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The effect of preheating resin composites on surface hardness: a systematic review and meta-analysis

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Conflict of Interest
The authors of this article certify that they have no proprietary, financial, or other personal interest of any nature or kind in any product, service, and/or company that is presented in this article.

ABSTRACT

Objectives: This paper presents a systematic review and meta-analysis of the effect of preheating on the hardness of nanofilled, nanoceramic, nanohybrid, and microhybrid resin composites.
Materials and Methods: An electronic search of papers on MEDLINE/PubMed, ScienceDirect, and EBSCOhost was performed. Only *in vitro* studies were included. Non-English studies, case reports, clinical trials, and review articles were excluded. A meta-analysis of the reviewed studies was conducted to quantify differences in the microhardness of the Z250 microhybrid resin composite using the Comprehensive Meta-Analysis software.
Results: Only 13 studies met the inclusion criteria for this systematic review. The meta-analysis showed that there were significant differences between the non-preheated and preheated modes for both the top and bottom surfaces of the specimens ($p < 0.05$). The microhardness of the Z250 resin composite on the top surface in the preheated mode (78.1 ± 2.9) was higher than in the non-preheated mode (67.4 ± 4.0; $p < 0.001$). Moreover, the microhardness of the Z250 resin composite on the bottom surface in the preheated mode (71.8 ± 3.8) was higher than in the non-preheated mode (57.5 ± 5.7, $p < 0.001$).
Conclusions: Although the results reported in the reviewed studies showed great variability, sufficient scientific evidence was found to support the hypothesis that preheating can improve the hardness of resin composites.

Keywords: Composite temperature; Meta-analysis; Microhardness; Microhybrid; Preheated composite; Systematic review

INTRODUCTION

Evidence-based dentistry is an approach to dental health care that requires the judicious integration of systematic assessments of clinically-relevant scientific evidence [1]. It has become more complicated to make decisions in clinical dental practice due to the large amount of scientific information that is continually published on new techniques, therapies, and restorative materials. Systematic reviews and meta-analyses are considered to provide an effective level of data to support evidence-based decision-making [2].

Author Contributions

Conceptualization: Mahmoud SH; Data curation: Elnegoly SA; Formal analysis: Eltoukhy RI; Funding acquisition: Elkaffas AA; Investigation: Elkaffas AA; Methodology: Elkaffas AA; Project administration: Mahmoud SH; Resources: Elkaffas AA; Software: Eltoukhy RI; Supervision: Mahmoud SH; Validation: Elnegoly SA; Visualization: Elnegoly SA; Writing - original draft: Elkaffas AA, Eltoukhy RI; Writing - review & editing: Elnegoly SA, Mahmoud SH.

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With rapid improvements in materials science, restorative resin composites have played a significant role in modern dentistry due to the growing demand for esthetic restorations [3]. Over the last decade, manufacturers have made improvements in the mechanical properties of composites, including reductions in polymerization shrinkage, which have encouraged clinicians to use resin composites in posterior restorations [4]. These improvements have primarily targeted monomer composition, aiming to enhance the microstructure of the material, including filler particle size, shape, and loading [4]. Increasing the filler content was one of the main concerns associated with enhancing the mechanical properties of resin composites [4], because doing so causes the viscosity of a composite material to increase, impairing its packing, handling, and adaptation during application [4].

Decreasing the filler load in order to obtain a less viscous composite material has resulted in one of the main drawbacks of current resin composites: namely, they contract or shrink during the monomer-to-polymer conversion [5]. This polymerization shrinkage stresses the adhesive bond between the tooth and the restorative material, frequently resulting in bond failure and marginal infiltration [6]. These problems have encouraged manufacturers to search for better solutions and to make either the material or the technique easier to apply and faster to use. Therefore, it is important to address the effect of reducing the viscosity to improve the adaptation of the resin composite and to improve the ease of placement. This is the primary basis for the development of preheated composites [7].

Warming resin composite restorations before application is a new trend in the field of dentistry. Preheating increases the flowability of the composite and reduces its viscosity, providing better adaptation to cavity walls, especially for high-viscosity materials [8,9]. Preheating the resin composite reduces microleakage, thereby increasing the durability of the restoration [10-12]. Preheating also increases the temperature of the composite because the higher thermal energy enhances the mobility of the radicals and monomers, resulting in a higher degree of monomer conversion and an improved polymerization rate [13-15].

Hardness has often been used to assess the physical properties of restorative materials, as it correlates well with the degree of conversion of resin composites [12,16-19]. Hardness refers to the resistance of a material against indentation. Therefore, there is a relationship between hardness, a material's strength, and its proportional limit. In dentistry, hardness is a measure of a restoration's ability to abrade or to be abraded by opposing structures. Consequently, factors affecting the hardness of a restoration can influence its durability [20].

Therefore, the mechanical properties of preheated resin composites should be studied to understand the effect of heat on the material's ability to resist fracture, wear, and the forces of mastication. Previous studies [16,21] have reported unclear, and sometimes conflicting, outcomes associated with this issue. Muñoz *et al.* [16] suggested that heating traditional resin composites can improve their hardness via greater monomer conversion. Conversely, Osternack *et al.* [21] concluded that composite hardness was not affected by precooling or preheating procedures. However, the available data about the impact of composite preheating on hardness are scarce, and still inconclusive.

The key question this systemic review sought to answer is: Does preheating a resin composite increase its hardness? However, no clear answer to this question currently exists due to the weak available scientific evidence. Therefore, this meta-review was designed to analyze and assess the currently available published studies evaluating the effect of preheating on the hardness of resin composites. The null hypothesis tested in this study was that preheating has no effect on the hardness of resin composites.

MATERIALS AND METHODS

Search strategy

In this structured systematic review, 3 electronic databases were searched: the National Library of Medicine (MEDLINE/PubMed), EBSCOhost, and ScienceDirect. The following keywords were used to search these databases: 'preheated composite' or 'preheating composite' or 'composite temperature' and 'composite microhardness' or 'composite hardness' or 'composite mechanical properties.'

Inclusion/exclusion criteria

Only *in vitro* studies and manuscripts written in English were included in this systematic review. Only studies from 2007 until 2019 were included. Manuscripts written in a language other than English, case reports, clinical trials, and review articles were excluded. Moreover, studies that evaluated the effect of preheating on microleakage and other viscoelastic and mechanical properties of composites than microhardness were excluded. The initial search of the National Library of Medicine database identified 117 articles; the 2 other databases were subsequently searched, followed by a gray literature search.

Three manuscripts were excluded because they were not written in English, and 2 studies were excluded because they were case reports. Of the remaining 112 manuscripts, 1 clinical trial and 1 review article were excluded, and 97 other studies were excluded because they evaluated the effect of preheating a composite on microleakage and other viscoelastic and mechanical properties of composites than microhardness. Finally, 13 studies were selected [8,16,19,21-30]. The detailed study selection procedures are illustrated in a flowchart (**Figure 1**).

The titles and abstracts of all the studies were independently assessed by 2 of the 3 authors of this systematic review. Only studies that evaluated the effect of preheating on the hardness of resin composites were included. The full text of the papers was independently assessed in triplicate by all 3 authors. A study was included if at least 2 of the reviewers (authors) agreed that it met the inclusion criteria. A meta-analysis of the reviewed studies was performed to quantify the differences in the mean microhardness of the Z250 microhybrid resin composite (3M ESPE, St. Paul, MN, USA) on both the top and bottom surfaces of the specimens using Comprehensive Meta-Analysis software, version 2 (Biostat, Englewood, NJ, USA), with 95% confidence intervals.

Assessment of risk of bias

The risk of bias was evaluated based on the following parameters: verifying the spectral irradiance of the light-curing units, using specimens with similar dimensions, using a universal preheating device, blinding of the examiner, and using the Vickers or Knoop test to determine the hardness of the specimen by making indentations on the top and bottom surfaces. If the authors reported that a parameter was used in the study, a 'Yes' was assigned for that parameter; if it was not possible to find the information, or if the parameter was not reported, the article was assigned a 'No'. Articles that reported 1 to 2 parameters were classified as having a high risk of bias. Those that reported 3 parameters were considered to have a medium risk of bias, and those that reported 4 or 5 parameters were classified as having a low risk of bias.

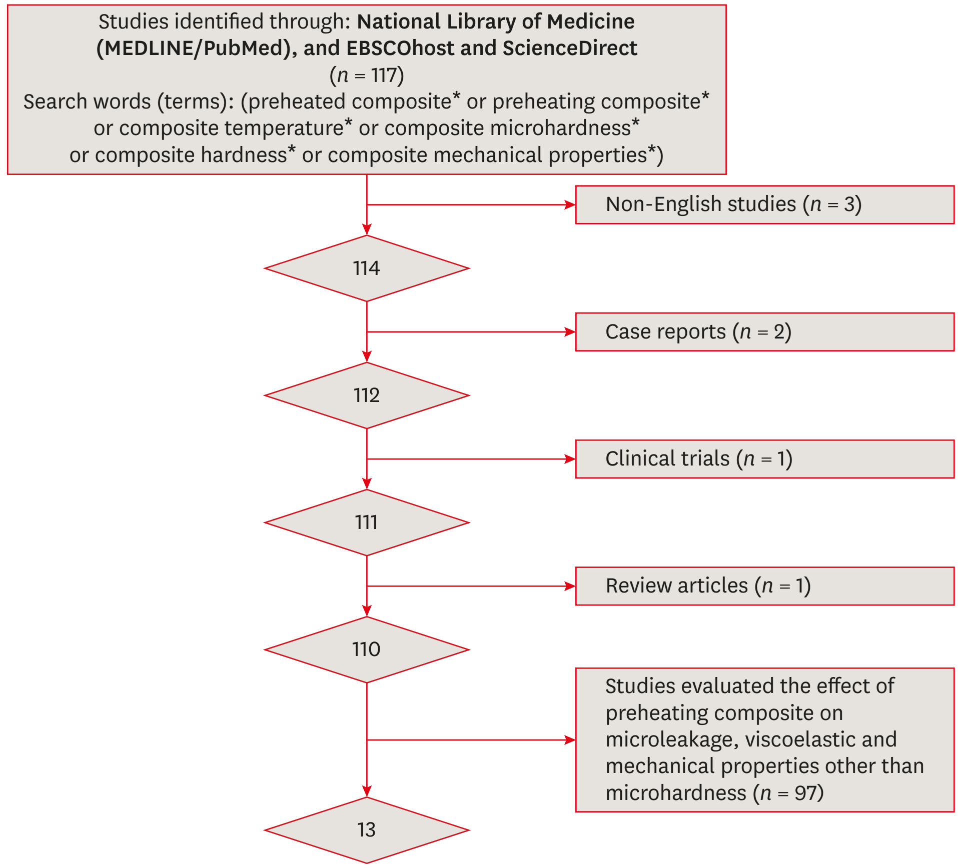

Figure 1. Flowchart of the study selection procedure.

RESULTS

This systematic review evaluated 13 studies that were conducted to evaluate the microhardness of 16 different brands of resin composites. Six of the studies (46%) evaluated the microhardness of the Z250 microhybrid resin composite [19,26-30]. Two studies (15%) evaluated the microhardness of the Filtek Silorane resin composite (3M ESPE) [27,29], and 2 other studies (15%) evaluated the microhardness of the TPH Spectra microhybrid resin composite (Dentsply Caulk, Milford, DE, USA) [8,16]. The remaining studies evaluated other resin composites: Charisma (Heraeus-Kulzer, Hanau, Germany) [21], Enamel Plus HFO (Micerium SpA, Avegno, Italy), Opallis (FGM Produtos Odontologicos, Joinville, Brazil), Ceram X Duo (Dentsply DeTrey GmbH, Konstanz, Germany) [22], Grandio (Voco, Cuxhaven, Germany), Simile (Jeneric Pentron, Wallingford, CT, USA), Tetric N-Ceram (Ivoclar Vivadent, Schaan, Liechtenstein) [23], Microhybrid Esthet-X (Dentsply Caulk) [16], light-cured low-stress posterior bulk fill flowable base composites, Surefil SDR (Dentsply Caulk) [24], Vit-l-escence (microhybrid, Ultradent, Salt Lake City, UT, USA), Tetric Ceram HB (Ivoclar Vivadent), Filtek Supreme Ultra (3M ESPE), Filtek LS Low Shrink Posterior Restorative System (3M ESPE) [25], and a nanofilled composite (Filtek Supreme Plus, 3M ESPE) [19].

Moreover, most of the reviewed articles were recently published. Two studies were published in 2017 [19,24], 1 was published in 2016 [27], 3 were published in 2015 [22,23,30], 1 was published in 2014 [25], and 1 was published in 2013 [21]. The rest of the studies were published between 2007 and 2011 [8,16,19,28]. All the reviewed studies (100%) used either the Vickers or Knoop hardness tests as the primary testing method to determine microhardness [8,16,19,21-30]. However, the studies showed considerable variation in the secondary testing methods: shrinkage gap formation [21], the 3-point bending test [22], depth of cure [16,24], viscosity [8,25], degree of conversion, plasticization [24], flexural strength, and the elastic modulus [27]. The type of preheating device used in the reviewed studies varied widely. Four studies used a Calset Unit 21 composite warming unit (AdDent, Inc., Danbury, CT, USA) [16,19,25,28]. Three studies used a commercially-available composite warmer (ENA Heat; Micerium SpA) [22,29,30]. Three studies used a water bath set to the specific preheating temperature (25°C, 37°C, or 68°C) [21,26,27]. Two studies used a dry, hot oven set to the specific preheating temperature for 15 or 30 minutes [8,23]. One study used an incubator (model 502, Fanem Ltda, Guarulhos, Brazil) with a preheating temperature (23°C and 54°C) for 1 hour [24]. A summary of the findings, testing methods, bibliographic data, and materials analyzed in the included studies is presented in **Tables 1** and **2**.

Table 1. Summary of the studies included in this systematic review

Study	Objective	Conclusion	Primary testing method	Secondary testing method
Osternack *et al*. [21]	This study evaluated the hardness and shrinkage of a precooled or preheated hybrid composite resin cured by a QTH light and LED curing units. The temperature on the tip of the devices was also investigated.	It was concluded that the hardness was not affected by precooling or preheating. However, polymerization shrinkage was slightly affected by different pre-polymerization temperatures. The QTH-curing generated greater shrinkage than LED-curing only when the composite was preheated. Different temperatures did not affect the composite hardness and shrinkage when cured by a LED curing unit.	Knoop hardness	Shrinkage gap formation
D'amario *et al*. [22]	This study assessed the flexural strength, flexural elastic modulus and Vickers microhardness of 3 resin composites prepared at room temperature or cured after 1 or repeated preheating cycles to a temperature of 39°C.	The tested preheating procedure did not negatively influence the mechanical properties of the resin composites even when extensively repeated.	Vickers microhardness	Three-point bending test
Jafarzadeh Kashi *et al*. [23]	This study evaluated the effect of 3 preheating temperatures on the microhardness of 3 different nanohybrid resin-based composites.	Regardless of the resin composite material used, surface hardness was considerably improved by increasing the temperature. The microhardness values were influenced significantly by the resin-based composite brand.	Vickers microhardness	
Muñoz *et al*. [16]	This study evaluated the depth of cure and surface hardness of 2 resin composites when subjected to 3 preheating temperatures, 3 polymerization times and 2 types of curing lights.	Preheating resin composites increased the monomer conversion rate and increased the depth of cure and hardness of the tested composites. LEDs produced statistically significantly better results that the halogen curing light. Shorter polymerization times with a preheated resin can produce similar hardness values as a room-temperature resin with longer curing times.	Knoop hardness	Depth of cure
Lucey *et al*. [8]	This study evaluated the effect of pre-heating resin composite on pre-cured viscosity and post-cured surface hardness.	Pre-heating a resin composite reduces its pre-cured viscosity and enhances its subsequent surface hardness. These effects may translate into easier placement, together with an increased degree of polymerization and depth of cure.	Vickers microhardness	Viscosity
Theobaldo *et al*. [24]	This study evaluated the effect of composite preheating and polymerization mode on the degree of conversion, microhardness, plasticization, and depth of polymerization of a bulk fill composite.	Composite preheating increased the polymerization degree of 4-mm-increment bulk fill, but it led to a higher plasticization compared to the conventional flowable composite evaluated. Microhardness was not affected by temperature or curing mode.	Knoop hardness	Degree of conversion Depth of polymerization Plasticization
Ayub *et al*. [25]	This study evaluated the effect of temperature on the microhardness and viscosity of 4 resin composite materials.	The effects of preheating resin composites may allow easier placement of restorations and greater monomer conversion.	Knoop hardness	Viscosity
Caneppele *et al*. [26]	This study evaluated the effects of the preheating or precooling resin composite on surface hardness.	It was concluded that preheating the resin composite significantly increased its microhardness, and a light-cure time of 40 sec improved top microhardness for the use of resins at 24°C or 5°C.	Vickers microhardness	

(continued to the next page)

Table 1. (Continued) Summary of the studies included in this systematic review

Study	Objective	Conclusion	Primary testing method	Secondary testing method
Mohammadi *et al.* [27]	This study evaluated the effect of preheating on the mechanical properties of 2 different classes of composites.	Preheating silorane enhanced the composite's microhardness and elastic modulus, but did not affect its flexural strength. In contrast, preheating Z250 increased its microhardness, but did not change its flexural strength or elastic modulus. In addition, the Z250 composite showed higher microhardness and flexural strength than silorane, but the elastic modulus values with preheating were similar.	Vickers microhardness	Flexural strength Elastic modulus
Awliya [28]	This study evaluated the effect of different temperatures on the efficacy of polymerization during the insertion of composite resin using different light-curing units.	The use of prewarmed composite resins might help to improve polymerization of composite resin, especially at the deeper areas of a restoration, which could result in an increase in the expected life of a composite restoration.	Vickers microhardness	
Theodoridis *et al.* [29]	This study evaluated the effect of preheating and shade on the surface microhardness of silorane-based composites.	Preheating, shade, and composition of the tested composite resins affected their surface microhardness.	Vickers microhardness	
Dionysopoulos *et al.* [30]	This study evaluated the microhardness of 2 composite resins when subjected to 3 different temperatures and 3 different light-curing times.	The temperature of composites affected their surface microhardness. Also, light-curing time influenced the microhardness values of the composites tested.	Vickers microhardness	
Tantbirojn *et al.* [19]	This study evaluated the effect of composite preheating and light-curing duration on hardness and postgel shrinkage.	Preheating of the composites only slightly increased hardness values and did not negatively affect postgel shrinkage. Reducing the light-curing durations, however, significantly reduced the hardness at both the top (0 mm) and bottom (2 mm) surfaces.	Vickers microhardness	Postgel shrinkage

QTH, quartz-tungsten-halogen; LED, light-emitting diode.

Table 2. Bibliographic data and materials used in the included studies

Study	Year	Total No. of specimens	Preheating device used	Type of composite used (brand name)
Osternack *et al.* [21]	2013	120	Water bath (TE 054 Mag, Tecnal, Piracicaba, Brazil)	Nanohybrid composite (Charisma, Heraeus-Kulzer, Hanau, Germany)
D'amario *et al.* [22]	2015	180	Commercially-available composite warmer (ENA Heat, Micerium SpA, Avegno, Italy)	Enamel Plus HFO microhybrid composite (Micerium SpA); microhybrid composite (Opallis, FGM Produtos Odontologicos, Joinville, Brazil); nanoceramic composite (Ceram X Duo, Dentsply DeTrey GmbH, Konstanz, Germany)
Jafarzadeh Kashi *et al.* [23]	2015	90	Laboratory oven at the specified temperatures for 30 min	Microhybrid composite (Grandio, Voco, Cuxhaven, Germany); microhybrid composite (Simile, Jeneric Pentron, Wallingford, CT, USA); nanohybrid composite (Tetric N-Ceram, Ivoclar Vivadent, Schaan, Liechtenstein)
Muñoz *et al.* [16]	2008	180	Calset Unit 21 composite warming unit (AdDent, Inc., Danbury, CT, USA)	Microhybrid (Esthet-X, Dentsply Caulk, Milford, DE, USA); microhybrid composite (TPH Spectra, Dentsply Caulk)
Lucey *et al.* [8]	2009	30	Dry oven for 15 min	Microhybrid composite (Spectrum TPH, Dentsply DeTrey GmbH)
Theobaldo *et al.* [24]	2017	40	Incubator (model 502, Fanem Ltda, Guarulhos, Brazil) with preheating temperature (23°C and 54°C) for 1 hr	Light-cured low-stress posterior bulk fill flowable base composite (Surefil SDR, Dentsply Caulk)
Ayub *et al.* [25]	2014	80	Calset Unit 3 composite warming unit (AdDent, Inc.)	Microhybrid composite (Vit-l-escence, Ultradent, Salt Lake City, UT, USA); nanohybrid composite (Tetric Ceram HB, Ivoclar Vivadent); nanofilled composite (Filtek Supreme Ultra, 3M ESPE, St Paul, MN, USA); Filtek LS Low Shrink Posterior Restorative System (3M ESPE)
Caneppele *et al.* [26]	2011	60	Water bath set to a specific preheating temperature	Microhybrid composite (Z250, 3M ESPE)
Mohammadi *et al.* [27]	2016	102	Water bath set to a specific preheating temperature (25°C, 37°C, or 68°C)	Filtek silorane-based composite (3M ESPE); microhybrid composite (Z250, 3M ESPE)
Awliya [28]	2007	45	Calset Unit 21 composite warming unit (AdDent, Inc.)	Microhybrid composite (Z250, 3M ESPE)
Theodoridis *et al.* [29]	2017	60	Commercially-available composite warmer (ENA Heat, Micerium SpA)	Filtek silorane-based composite (3M ESPE); microhybrid composite (Z250, 3M ESPE)
Dionysopoulos *et al.* [30]	2015	90	Commercially-available composite warmer (ENA Heat, Micerium SpA)	Microhybrid composite (Z250, 3M ESPE), Nanohybrid composite (GrandioSO, Voco)
Tantbirojn *et al.* [19]	2011	40	Calset Unit 21 composite warming unit (AdDent, Inc.)	Microhybrid composite (Z250, 3M ESPE); nanofilled composite (Filtek Supreme Plus, 3M ESPE)

Table 3. Criteria used for quality assessment and determination of the risk of bias

Study	Verifying spectral irradiance of light-curing units	Specimen with similar dimension	Universal preheating device	Blinding of the examiner	Vickers or Knoop indentation on the top and bottom surfaces	Risk of bias
Osternack *et al*. [21]	Yes	7-12 × 2 mm Yes	No	No	Yes	Medium
D'amario *et al*. [22]	Yes	10 × 2 mm Yes	Yes	No	Top surface No	Medium
Jafarzadeh Kashi *et al*. [23]	Yes	10 × 2 mm Yes	No	No	Yes	Medium
Muñoz *et al*. [16]	Yes	4 × 6 mm Yes	Yes	No	Yes	Low
Lucey *et al*. [8]	Yes	8 × 1.5 mm Yes	No	No	Yes	Medium
Theobaldo *et al*. [24]	Yes	5 × 4 mm Yes	No	No	Yes	Medium
Ayub *et al*. [25]	Yes	5 × 2 mm Yes	Yes	No	Yes	Low
Caneppele *et al*. [26]	No	5 × 3 mm Yes	No	No	Yes	High
Mohammadi *et al*. [27]	No	4 × 2 mm Yes	No	No	Top surface No	High
Awliya [28]	Yes	8 × 2 mm Yes	Yes	No	Yes	Low
Theodoridis *et al*. [29]	Yes	4 × 2 mm Yes	Yes	No	Yes	Low
Dionysopoulos *et al*. [30]	No	6 × 2 mm Yes	Yes	No	Yes	Medium
Tantbirojn *et al*. [19]	Yes	4.7 × 2 mm Yes	Yes	No	Yes	Low

In terms of the quality of the included studies, 5 studies were found to have a low risk of bias, while 6 had a medium risk of bias and 2 had a high risk of bias. These results are based on the parameters considered in the analysis; the findings are presented in **Table 3**. All the included studies scored poorly on the blinding of the examiner parameter [8,16,19,21-30]. Six studies scored poorly on the universal preheating parameter [8,21,23,24,26,27]. Two studies scored poorly on the parameter of using the Vickers or Knoop test to determine the hardness of the material by making indentations on the top and bottom surfaces of the device [22,27]. Three studies scored poorly on the parameter of verifying the spectral irradiance of the light-curing units [26,27,30].

The outcomes of the microhardness testing of different resin composites for the top and bottom surfaces of the specimens used in the reviewed articles are shown in **Table 4**. After carefully reviewing the selected articles, it was found that 45% of the studies evaluated the microhardness of the Z250 microhybrid resin composite; therefore, a meta-analysis was conducted. The meta-analysis was performed by combining all the data about the microhardness of the Z250 microhybrid resin composite in the non-preheated and preheated modes with the corresponding number of teeth used per group. The results of the meta-analysis of microhardness of the Z250 resin composite obtained for the top and bottom surfaces of the specimens in the non-preheated and preheated modes are presented in **Tables 5** and **6** and illustrated in forest plots in **Figures 2** and **3**. According to the statistical model presented by Borenstein *et al.* [31] a significant difference was found between the non-preheated and preheated modes for both the top and bottom surfaces of the specimens. The microhardness of the Z250 resin composite on the top surface in the preheated mode (78.1 ± 2.9) was higher than in the non-preheated mode (67.4 ± 4.0; $p < 0.001$). Moreover, the microhardness of the Z250 resin composite on the bottom surface in the preheated mode (71.8 ± 3.8) was higher than in the non-preheated mode (57.5 ± 5.7; $p < 0.001$, **Table 7**).

Table 4. Microhardness of different resin composites for the top and bottom surfaces of specimens used in the included studies

Study	Resin composite brand name	Microhardness (KHN or VHN)			
		Non-preheated (21°C–25°C)		Preheated (55°C–60°C)	
		Top	Bottom	Top	Bottom
Osternack *et al*. [21]	Charisma*	29.6 ± 2.0	29.9 ± 2.7	31.1 ± 1.85	29.1 ± 3.6
D'amario *et al*. [22]	Enamel Plus HFO*	78.2 ± 5.8	-	72.5 ± 8.6	-
	Opallis*	64.1 ± 2.2	-	66.4 ± 5.2	-
	Ceram X Duo*	70.1 ± 4.8	-	72.5 ± 5.5	-
Jafarzadeh-Kashi *et al*. [23]	Grandio†	118.8 ± 3.2	111.8 ± 4.4	125.3 ± 3.8	121.8 ± 3.5
	Simile†	67.9 ± 5.4	64.1 ± 5.1	71.0 ± 3.7	66.1 ± 3.8
	Tetric N-Ceram†	54.4 ± 3.1	49.9 ± 4.5	56.8 ± 3.3	51.6 ± 6.1
Muñoz *et al*. [16]	Microhybrid Esthet X*	41.3 ± 0.6	35.1 ± 0.4	59.4 ± 0.7	52.8 ± 0.2
	TPH Spectra*	36.6 ± 0.5	30.1 ± 0.6	54.5 ± 0.2	40.7 ± 0.2
Lucey *et al*. [8]	TPH Spectra†	60.6 ± 1.4	59.0 ± 3.5	68.6 ± 2.3	68.7 ± 1.8
Theobaldo *et al*. [24]	Surefil SDR*	49.1 ± 6.1	47.4 ± 5.2	48.8 ± 3.3	48.3 ± 5.0
Ayub *et al*. [25]	Vit-l-escence*	52.0 ± 1.7	42.6 ± 2.4	57.2 ± 2.3	48.1 ± 1.7
	Tetric Ceram HB	52.3 ± 2.0	43.1 ± 3.3	53.0 ± 1.9	43.6 ± 3.9
	Filtek Supreme Ultra*	70.8 ± 0.8	68.6 ± 1.7	76.0 ± 2.2	72.2 ± 2.2
	Filtek LS*	49.8 ± 1.2	44.0 ± 0.7	60.1 ± 0.9	53.0 ± 1.9
Caneppele *et al*. [26]	Z250*	68.8 ± 1.7	45.0 ± 6.1	81.1 ± 2.7	61.0 ± 6.0
Mohammadi *et al*. [27]	Z250*	114.7 ± 27.1	-	124.3 ± 22.3	-
	Filtek Silorane*	102.8 ± 25.7	-	91.5 ± 18.3	-
Awliya [28]	Z250*	90.6 ± 1.5	81.0 ± 1.4	98.2 ± 6.4	92.9 ± 8.3
Theodoridis *et al*. [29]	Z250*	67.0 ± 0.2	57.0 ± 0.2	78.1 ± 0.2	72.0 ± 0.3
	Filtek Silorane*	57.3 ± 0.3	51.2 ± 0.3	66.4 ± 0.3	61.3 ± 0.1
Dionysopoulos *et al*. [30]	Z250†	65.4 ± 3.3	55.1 ± 2.8	78.4 ± 4.6	72.3 ± 3.8
	GrandioSO†	68.1 ± 3.4	58.1 ± 2.5	75.3 ± 3.6	68.7 ± 3.3
Tantbirojn *et al*. [19]	Z250†	63.0 ± 2.0	58.0 ± 2.0	63.0 ± 4.5	58.0 ± 3.0
	Filtek Supreme Plus†	53.0 ± 2.5	28.0 ± 1.5	56.0 ± 2.0	26.0 ± 2.5

The values are shown as mean ± standard deviation.
KHN, Knoop hardness number; VHN, Vickers hardness number.
*Light-emitting diode light-cured for 20 seconds; †Quartz-tungsten-halogen light-cured for 20 seconds.

Table 5. Results of the meta-analysis of the microhardness of the Z250 resin composite obtained from the top surface in the non-preheated and preheated modes

Study	N1	N2	Total	SMD	SE	95% CI	t	*p*
Caneppele *et al*. [26]	10	10	20	−5.221	0.930	−7.175 to −3.267		
Mohammadi *et al*. [27]	17	17	34	−0.378	0.338	−1.066 to 0.311		
Awliya [28]	5	5	10	−1.476	0.659	−2.997 to 0.0447		
Theodoridis *et al*. [29]	5	5	10	−50.100	11.217	−75.967 to −24.233		
Dionysopoulos *et al*. [30]	5	5	10	−2.931	0.869	−4.936 to −0.927		
Tantbirojn *et al*. [19]	5	5	10	0.000	0.571	−1.317 to 1.317		
Total (fixed effects)	47	47	94	−1.024	0.245	−1.512 to −0.537	−4.175	< 0.001
Total (random effects)	47	47	94	−2.251	0.972	−4.181 to −0.321	−2.317	0.023

N1, number of specimens for the non-preheated mode; N2, number of specimens for the preheated mode; SMD, standardized mean difference; SE, standard error; CI, confidence interval.

Table 6. Results of the meta-analysis of the microhardness of the Z250 resin composite obtained from the bottom surface in the non-preheated and preheated modes

Study	N1	N2	Total	SMD	SE	95% CI	t	*p*
Caneppele *et al*. [26]	10	10	20	−2.533	0.586	−3.764 to −1.301		
Awliya [28]	5	5	10	−1.805	0.699	−3.417 to −0.193		
Theodoridis *et al*. [29]	5	5	10	−53.110	11.890	−80.528 to −25.693		
Dionysopoulos *et al*. [30]	5	5	10	−4.652	1.187	−7.388 to −1.916		
Tantbirojn *et al*. [19]	5	5	10	0.000	0.571	−1.317 to 1.317		
Total (fixed effects)	30	30	60	−1.686	0.338	−2.363 to −1.009	−4.986	< 0.001
Total (random effects)	30	30	60	−2.643	1.195	−5.036 to −0.251	−2.211	0.031

N1, number of specimens for the non-preheated mode; N2, number of specimens for the preheated mode; SMD, standardized mean difference; SE, standard error; CI, confidence interval.

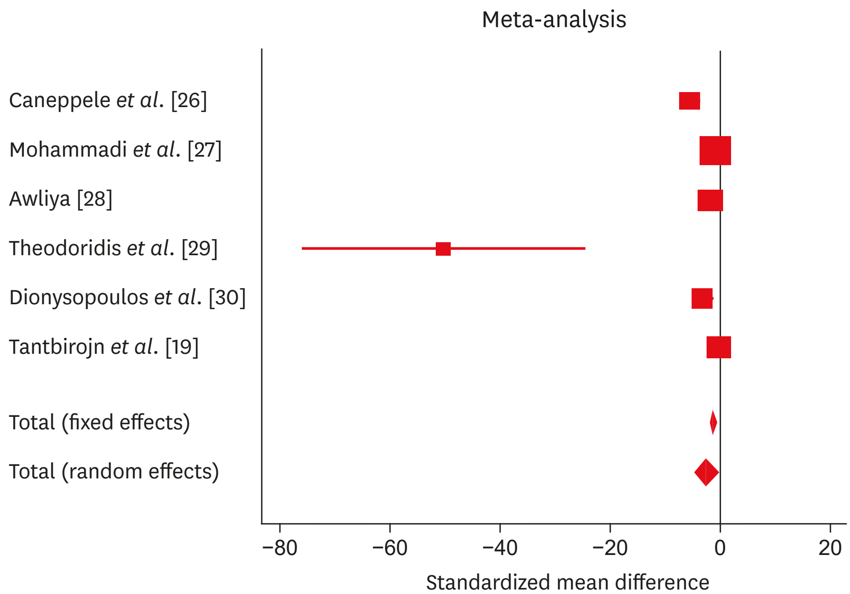

Figure 2. Results of the meta-analysis of microhardness of the Z250 resin composite obtained from the top surface in the non-preheated and preheated modes.

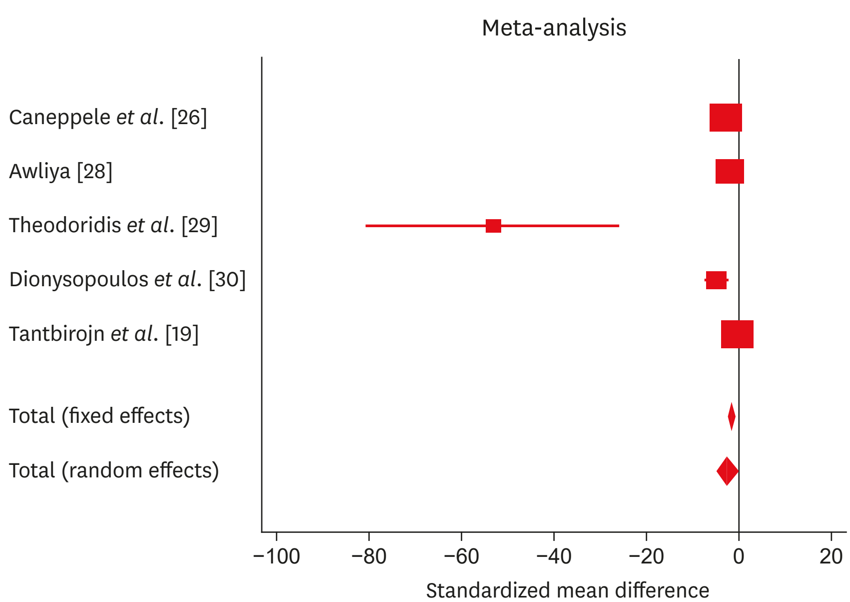

Figure 3. Results of the meta-analysis of microhardness of the Z250 resin composite obtained from the bottom surface in the non-preheated and preheated modes.

Table 7. Comparison of microhardness (Knoop hardness number; KHN) values of the Z250 resin composite obtained from the top and bottom surfaces using the non-preheated and preheated modes

Heating mode	Microhardness (KHN)	
	Top	Bottom
Non-preheated	67.4 ± 4.0	57.5 ± 5.7
Preheated	78.1 ± 2.9	71.8 ± 3.8

Results are based on the *t*-test of the meta-analysis data following the statistical model of Borenstein *et al.* [31].
The values are shown as mean ± standard deviation.

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DISCUSSION

Systematic reviews are a useful tool for clinical practitioners because they provide accurate evidence-based answers to relevant questions about the best available scientific knowledge. Furthermore, systematic reviews can recommend new standardized research protocols and methodologies [32,33].

The majority of the studies included in this systematic review utilized the Z250 microhybrid resin composite. Therefore, it was beneficial to conduct a meta-analysis of those studies. The meta-analysis revealed significant differences in microhardness between the non-preheated and preheated modes for both the top and bottom surfaces of the specimens.

Hardness measurements are an indirect method used to evaluate the conversion of carbon double bonds in resin composites. Trujillo *et al.* [34] stated that warming a composite resin within biologically compatible temperatures could improve the rate and conversion of polymerization. Additionally, Daronch *et al.* [13] investigated the effect of different curing times and preheating temperatures on the monomer-to-polymer conversion. They concluded that the degree of conversion was significantly affected by preheating of both the top and bottom surfaces of the specimens, for all light-curing times. However, it should be emphasized that any correlation between hardness and the degree of conversion is specific for each particular resin composite material; thus, these correlations should not be used as absolute measures to determine the physical properties of different materials.

Some factors have been proposed as possible ways to increase the monomer-to-polymer conversion of preheated composites. An elevated composite temperature leads to increased molecular mobility. Therefore, the propagation stage takes longer without causing a diffusion-controlled reaction. Furthermore, an increase in the temperature below the glass transition improves the mobility of the polymer chain, postponing the termination of the diffusion-controlled reaction. By improving the monomer conversion, the glass transition temperature increases, inducing a greater amount of conversion at higher polymerization temperatures. Dimethacrylate-based systems show Arrhenius behavior, in which a small increase in temperature results in a large increase in the polymerization rate [13]. Therefore, by improving the degree of conversion, greater cross-linking and better mechanical properties can be expected [13,34,35].

The greater increase in microhardness achieved at the top surface of the specimens relative to their bottom surface can be explained by the attenuation of light (due to reflection, absorption, and dispersion) as it travels through the composite. Hence, at a depth of 2 mm, the attenuation of light may reduce the irradiance to approximately 75% of the irradiance that reaches the top surface [36].

Conversely, other studies [21,22,24] reported that preheating did not affect the microhardness of resin composites. This finding might be attributed to the residual stresses that can be generated due to elevated temperatures. Residual stress is a form of concentrated energy in the bulk of the material without the application of an external load. When the composite resin restoration experiences an occlusal load, the microhardness decreases and the bonding failure increases [37,38].

Moreover, the microhardness of methacrylate-based resin composites was higher than that of silorane-based resin composites [27,29]. This is because silorane monomers contain silicon

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for compatibility and have an oxaspirocyclic core, which provides the possibility of double-ring opening polymerization, leading to volume expansion and reduced polymerization shrinkage of the composite. Kusgoz *et al.* [39] claimed that this peculiar initiating system could be responsible for the lower depth of cure of silorane-based composites in comparison to methacrylate-based composites. Consequently, the reduced depth of cure of silorane-based composites is reflected in their reduced hardness [24].

Therefore, multiple factors could affect the effectiveness of preheating, such as the preheating temperature, the time between dispensing the composite and utilizing the light-curing process, the preheating device used, the irradiance of the light-curing device, the light-application period, and the thickness of the material. Furthermore, most of the studies showed a medium risk of bias. Accordingly, it would be too difficult to control for all the variables that may have influenced the outcomes of the studies. Considering all these factors, even if hardness (and thus the physical properties of a material) might not significantly improve under preheating conditions, the handling advantages of preheated resin composites is sufficient to recommend the practice of preheating.

CONCLUSIONS

Although the results reported in the reviewed studies showed some variability, preheating of the microhybrid Z250 resin composite yielded marked improvements in hardness compared to the non-preheated mode. Thus, sufficient scientific evidence was found to support the hypothesis that preheating can improve the hardness of resin composites.

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