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INTERNATIONAL EXPERIENCE IN SCIENTIFIC RESEARCH

PROCEEDINGS OF XI INTERNATIONAL SCIENTIFIC AND PRACTICAL CONFERENCE
JUNE 11-13, 2026

CHICAGO
2026

INTERNATIONAL EXPERIENCE IN SCIENTIFIC RESEARCH

Proceedings of XI International Scientific and Practical Conference

Chicago, USA

11-13 June 2026

Chicago, USA

2026

UDC 001.1

The 11th International scientific and practical conference "International experience in scientific research" (June 11-13, 2026) BoScience Publisher, Chicago, USA. 2026. 771 p.

ISBN 978-1-73981-121-1

The recommended citation for this publication is:

Ivanov I. Analysis of the phaunistic composition of Ukraine // International experience in scientific research. Proceedings of the 11th International scientific and practical conference. BoScience Publisher. Chicago, USA. 2026. Pp. 21-27. URL: https://sci-conf.com.ua/xi-mizhnarodna-naukovo-praktichna-konferentsiya-international-experience-in-scientific-research-11-13-06-2026-chikago-ssha-arhiv/.

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RESTORATION OF CLASS V LESIONS WITH AN INNOVATIVE IN-SITU HEATING PROTOCOL: IMPACT ON COMPOSITE SURFACE MICROHARDNESS AND PERIODONTAL HEALTH

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Abstract. This study evaluated the impact of an innovative in-situ composite heating protocol (40°C–45°C) on the surface microhardness of a universal resin composite and longitudinally assessed the 2-year clinical performance and adjacent periodontal tissue response of Class V restorations. Results: In-vitro thermal conditioning to 42°C–43°C yielded a statistically significant 35% increase in surface microhardness (49.4 ± 6.6 VHN) compared to the room-temperature control group (36.6 ± 4.8 VHN; $p < 0.001$). Clinically, Group 2 restorations demonstrated a significantly superior 2-year general quality mean score (1.3 ± 0.6) compared to Group 1 (1.9 ± 0.7; $p < 0.001$). Furthermore, the long-term periodontal status evaluated via FDI Track 7 showed a significantly better profile for the preheated cohort (1.4 ± 0.7) than the unheated control (2.2 ± 0.8; $p < 0.001$), indicating a profound reduction in chronic gingival margin inflammation and recession. Conclusions: An In-Situ thermal matrix protocol is highly beneficial and effectively overcomes the localized substrate "thermal sink" effect induced by rubber dam and HVA isolation. It significantly optimizes composite surface hardness while simultaneously ensuring excellent clinical adaptation and decreasing the incidence of gingival recession around Class V restorations.

Keywords: Class V Lesions • In-Situ Heating • Microhardness • Periodontal Health.

Introduction. The longevity of resin composite restorations in Class V cervical defects is strictly limited by the unique biomechanical and microenvironmental challenges of the cervical region [1, 2]. Unlike occlusal restorations, cervical cavities terminate primarily in dentin or cementum, which exhibit lower mineral density, reduced inorganic content, and a significantly more complex, highly hydrated tubular structure than enamel [3, 4]. Furthermore, clinical isolation during Class V procedures routinely utilizes a rubber dam combined with continuous high-velocity aspiration (HVA) to ensure an absolute moisture-free operational field [5, 6]. While this protocol effectively prevents moisture and saliva contamination, the continuous convective airflow across the isolated site and the lack of proximal tissue contact dramatically lower the baseline temperature of the isolated tooth substrate from a physiological state (34°C–35°C) down to ambient room temperature (20°C–24°C) [7, 8].

When a universal resin composite is packed into this chilled cavity preparation, the cold dentin operates as a local thermal sink [8, 9]. This rapid drop in temperature increases the viscosity of the monomer matrix, significantly restricting the mobility of free radicals and propagation kinetics during photo-polymerization [10, 11]. Consequently, the Degree of Conversion (DC) at the crucial cavity floor and cervical margin interface is severely compromised [11, 12]. A suboptimal DC at the cervical margin results in an influx of unreacted, cytotoxic monomers (e.g., Bis-GMA, TEGDMA) leaching into the adjacent gingival crevicular fluid, which directly sparks localized inflammatory pathways [13, 14]. Additionally, poorly polymerized composite demonstrates low surface microhardness, leaving the cervical restoration highly vulnerable to accelerated toothbrush abrasion, microleakage-induced marginal staining, and premature interfacial debonding [1, 15].

To overcome the thermodynamic limitations of cold isolated substrates, the preheating of composite materials prior to light-curing has been widely proposed in contemporary operative dentistry [16]. Elevated temperatures lower the viscosity of the composite paste, enhancing its viscoelastic adaptation to micro-retentive dentin walls and increasing the kinetic energy of free radicals to delay vitrification during light activation [11, 17]. Moreover, recent studies have demonstrated that utilizing preheated universal composite resins is highly effective not only for direct restorations but also as an innovative luting agent for contemporary additively manufactured and indirect hybrid restorations, showcasing comparable immediate shear bond strength to traditional dual-polymerizing cements [31]. However, standard commercial extraoral warming devices introduce a narrow "operational window" (typically under 15 seconds) due to rapid heat dissipation upon removal from the heating unit [18, 19]. To address these handling deficits, an innovative in-situ heating technique was developed to warm the composite matrix directly inside the cavity configuration immediately prior to and during photo-polymerization, maintaining a strict biological ceiling of 43°C–45°C to avoid protein denaturation of hard and soft tissues [19, 20].

The aim of this study was twofold: first, to evaluate the effect of in-situ preheating (40°C–43°C) versus room-temperature placement (24°C–26°C) on the Vickers microhardness of a universal submicron-filled composite; and second, to clinically assess the long-term periodontal tissue status and marginal surface stability of Class V restorations placed utilizing this custom in-situ thermal protocol.

Materials and Methods. The ***in-vitro*** part of the study was made on 40 filling samples. On the surface of each sample 6 indentations were made for evaluation of surface microhardness value variety. A universal, supra-nano filled resin composite Estelite Sigma Quick (Tokuyama Dental Corp., Tokyo, Japan; shade A2) was a material of choice. The composite material was packed into customized, rigid plastic molds to standardize specimen dimensions at 3.0 mm in diameter and 1.5 mm in height. Specimens were randomly allocated into two equal experimental groups of 20 each based on the thermal conditioning of the material.

In the Group 1 (Control) a composite material was packed and polymerized at standardized room temperature (24ºC–26ºC). In the Group 2 (Preheated) a composite material was packed at room temperature and subsequently preheated using a customized glass heating panel until a target mass temperature of (42ºC–43ºC) was achieved. The onset of thermal equilibrium and a reduction in monomer viscosity were visually cross-referenced by the manifestation of a highly reflective, smooth, glossy surface appearance across the composite mass.

All specimens in both groups were photo-polymerized utilizing a multi-wavelength LED curing unit (VALO X, Ultradent Products Inc., South Jordan, UT, USA) operated in Standard Mode at an irradiance of 1,250 mW/cm². Prior to photo-polymerization, the unpolymerized surface was covered with a 1 mm thick transparent plastic strip. The light guide tip was positioned perpendicular to and in direct contact with the strip for a standardized exposure duration of 20 seconds. Following polymerization, specimens were stored dry in light-proof containers at (37ºC) for 24 hours to allow post-cure stabilization before microhardness testing.

Vickers Microhardness (VHN) measurements were executed using a calibrated ПМТ-3 microhardness tester (USSR) equipped with a square-based diamond pyramid indenter. A standardized load of 50 g (0.49 N) was applied orthogonally to the top surface of each composite tablet with a dwell time of 15 seconds. A total of six indentations were made along the linear path spanning a 3 mm diameter. To prevent stress field overlapping between adjacent indentations, all measurements points were equally spaced. The diagonal lengths of the indentations were measured optically under high-power magnification (400×), and the VHN were computed via the standard Vickers formula:

$$HV = (1854.4 \times P)/d^2$$

Where (P) represents the applied load in grams and (d) is the mean diagonal length of the indentation imprint in micrometers.

The ***in-vivo*** clinical part of the study evaluated a total of 86 Class V cervical restorations performed on single-rooted teeth. The study design required at least two restorations placed on either adjacent teeth or antagonist teeth for each included participant. All procedures were executed under strict absolute moisture isolation utilizing a rubber dam and high-velocity evacuation (HVA) for total saliva control.

Mechanical access and isolation of the cervical margins were achieved via temporary gingival retraction. Prior to adhesive application, the target tooth surfaces underwent standardized surface conditioning via sandblasting with Erythritol powder to eliminate biofilm and organic remnants. A single-step self-etch adhesive system (Bond Force 2, Tokuyama Dental Corp., Tokyo, Japan) was applied to the conditioned dentin substrates according to the manufacturer's operational instructions after selective etching of enamel margin with phosphoric acid. A universal resin composite Estelite Sigma Quick (Tokuyama Dental Corp., Tokyo, Japan.) was chosen for restoration of class 5 lesions.

To eliminate mechanical confounding variables and isolate temperature as the sole experimental factor, a custom-engineered, anatomically contoured matrix tip device featuring a specialized zenith curvature design was utilized for all restorations across both cohorts. The device functioned simultaneously as a mechanical gingival retractor, sulcus barrier, and anatomical shaper matrix to compress the marginal gingiva, prevent composite crevicular flash, and eliminate the oxygen inhibition layer.

The restorations were divided into two equal operational cohorts based on material temperature: in the Group 1 (Control; n=43) restorations were performed utilizing the custom matrix device solely for mechanical contouring and adaptation with the heating element completely deactivated to maintain the composite resin at standard room temperature; in the Group 2 (Experimental; n=43): Restorations were performed utilizing the same custom matrix device, with the heating element activated to warm the material directly within the cavity configuration until a stable target mass temperature of 40°C–45°C was reached, marked clinically by the transformation of the composite surface into a smooth, glossy presentation. Photo-polymerization for both groups was conducted using the VALO X unit in Standard Mode for 20 seconds.

The qualitative, structural, and biological integrity of the composite restorations and adjacent structures was comprehensively evaluated over a 2-year longitudinal observational period using the World Dental Federation (FDI) Criteria.

Specific tracks selected for the mechanical and aesthetic assessment of the restorations included Surface Luster/Texture (to measure surface abrasion), Plaque Accumulation, Marginal Discoloration, and Functional Retention (to document complete loss of restorations). Scoring was made using 1 – 5 scale: 1 – clinically excellent; 2 – clinically good; 3 – clinically satisfactory (minor interventions needed); 4 – clinically unsatisfactory (repair needed); 5 – clinically unacceptable (replacement/complete loss). Restorations were compared dynamically against intact adjacent or antagonist natural teeth to establish baseline wear kinetics.

To account for the high clinical probability of long-term apical tissue migration and structural remodeling around Class V restorations, local periodontal tissue status was explicitly quantified utilizing FDI Track 7 (Periodontal Response). This track scores the adjacent soft tissue interface similar to aesthetic assessment of the restorations on a scale from 1 (clinically excellent; healthy gingiva with normal tissue adaptation and no recession) to 5 (clinically unacceptable; severe recession or attachment loss requiring surgical or restorative intervention). Gingival profile was compared dynamically against intact adjacent natural teeth to establish baseline status and changes.

Statistical analysis of continuous data derived from the in-vitro Vickers microhardness testing were subjected to the Shapiro-Wilk test to verify normal distribution. Group means were compared using an independent-samples t-test, with data expressed as Mean ± Standard Deviation (SD). Ordinal clinical evaluation scores derived from the Loe and Silness Gingival Index and FDI criteria tracks were analyzed using non-parametric parameters. The Mann-Whitney U test was implemented to detect statistically significant distributions between Group 1 and Group 2. All statistical analyses were computed at a significance threshold of alpha = 0.05.

Results. The surface microhardness measurements obtained via the ПМТ-3 microhardness tester revealed a highly significant thermodynamic benefit from the in-situ heating protocol. The mean values, standard deviations, and statistical comparisons for the two updated laboratory cohorts are detailed in Table 1.

Specimens polymerized at standardized room temperature (Group 1, n=20) demonstrated a mean surface microhardness of 36.6 ± 4.8. In contrast, specimens subjected to in-situ preheating (Group 2, n=20) exhibited a mean surface microhardness of 49.4 ± 6.6. An independent-samples t-test confirmed that this 35% increase in superficial microhardness was statistically highly significant ($p < 0.001$).

Table 1:

In-Vitro Surface Microhardness and Curing Parameters

Groups	Thermal Conditioning (C)	Surface Microhardness (Mean ± SD, VHN)	Statistical Significance (p-value)
Group 1 (Control)	24ºC – 26ºC	36.6 ± 4.8	-
Group 2 (Preheated)	42ºC – 43ºC	49.4 ± 6.6	< 0.001

At the 2-year longitudinal recall interval, the structural and qualitative status of the 86 Class V restorations was evaluated using the World Dental Federation (FDI) criteria tracks (surface luster, marginal adaptation, and discoloration). The collective clinical presentation scores for both cohorts are outlined in Table 2.

Restorations executed at room temperature with the unheated device (Group 1, Control: n=43) exhibited a mean clinical presentation score of 1.9 ± 0.7. Restorations performed utilizing the active in-situ preheating protocol (Group 2: 40ºC–45ºC, n=43) demonstrated a significantly lower, superior mean score of 1.3 ± 0.6. A Mann-Whitney U test confirmed a statistically significant shift toward superior FDI clinical scores in the actively preheated cohort ($p < 0.001$). Group 1 restorations displayed a significantly higher cumulative incidence of surface abrasion, marginal staining, and structural micro-ditching.

Table 2:

2-Year Clinical Restoration Quality and Periodontal Outcomes

Evaluation Metric (n=43)	Group 1: Control (Room Temp)	Group 2: Experimental (Preheated)	Statistical Significance (p-value)
FDI Clinical Restoration Score	1.9 ± 0.7	1.3 ± 0.6	<0.001
FDI Track 7 Periodontal Status	2.2 ± 0.8	1.4 ± 0.7	<0.001

The long-term biological behavior of the surrounding soft tissues and apical margin stability tracked via FDI Track 7 also revealed a stark contrast between the cohorts (Table 2). Gingival status around teeth restored with room-temperature composite (Group 1, n=43) generated an unfavorable mean score of 2.2 ± 0.8, showing clear clinical trends toward localized plaque accumulation and marginal gingival recession. Conversely, the gingival profile around teeth treated with the active in-situ thermal protocol (Group 2, n=43) yielded a significantly better mean score of 1.4 ± 0.7. The Mann-Whitney U test proved that the distribution of periodontal response scores was statistically superior for the preheated restorations ($p < 0.001$). The soft tissues surrounding the majority of the Group 2 restorations remained healthy, firmly adapted, and visually resilient over the 24-month window.

Discussion. The quantitative findings of this investigation definitively substantiate the clinical value of the custom in-situ thermal matrix device. The statistical divergence across both laboratory and clinical parameters confirms that material temperature during light initiation dictates the structural and biological fate of Class V restorations [9, 11].

The laboratory data demonstrates a massive leap in Vickers microhardness (36.6 ± 4.8 VHN up to 49.4 ± 6.6 VHN) when Estelite Sigma Quick is polymerized at 42°C–43°C. In traditional room-temperature setups under rubber dam and HVA isolation, the tooth operates as a cold thermal sink [7, 8]. This ambient drop severely restricts monomer mobility, sparking premature vitrification and leaving a weak polymer network [10, 12]. This outcome correlates with emerging in-vitro adhesion data for indirect restorations luted with preheated composites, which emphasizes that while immediate interfacial bonding can be effectively established, the long-term hydrolytic and structural durability of the resin-dentin interface is heavily dependent on optimizing polymer cross-linking density and selecting an adhesive system capable of maintaining high chemical and functional stability against degradation stresses over time [31]. By using the glass heating panel in-vitro — shielded uniformly by a 1.0 mm plastic spacer to replicate the clinical matrix profile — thermal energy is safely delivered to the monomer system. This energy extends radical propagation and delays vitrification, allowing Tokuyama's Radical-Amplified Photopolymerization (RAP) initiators to maximize cross-linking and superficial polymer network density [15, 21].

This laboratory superiority explains the excellent 2-year clinical outcomes (1.3 ± 0.6 mean score for Group 2 vs. 1.9 ± 0.7 for Group 1). Because Class V boundaries undergo relentless toothbrush abrasion and biophysical flexure, a softer polymer network (Group 1) inevitably undergoes rapid structural degradation, marginal micro-ditching, and microleakage-driven staining [1, 2]. By raising the superficial and interfacial hardness via in-situ heating, the Group 2 restorations successfully resist the abrasive mechanics of everyday dental hygiene, maintaining clean margins and high surface luster over 24 months [15, 22]. Furthermore, while the favorable, unconstrained configuration factor of a Class V cavity (C-factor ≤ 1) naturally reduces immediate polymerization contraction forces, in-situ preheating further optimizes this biomechanical interface [23, 24]. The thermal reduction in resin viscosity enhances molecular adaptation to the dentin substrate during initial shrinkage, ensuring the long-term bond strength easily withstands regular functional stresses [17, 24].

A critical finding of this study relates to the long-term periodontal tissue behavior. While short-term clinical evaluations of Class V margins frequently utilize indices focused on acute inflammation — such as the Loe and Silness Gingival Index — a 2-year observational window demands a shift in periodontal assessment methodology [25, 26]. Over an extended longitudinal timeline, acute catarrhal manifestations (such as localized edema, erythema, and bleeding) typically transition into chronic, irreversible tissue remodeling, predominantly characterized by apical migration of the gingival margin, or gum recession [26, 27]. Tracking localized acute inflammation alone fails to capture this structural degradation of the attachment apparatus [25, 27]. Therefore, the implementation of FDI Track 7 (Periodontal Response) was highly appropriate for this study, as its ordinal scoring matrix explicitly scales structural tissue remodeling alongside baseline gingival health [28, 29].

The clinical data from FDI Track 7 clearly documents this chronic transition, showing a significantly worse mean score of 2.2 ± 0.8 for the room-temperature cohort (Group 1) compared to 1.4 ± 0.7 for the preheated cohort (Group 2) ($p < 0.001$). In the room-temperature control restorations, suboptimal polymerization allows unreacted, cytotoxic monomers to elute continuously into the gingival crevicular fluid [13, 14]. Over 24 months, this persistent chemical micro-irritation triggers chronic, low-grade alveolar bone and connective tissue remodeling, ultimately driving marginal gingival recession [2, 27].

Conversely, the active in-situ thermal protocol completely exhausts these residual monomers into a highly cross-linked, biocompatible matrix, halting chronic chemical irritation at its source [11, 14]. Furthermore, because the custom-engineered matrix device was utilized as a perfect sham control in Group 1 (deactivated heating element), the mechanical benefits of the instrument — such as physical tissue retraction, sulcus protection, and flash prevention — were completely standardized between both groups. This isolates thermal energy as the sole independent variable driving the periodontal outcomes. The custom heating tip compresses the sulcus, shields the tissue from photo-thermal light spikes, and completely eliminates the oxygen-inhibition layer [6, 30]. This avoids the necessity of aggressive post-operative finishing with rotary burs, which routinely traumatizes the junctional epithelium and acts as an additional trigger for accelerated recession [26, 30]. The resulting highly converted, micro-smooth cervical margin resists bacterial colonization and tooth-brushing friction, successfully preventing long-term gingival recession and preserving the structural architecture of the periodontium [22, 28].

The strict temperature calibration variance (39°C–45°C) observed in the prototype device represents a vital clinical safety threshold. Dentin is a highly efficient natural thermal insulator [7, 19]. Within the 25-to-40-second pre-heating window, a maximum surface temperature of 45°C is completely safe, as the delayed thermal wave does not have sufficient time to penetrate the dentin and cause intrapulpal damage or soft-tissue protein denaturation [8, 19, 20]. However, future iterations of this device should integrate tighter proportional-integral-derivative (PID) temperature feedback loop controls to stabilize the tip precisely at 43°C–44°C, ensuring maximum polymerization efficiency with an absolute biological safety margin.

Conclusion. In-situ preheating of composite resin to 42–43°C significantly increases surface microhardness and improves 2-year clinical outcomes compared to room temperature, according to statistical analysis of data using FDI criteria. The thermal protocol results in reduction of material degradation and maintaining gingival health ($p < 0.001$). The findings indicate that photo-activation of in-situ preheated composite provides a superior, biologically safe, and durable long-term restorative solution for Class V lesions.

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