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Original Article

Dentistry Section

Effect of Preheating on the Flexural Strength and Microhardness of Giomer and Nanohybrid Composite Resin: An In-vitro Study

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ABSTRACT

Introduction: Although composite restorations have become very common in restorative dentistry, inadequate polymerisation results in clinically unsuccessful restoration due to fracturing and wear. Preheating is a technique adopted in clinical practice to decrease the viscosity and increase monomers' mobility, hence optimising the mechanical properties.

Aim: To compare the flexural strength and microhardness of a giomer and nanohybrid composite following preheating to 50°C.

Materials and Methods: This in-vitro experimental comparative study was conducted in the Department of Conservative Dentistry and Endodontics in collaboration with the Dental Materials/Mechanical Testing Laboratory, Bharati Vidyapeeth (Deemed to be University) Dental College and Hospital, Pune, Maharashtra, India, over a period of six months from August 2025 to January 2026. A total of 96 samples were fabricated, then equally subdivided into two groups of four subgroups each: preheated (at 50°C for 5 mins) and control groups. The flexural strength was determined using the three point bend test on Universal testing machine, while surface durability was measured by a Vickers microhardness tester applying a load of 200 g. Statistical analysis was carried out using independent and paired sample t-tests ($p<0.05$).

Results: Preheating resulted in significant improvements in flexural strength of 19.67% and 29.02% for giomer and Nanohybrid composite respectively. Preheating significantly improved microhardness for 11.96% and 15.94% in Giomer and Nanohybrid composite respectively. Giomer showed significantly higher absolute values than the Nanohybrid composite ($p<0.001$) in all parameters.

Conclusion: Within the study's limitations, preheating at 50°C significantly enhances the mechanical and surface properties of both tested materials.

Keywords: Polymerisation shrinkage, Surface roughness, Universal testing machine

INTRODUCTION

Restorative dentistry has moved towards minimally invasive procedures thanks to the development of adhesive systems and resin-based composites. Today, composites are the material of choice for anterior and posterior teeth, replacing older poorly polishing silicate cements and macrofilled systems. When properly handled they allow conservative cavity preparations, high aesthetic demands and functional durability [1-3]. The manufacturing has evolved from microfilled and hybrid to nanofilled and nanohybrid materials. The distribution of filler is balanced to optimise strength, wear resistance and surface polish over time [4,5].

These modern composites are complex biomaterials composed of an organic resin matrix, inorganic filler particles and a silane coupling agent. The organic matrix combines monomers such as Bisphenol A Glycidyl Methacrylate (Bis-GMA), Urethane dimethacrylate (UDMA), Triethylene Glycol Dimethacrylate (TEGDMA), and Bisphenol A Ethoxylated Methacrylate (Bis-EMA) to regulate viscosity and polymerisation kinetics [6]. The inorganic fillers, typically silica or glass based, impart wear resistance, strength, and radiopacity, whereas the silane coupling agent links the hydrophobic matrix to the hydrophilic fillers, providing a uniform stress distribution [7,8]. However, these materials are not free of disadvantages as polymerisation shrinkage generates volumetric contraction stresses that may cause marginal gaps, microleakage and recurrent caries [9,10]. Also, incomplete monomer conversion leaves residual monomers that can compromise the biocompatibility and physical strength of the restoration. These factors lead to clinical failure rates of 1% to 5% per year [11-14].

The material should be optimised to withstand the complex intraoral environment (masticatory forces, thermal fluctuations, and hydrolytic degradation) with respect to mechanical performance and surface durability [15,16]. Flexural strength is a measure of a material's resistance to catastrophic fracture under combined tensile and compressive forces, while microhardness is a measure of the resistance of the surface to ongoing abrasion by chewing, brushing and dietary acids [15-20]. Both properties are strongly dependent on the degree of conversion, since higher monomer conversion results in a denser, stronger and less soluble polymer network [21-23].

Pre-curing heating of composite resins in the temperature range of 37°C to 68°C has been shown to be a practical technique to enhance these results without affecting the clinical workflow. At the atomic level, the higher thermal energy reduces the viscosity of the material to improve the cavity adaptation and enhances the mobility of the monomers to allow the polymer chain to propagate more before the vitrification [24-30]. However, the different internal structures of the composite classifications may react differently to this thermal conditioning. Giomers contain Surface Pre-Reacted Glass Ionomer (S-PRG) fillers which offer benefits of fluoride release and biocompatibility but have raised concerns about high-stress posterior placement [5,6,18]. On the other hand, nanohybrid composites employ a mixture of nano-sized and conventional fillers to achieve high packing density, wear resistance and polishability. However, their success is highly dependent on the curing efficiency [2,3,5].

The literature is still inconsistent regarding the real mechanical benefits of preheating mainly because of differences in testing protocols,

curing intensities and environmental settings [19,22,23,25]. Furthermore, the majority of the existing evidence is derived from western laboratory settings and there is a lack of region specific data for different dietary habits and clinical settings such as in India [18,22-24]. In the present in-vitro study, standardised three point bending and Vickers microhardness testing is used to control the experimental variables and assess the true baseline mechanical properties of preheated giomer and nanohybrid composites. This will help to elucidate whether thermal conditioning provides a overall benefit or is material specific.

The study aimed to evaluate and compare the flexural strength and microhardness of giomer and nanohybrid composite material after preheating.

MATERIALS AND METHODS

The present in-vitro experimental comparative study was conducted in the Department of Conservative Dentistry and Endodontics in collaboration with the Dental Materials/ Mechanical Testing Laboratory, Bharati Vidyapeeth (Deemed to be University) Dental College and Hospital, Pune, Maharashtra, India, over a period of six months from August 2025 to January 2026. The study protocol was approved by the Institutional Ethics Committee (IEC Approval No.BVDU/DCH/5/3033-24) prior to commencement of the study.

Sample size calculation: Sample size was calculated using the formula for comparison of two independent means: $n=2(Z\alpha/2+Z\beta)^2\sigma^2/\Delta^2$. The calculation was based on the flexural strength values reported by Kimyai S et al., who evaluated the effect of preheating on Beautifil II giomer and nanohybrid composite resin [3]. In that study, the mean flexural strength values were 120.67±7.98 MPa for the non preheated giomer group and 132.93±10.26 MPa for the preheated giomer group. Using an expected pooled standard deviation of 9.19 MPa and an expected mean difference of 12.26 MPa, with a 95% confidence level ($Z\alpha/2=1.96$) and 80% power ($Z\beta=0.84$), the minimum required sample size was calculated as 8.8 specimens per group. To compensate for possible specimen loss and ensure adequate power, the sample size was increased to 12 specimens per subgroup. Accordingly, 48 specimens were included for flexural strength testing and 48 for microhardness testing, giving a total sample size of 96 specimens.

Total 96 specimens were divided into two main experimental groups based on the type of mechanical test performed. The details of restorative materials used are shown in [Table/Fig-1]. Both the groups were again divided into four subgroups according to the materials and the heating protocol used [Table/Fig-2].

Study Procedure

Mould fabrication and specimen preparation: Custom acrylic resin split moulds were created for the preparation of specimens for flexural strength (25×2×2 mm according to ISO 4049) and microhardness 10 mm diameter by 2 mm thickness tests. All moulds were cleaned with alcohol and dried to remove contaminants before use. The moulds were placed on a clean glass slab covered with a transparent Mylar strip to prevent oxygen inhibition and to get a smooth surface finish. The composite resin was placed in the mould cavity in a single increment using a gold-plated hand instrument.

S. No.	Material type	Brand name	Manufacturer	Country	Composition/ Type
1	Giomer composite resin	Beautifil II	Shofu Inc.	Japan	Giomer restorative material containing S-PRG fillers
2	Nanohybrid composite resin	Nanofill Zirconium	Waldent	India	Nanohybrid composite resin

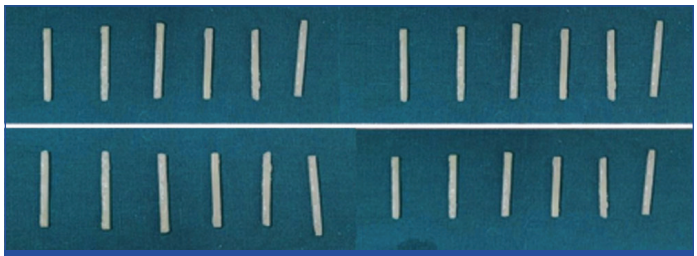
[Table/Fig-1]: Restorative materials used in the study.

Group-A: Flexural strength testing (n=48)			
Subgroup	**Material**	**Condition**	**Sample size**
A1	Giomer	Preheated	n=12
A2	Giomer	Non heated	n=12
A3	Nanohybrid	Preheated	n=12
A4	Nanohybrid	Non heated	n=12
Group-B: Microhardness testing (n=48)			
Subgroup	**Material**	**Condition**	**Sample size**
B1	Giomer	Preheated	n=12
B2	Giomer	Non heated	n=12
B3	Nanohybrid	Preheated	n=12
B4	Nanohybrid	Non heated	n=12

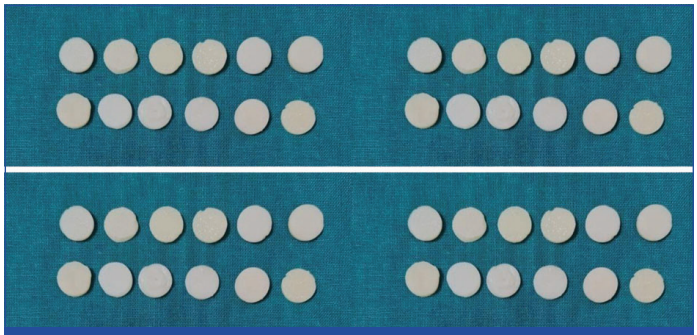
[Table/Fig-2]: Sample distribution.

Air was not included and a slow condensation was applied for full conformity with the mould walls.

A second Mylar strip and a glass slide were placed on top of the filled mould, and gentle pressure was applied to squeeze out excess material and ensure uniform specimen thickness [Table/ Fig-3,4]. The thermal conditioning of the composite syringes for the preheated groups was uniform and controlled by using a composite warmer (Endoking Nanowarm).



[Table/Fig-3]: Specimens for flexural strength (Preheated and non heated) using giomer.



[Table/Fig-4]: Specimens for microhardness (Preheated and non heated).

Temperature stabilisation: Before use, the composite warmer was switched on and allowed to operate for 30 minutes to achieve thermal stabilisation. To ensure optimal material properties and adherence to standardised protocols, the composite warming device was calibrated to a target temperature of 50°C, strictly following the manufacturer's recommendations [1,3,16,23].

For pre-warmed groups (A1, A3, B1, B3), the composite syringes were thermally conditioned in the warming chamber for 5 minutes to ensure uniform temperature distribution [11,17,23]. The syringes were removed and dispensed in under 30 seconds to minimise heat loss [22,26]. Specimen placement and photopolymerisation were performed directly adjacent to the heating device using pre-aligned dispensing tips to prevent temperature drops. For the Non heated control groups (A2, A4, B2, B4), the composite resin was injected and manipulated at room temperature (23±1°C) without thermal conditioning.

Specimens were cured with an LED light curing unit (minimum output intensity: 1000 mW/cm^2) in continuous mode for 30 seconds.

The curing tip was held perpendicular to and in direct contact with the overlying Mylar strip. Output intensity was verified with a radiometer before each experimental session to ensure uniform curing conditions.

The specimens were carefully taken out of the moulds after polymerisation to avoid deformation. To achieve a standardised surface smoothness for mechanical testing, the specimens were finished and polished sequentially using Sof-Lex discs (coarse to superfine grit) under continuous water cooling.

All specimens were stored for 24 hours at room temperature in sealed containers of distilled water before mechanical testing to allow for post-cure polymerisation and to simulate short-term moisture exposure. Flexural strength was determined using a calibrated Universal Testing Machine (UTM; 5 kN load cell) with a three-point bending fixture with a 20 mm support span. Each rectangular bar specimen was placed horizontally in the centre of the parallel supporting rods ensure an even load distribution. The specimen was loaded in compression vertically at a constant crosshead speed of 1 mm/min to the midpoint of the specimen until failure. The system software recorded the maximum load at failure. Each specimen was tested once under laboratory-controlled conditions.

Calculation of flexural strength: Flexural strength (σ) was calculated using the following formula:

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

Where:

- σ=Flexural strength (MPa)
- F=Maximum load at fracture (N)
- L=Support span (mm)
- b=Specimen width (mm)
- d=Specimen thickness (mm)

The dimensions of each specimen were verified using a digital vernier calliper prior to testing [5,23,25].

The calculated values were recorded in a predesigned data sheet.

Vickers microhardness measurements were performed using a calibrated hardness tester with a diamond pyramid indenter. The testing surfaces of disc specimens were cleaned with alcohol and securely fixed on testing stage. Each specimen surface was indented twice with 200 g load and 15 seconds dwell time. Indentations were separated by at least 1 mm from the specimen edges and at least 500 μm apart to prevent overlap of the stress field. The resulting impressions were observed under a magnification of 40× and the two diagonals of each indentation were measured using an integrated optical micrometer to calculate the average diagonal length (d) for the hardness calculation.

Calculation of microhardness: Vickers Hardness Number (VHN) was calculated using the formula:

$$VHN = \frac{1.854P}{d^2}$$

Where:

- VHN=Vickers hardness number (kgf/mm^2)
- P=Applied load (kgf)
- d=Mean diagonal length (mm)

The average of two readings per specimen was considered as the final microhardness [1,2,4].

STATISTICAL ANALYSIS

Data were entered into Microsoft Excel (Microsoft Corporation, Redmond, WA, USA) and analysed using IBM SPSS Statistics for Windows, Version 26.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics were calculated and presented as mean, standard deviation, minimum, maximum, and 95% confidence intervals. The normality of data distribution was assessed using the Shapiro-Wilk test. Since the data demonstrated normal distribution ($p>0.05$), parametric tests were applied. Intergroup comparisons between giomer and nanohybrid composite resins under normal and preheated conditions were performed using the independent samples t-test. Intragroup comparisons between normal and preheated specimens were performed using the paired samples t-test. Correlation between normal and preheated values was assessed using Pearson's correlation coefficient (r). A p-value of <0.05 was considered statistically significant.

RESULTS

The present study evaluated the effect of preheating on the flexural strength and microhardness of giomer and nanohybrid composite resins under normal and preheated conditions. Comprehensive statistical analysis was performed to assess central tendency, variability, distribution characteristics, intergroup differences, and the magnitude of observed effects.

Independent samples t-tests showed that giomer had significantly higher flexural strength than the Nanohybrid composite under both normal and preheated conditions ($p<0.001$) [Table/Fig-5]. Similarly, giomer exhibited significantly superior surface microhardness compared to the Nanohybrid composite across both testing states ($p<0.001$) [Table/Fig-6].

A strong and highly significant correlation ($r>0.90$, $p<0.001$) was observed between the normal and preheated states for all tested groups [Table/Fig-7].

The paired t-test analysis showed a systematic and significant improvement of mechanical properties of both restorative materials following thermal conditioning ($p<0.001$). Giomer: Preheating significantly increased flexural strength by 23.75MPa ($t(11)=-40.12$, $p<0.001$) and microhardness by 13.58 VHN ($t(11)=-43.42$, $p<0.001$). Nanohybrid Composite: The flexural strength was significantly increased with preheating by a mean of 21.33 MPa ($t(11)=-60.04$,

Comparison	Group	n	Mean±SD (MPa)	t	df	p-value	Mean difference	95% CI
Normal condition	Giomer	12	120.75±5.38	22.997	22	<0.001	47.25	42.99-51.51
	Nanohybrid	12	73.50±4.66					
Preheated condition	Giomer	12	144.50±4.60	27.307	22	<0.001	49.67	45.89-53.44
	Nanohybrid	12	94.83±4.30					

[Table/Fig-5]: Comparison of flexural strength between giomer and nanohybrid composite.

Comparison	Group	n	Mean±SD (VHN)	t	df	p-value	Mean difference	95% CI
Normal condition	Giomer	12	113.50±3.61	30.571	22	<0.001	45.00	41.95-48.05
	Nanohybrid	12	68.50±3.61					
Preheated condition	Giomer	12	127.08±4.06	27.388	22	<0.001	47.67	44.06-51.28
	Nanohybrid	12	79.42±4.46					

[Table/Fig-6]: Comparison of microhardness between giomer and nanohybrid composite.

Pair	Property	n	Correlation (r)	p-value
1	Flexural strength - Giomer	12	0.927	<0.001
2	Flexural strength - Nanohybrid	12	0.965	<0.001
3	Microhardness - Giomer	12	0.967	<0.001
4	Microhardness - Nanohybrid	12	0.975	<0.001

[Table/Fig-7]: Paired samples correlation between normal and preheated groups.

p<0.001) and microhardness by 10.92 VHN (t(11)=-30.49, p<0.001) [Table/Fig-8].

Pair	Property	Mean difference (Normal - Preheated)	t	df	p-value	95% CI
1	Flexural strength -giomer	-23.75	-40.12	11	<0.001	-25.05 to -22.45
2	Flexural strength - nanohybrid	-21.33	-60.04	11	<0.001	-22.12 to -20.55
3	Microhardness -giomer	-13.58	-43.42	11	<0.001	-14.27 to -12.89
4	Microhardness - nanohybrid	-10.92	-30.49	11	<0.001	-11.70 to -10.13

[Table/Fig-8]: Effect of preheating on mechanical properties.

DISCUSSION

The present in-vitro study evaluated the effect of preheating at 50°C on the flexural strength and surface microhardness of giomer and nanohybrid composite resins under standardised laboratory conditions. The findings demonstrated that preheating significantly enhanced both mechanical properties in both restorative materials (p<0.001). Preheated giomer exhibited the highest flexural strength (144.50±4.60 MPa) and microhardness (127.08±4.06 VHN), while the normal nanohybrid composite showed the lowest values. Giomer consistently demonstrated superior performance compared with nanohybrid composite under both normal and preheated conditions, suggesting that both material composition and thermal conditioning significantly influence mechanical behaviour [1,3,4].

Resin composite performance is strongly dependent on polymerisation efficiency, filler-matrix interaction, and the final cross-linked polymer structure. Preheating has been proposed as a practical method to improve handling characteristics and polymerisation kinetics by reducing viscosity and increasing monomer mobility before light activation [5,6]. Reduced viscosity improves adaptation of the material to cavity walls and may facilitate more effective polymer chain propagation before vitrification limits molecular movement [7,8]. These physicochemical effects may explain the substantial improvement in flexural strength and microhardness observed in the present study.

Flexural strength is an important mechanical property because restorative materials in clinical function are subjected to repeated bending, tensile, and compressive stresses during mastication. A material with higher flexural strength is generally considered more resistant to fracture and crack propagation in stress-bearing areas [9,10]. In the present study, preheating resulted in a 19.67% increase in flexural strength for giomer and a 29.02% increase for nanohybrid composite. These findings indicate that thermal conditioning significantly improves bulk structural resistance.

The present results are consistent with previous investigations reporting improved flexural performance after composite preheating. Kimyai S et al., demonstrated significant enhancement in flexural strength in both giomer and nanohybrid composite materials following thermal conditioning, attributing the improvement to enhanced polymerisation efficiency and increased molecular mobility [3]. Sharafeddin F et al., similarly reported increased flexural strength in preheated composite systems, supporting the concept that elevated temperature improves mechanical behaviour by reducing resin viscosity and promoting greater monomer conversion [6]. Abed Kahnamouei M et al., also observed improved flexural strength in bulk-fill resin composites following preheating, concluding that thermal conditioning positively affects structural performance [2]. Kramer MR et al., further reported enhanced flexural strength and improved bonding properties of preheated resin composites to dentin and glass-ceramic substrates, reinforcing the beneficial effect of temperature modulation on resin-based materials [19].

However, the literature is not entirely uniform. Abdulmajeed AA et al., found that preheating did not significantly improve fatigue resistance or flexural properties in certain bulk-fill composite systems [5]. The authors suggested that differences in resin chemistry, filler loading, and polymer architecture may influence responsiveness to heat treatment. Similarly, Uribe-Hernández L et al., reported that the effect of preheating on the degree of conversion was material-dependent and varied according to resin formulation and curing conditions [17]. Pérez-Pachas B et al., further demonstrated that the influence of preheating on microhardness was not consistent across all bulk-fill composites, with some materials showing significant improvement while others exhibited minimal or no benefit [11]. In addition, da Silva EM et al., observed that the physicochemical response to thermal conditioning may vary according to composite composition and handling protocols [12]. These discrepancies highlight that the effectiveness of preheating is material-dependent and technique-sensitive.

Surface microhardness is another clinically relevant parameter because it reflects resistance to localised indentation, wear, and surface degradation. It is also widely considered an indirect indicator of degree of conversion and polymer network integrity [13,14]. In the present study, preheating significantly increased microhardness in both materials, with improvements of 11.96% for giomer and 15.94% for nanohybrid composite. These findings suggest that thermal conditioning improves not only bulk strength but also surface polymer quality.

The current findings are in agreement with several previous studies. Singha A et al., reported that preheating significantly improved both microhardness and depth of cure in bulk-fill composites [1]. Değirmenci A and Bilgili D similarly demonstrated increased microhardness after preheating, attributing the effect to enhanced polymerisation kinetics [7]. Uribe-Hernández L et al., also reported improved polymerisation efficiency under thermal conditioning, indirectly supporting the microhardness improvements observed in the present study [17]. Elkaffas AA et al., in both an experimental investigation and a systematic review with meta-analysis, concluded that preheating generally improves surface hardness across multiple resin composite systems [4,9]. These findings collectively support the concept that thermal conditioning enhances polymerisation-related properties and contributes to improved surface durability of resin-based restorative materials.

Nevertheless, contradictory evidence exists. Ayub KV et al., reported that the effect of preheating on hardness and viscosity varied considerably among different resin composites, suggesting formulation-dependent responses [16]. Elkaffas AA et al., in their systematic review and meta-analysis, noted that the influence of preheating on composite properties is material-dependent and may vary according to the heating protocol, composite formulation, and testing methodology [9]. Similarly, Uribe-Hernández L et al., reported that the effectiveness of thermal conditioning on polymerisation-related outcomes differed among nanohybrid resin composites and was influenced by material composition and curing conditions [17]. These findings indicate that optimal preheating conditions likely vary according to composite composition, filler architecture, and resin chemistry.

A notable finding in the present study was the superior performance of giomer compared with nanohybrid composite under both experimental conditions. Giomer demonstrated significantly higher flexural strength and microhardness values, with intergroup differences exceeding 45 MPa for flexural strength and 45 VHN for microhardness. This suggests that intrinsic material composition substantially influences mechanical performance. Giomers incorporate S-PRG filler technology within a resin matrix, which may contribute to improved stress distribution, stronger filler–matrix interaction, and enhanced structural integrity [3,18]. The presence of reactive glass fillers may also improve mechanical stability and resistance to crack propagation. Nanohybrid composites, although engineered for improved aesthetics and polishability, may exhibit comparatively lower bulk mechanical resistance depending on filler loading and resin matrix composition [19]. Interestingly, despite lower baseline values, nanohybrid composite showed a greater percentage improvement after preheating, suggesting greater thermal responsiveness. This may reflect a larger viscosity reduction effect or enhanced monomer mobility in the nanohybrid resin matrix.

The strong paired correlations observed between normal and preheated groups ($r>0.90$, $p<0.001$) indicate highly consistent specimen behaviour and support the reliability of the findings. The narrow confidence intervals and low standard deviations further reinforce measurement precision and internal consistency. These findings strengthen confidence that the observed differences were systematic rather than random experimental variation.

From a clinical perspective, the results suggest that preheating may be a useful adjunctive step for improving composite performance. Composite warming devices are relatively simple to integrate into restorative practice, and the resulting improvements in handling, adaptation, and polymerisation efficiency may enhance restoration durability [20,27]. However, the benefits of preheating depend on prompt placement and curing because composite materials lose heat rapidly after removal from the warming source [12,28].

Despite these promising findings, clinical extrapolation should be approached cautiously. Improved laboratory mechanical properties do not automatically translate into superior long-term clinical performance. The oral environment introduces thermal cycling, moisture exposure, occlusal fatigue, enzymatic degradation, and chemical challenges that may alter material behaviour over time [21,22,29]. Some studies have suggested that preheating may also influence monomer elution, porosity, and cytotoxic potential, which warrants further investigation [23,24,30].

Overall, the findings of the present study demonstrate that preheating significantly enhances the flexural strength and microhardness of both giomer and nanohybrid composite resins. Giomer exhibited superior absolute mechanical performance, while nanohybrid composite showed greater relative improvement following thermal conditioning. These results support the use of controlled preheating as a practical strategy for improving composite mechanical behaviour, although material-specific responses and long-term clinical relevance require further investigation.

The present study has several strengths. Standardised specimen fabrication, controlled thermal conditioning, calibrated testing equipment, and assessment of both flexural strength and microhardness provide robust internal validity.

Limitation(s)

The present study was conducted under controlled in-vitro laboratory conditions without aging simulations such as thermocycling or water storage. Only one preheating temperature was evaluated, and the degree of conversion, polymerisation shrinkage stress, and long-term degradation behaviour were not directly assessed. Therefore, extrapolation of these findings to long-term clinical performance should be made cautiously.

Future studies should evaluate multiple preheating temperatures, incorporate artificial aging protocols, and assess long-term mechanical stability under simulated oral conditions. Direct measurement of the degree of conversion using FTIR spectroscopy and evaluation of polymerisation shrinkage would provide further mechanistic insight into the effects of preheating on composite materials.

CONCLUSION(S)

The present in-vitro investigation provides a comprehensive evaluation of the influence of thermal conditioning on the mechanical properties of contemporary resin-based restorative materials. Within the limitations of the present study, preheating at 50°C significantly enhanced both flexural strength and surface microhardness of the tested materials, indicating improved resistance to fracture and surface wear. Giomer composite resin containing S-PRG filler technology demonstrated superior mechanical performance compared with the nanohybrid composite under both normal and preheated conditions, suggesting its potential suitability for restorations subjected to higher functional stresses. The reduction in viscosity associated with preheating may facilitate improved material flow and adaptation to cavity walls, potentially minimising marginal discrepancies. However, the clinical benefits of thermal conditioning are dependent on prompt placement and light curing following removal from the warming device, as rapid heat loss may reduce the advantages achieved through preheating. Further long-term clinical studies are required to determine whether these improvements translate into enhanced restoration longevity under intraoral conditions.

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