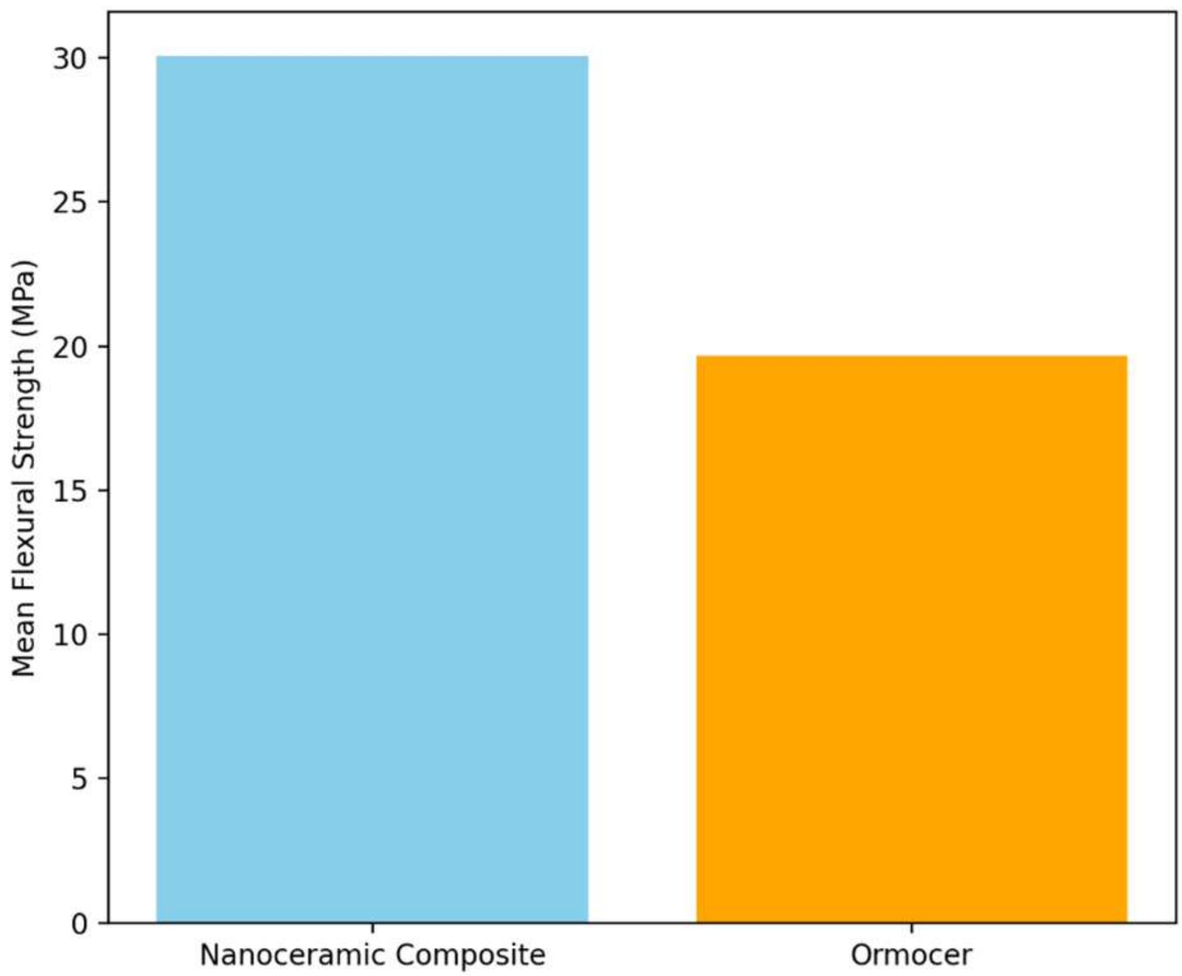
was statistically highly significant ($t = 4.87$, $p < 0.001$), indicating superior flexural performance of the nanoceramic composite following thermocycling and immersion in the different media.

Table 2: Comparison of Overall Flexural Strength Between Nanoceramic and Ormocer

Material	n	Mean (MPa)	SD	t-value	p-value
Nanoceramic Composite	30	30.09	5.92	4.87	<0.001*
Ormocer	30	19.66	9.47		

Figure 1: Bar graph showing overall comparison between the two materials



One-way analysis of variance (ANOVA) demonstrated a statistically significant difference in flexural strength among the six experimental groups ($F = 9.86$, $p < 0.001$), indicating that the combination of restorative material and immersion medium significantly influenced flexural strength.

Table 3: One-Way ANOVA Comparison Among Six Study Groups

Source of Variation	Sum of Squares	df	Mean Square	F-value	p-value
Between Groups	2438.72	5	487.74	9.86	<0.001*
Within Groups	2672.18	54	49.48		

Total	5110.90	59			

Post hoc analysis using Tukey's test identified significant pairwise differences among the experimental groups (Table 4). The nanoceramic composite immersed in the cold carbonated beverage demonstrated significantly higher flexural strength than the ormocer-based composite immersed in distilled water ($p < 0.001$) and the hot beverage ($p = 0.003$). Similarly, the nanoceramic composite immersed in the hot beverage exhibited significantly higher flexural strength than the ormocer-based composite immersed in distilled water ($p < 0.001$) and the hot beverage ($p = 0.013$). In addition, the nanoceramic composite immersed in distilled water and the ormocer-based composite immersed in the cold beverage demonstrated significantly greater flexural strength than the ormocer-based composite immersed in distilled water ($p < 0.05$).

Table 4: Tukey Post Hoc Multiple Comparison Test (Significant Pairs Only)

Comparison Groups	Mean Difference	p-value	Significance
Nanoceramic Cold vs Ormocer Distilled Water	19.64	<0.001	Significant
Nanoceramic Cold vs Ormocer Hot	12.85	0.003	Significant
Nanoceramic Hot vs Ormocer Distilled Water	18.17	<0.001	Significant
Nanoceramic Hot vs Ormocer Hot	11.38	0.013	Significant
Nanoceramic Distilled vs Ormocer Distilled Water	12.85	0.003	Significant
Ormocer Cold vs Ormocer Distilled Water	12.59	0.004	Significant

Discussion

The present in vitro study compared the flexural strength of a nanoceramic composite and an ormocer-based composite following thermocycling and immersion in hot coffee, a cold carbonated beverage, and distilled water. The nanoceramic composite demonstrated significantly higher flexural strength than the ormocer-based composite under all experimental conditions. Furthermore, immersion media significantly influenced the flexural strength of both materials, with the cold carbonated beverage group exhibiting the highest values and the distilled water group the lowest. These findings suggest that both the restorative material and the storage conditions influence the mechanical behavior of resin-based composites.

Flexural strength is considered an important indicator of the clinical performance of restorative materials because restorations are continuously subjected to complex occlusal forces. The present findings are in agreement with **Sulaiman et al.,** who reported significant differences in the flexural strength of various tooth-coloured restorative materials, emphasizing that differences in material composition directly influence their mechanical performance [12]. The higher flexural strength observed in the nanoceramic composite in the present study may be attributed to improved filler distribution and stronger filler-matrix interaction.

Water storage has been reported to adversely affect the mechanical properties of composite resins through hydrolytic degradation of the resin matrix and deterioration of the filler-matrix interface. **Bagheri et al.** demonstrated that water sorption leads to subsurface degradation of resin composites, resulting in reduced mechanical strength over time [13]. Similarly, **Chen** reported that nanotechnology improves filler distribution and enhances the mechanical properties of composite resins, contributing to greater resistance to crack propagation and fracture [14]. These findings support the superior flexural strength demonstrated by the nanoceramic composite in the present investigation.

Temperature variation is another important factor affecting composite restorations. **Papadogiannis et al.** reported that temperature changes significantly influence the viscoelastic properties of resin composites, with lower temperatures increasing material rigidity and higher temperatures increasing molecular mobility [15]. This could explain the comparatively higher flexural strength observed in specimens immersed in the cold carbonated beverage.

Artificial aging also influences the durability of restorative materials. **Hahnel et al.** demonstrated that aging procedures reduce the mechanical properties of composite resins owing to degradation of the polymer network [16]. Likewise, **Scribante et al.** reported that exposure to acidic environments altered the flexural properties of composite restorative materials, although the extent of deterioration depended on the material composition [17]. These observations are consistent with the present study, where immersion media significantly affected flexural strength.

Recent developments in restorative materials have focused on improving filler technology and resin chemistry to enhance mechanical performance and longevity. **Aminoroaya et al.** concluded that advances in filler characteristics and polymer chemistry have substantially improved the physical and mechanical properties of contemporary resin composites [18]. The superior performance of the nanoceramic composite observed in the present study is in accordance with these improvements.

The findings of the present study are further supported by El-Askary et al., who reported that the flexural strength of ormocer-based composites is influenced by their composition and polymerization characteristics. Although ORMOCER materials offer advantages such as reduced polymerization shrinkage and improved biocompatibility, their mechanical performance may vary depending on filler loading and resin formulation [19]. This may explain the comparatively lower flexural strength of the ormocer-based composite observed in the present study.

The influence of beverages on composite restorations has been investigated in several studies. Szalewski et al. demonstrated that commonly consumed beverages can alter the mechanical properties of resin composites depending on their composition and exposure conditions [20]. Similarly, Bahari et al. reported that thermocycling significantly affected the flexural strength of composite resins, emphasizing the importance of artificial aging protocols when evaluating restorative materials under laboratory conditions [21]. These findings support the significant effect of immersion media observed in the present investigation.

A study by Sushma et al. showed that carbonated beverages can influence the flexural strength of composite restorative materials because of their acidic nature [22]. Likewise, Taskeen et al. reported that thermocycling significantly affected the flexural strength of different composite restorative materials, highlighting that material composition plays a critical role in determining resistance to thermal stresses [23]. Although the present study also demonstrated significant differences among immersion media, the cold carbonated beverage group exhibited the highest flexural strength, suggesting that reduced temperature may have had a greater influence than the acidic challenge under the present experimental conditions.

The degree of polymerization is another important factor affecting the mechanical behavior of composite restorations. El-Maksoud et al. demonstrated that storage temperature influences the degree of conversion and microhardness of composite restorative materials, thereby affecting their overall mechanical properties [24]. Furthermore, Jansen van Rensburg et al. reported that nanocomposite restorative materials exhibited superior physical and mechanical properties compared with ormocer-based composites following aging procedures, which is consistent with the findings of the present study [25].

Surface degradation caused by beverages may further influence the long-term clinical performance of resin composites. Elmalawany et al. observed that exposure to different beverages altered the surface properties of resin composites, with the magnitude of change depending on the restorative material evaluated [26]. In addition, Soni et al. concluded that filler characteristics, resin matrix composition, degree of conversion, and aging conditions are the major factors governing the mechanical performance of contemporary resin composites [27]. These observations further support the superior flexural strength demonstrated by the nanoceramic composite in the present study.

More recently, Temizci and Bozoğulları demonstrated that thermocycling significantly affected the mechanical properties of composite restorative materials irrespective of the manufacturing technique, emphasizing the importance of thermal aging when assessing the long-term performance of restorative materials [28]. Overall, the findings of the present study indicate that nanoceramic composites possess

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superior resistance to flexural loading compared with ormocer-based composites following thermocycling and beverage immersion. These results suggest that the selection of restorative material, together with consideration of the oral thermal environment, may influence the long-term mechanical performance of direct composite restorations.

Limitations

The present study has certain limitations that should be considered while interpreting the results. Firstly, experiment was done in a controlled laboratory settings, which may not fully represent oral environment where multiple factors such as saliva, enzymatic activity, masticatory forces, and pH variations act simultaneously on restorative materials. Secondly, although thermocycling was performed to simulate temperature variations, it may not fully reproduce the dynamic and continuous thermal changes occurring in the oral cavity during daily function. Another limitation is that the study evaluated flexural strength as the sole mechanical property. Other important properties such as wear resistance, fracture toughness, surface hardness, and long-term aging behavior were not assessed, which may also influence the clinical performance of restorative materials. Additionally, the duration of immersion in beverages was limited, and long term exposure effects were not evaluated. In clinical situations, restorative materials are subjected to prolonged and repeated exposure to various dietary substances, which may produce different outcomes over time.Finally, the sample size for actual experimental testing was limited, and although statistical modeling was used to enhance analysis, a larger number of physically tested specimens would provide more robust and generalizable results.

Conclusions

Within the limitations of this in vitro study, the nanoceramic composite exhibited significantly higher flexural strength than the ormocer-based composite following thermocycling and immersion in different media. Among the immersion media, the cold carbonated beverage group demonstrated the highest flexural strength, whereas distilled water showed the lowest values. The null hypothesis was rejected, as significant differences were observed between the restorative materials and immersion media. Further long-term in vitro and clinical studies are required to validate these findings.

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