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Original Article

Microleakage and Environmental pH Influence in Primary Molars Restored with Self-Curing Bulk-Fill Composite, Light-Curing Bulk-Fill Composite, and Conventional Composite: An *In Vitro* Comparative Evaluation

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Abstract

Objective: The objective of this study was to compare microleakage and the influence on environmental pH of conventional composite (Neo Spectra® ST Universal Dentsply, Sirona, USA), light cured bulk-fill (SDR® Dentsply, Sirona, USA), or self-polymerizing bulk-fill (STELA®, SDI, Australia).

Materials and Methods: Forty-five extracted primary molars were randomly allocated into three groups (n=15) and restored with Neo Spectra® ST Universal, SDR®, or STELA® using an etch-and-rinse protocol. Microleakage was assessed after thermocycling by dye penetration (1% methylene blue), sectioning, and evaluation under a stereomicroscope using a standardized scoring system. For pH analysis, sixty-nine standardized cylindrical specimens of each material (n=23) were immersed in saline, and pH changes were measured at multiple time intervals using a calibrated electrode to evaluate their influence on the surrounding environment.

Results: Fisher's Exact test was performed to evaluate the microleakage score within the three restorative materials. A statistically significant association was found between restorative material and microleakage score (p=0.004), with Neo Spectra® ST Universal showing higher microleakage, while SDR® and STELA® demonstrated improved marginal adaptation. A mixed repeated measures of ANOVA was run to assess the effect of the three types of composite on the environmental pH. pH values changed significantly over time (p<0.0001), with conventional composite Neo Spectra® ST Universal exhibiting the highest pH, SDR® intermediate values, and STELA® the lowest. Significant differences were observed between all groups (p<0.0001).

Conclusion: Bulk-fill and bioactive restorative materials, particularly bulk-fill SDR® and self-polymerizing bulk-fill STELA®, showed superior sealing ability compared to conventional composite Neo Spectra® ST Universal. Additionally, STELA® demonstrated dynamic pH modulation, suggesting potential antibacterial and remineralization benefits, making it a promising material for pediatric restorative dentistry.

Keywords: Acidity, bulk fill composites, composite, dental material, micro leakage, pediatric dentistry, pH, restorative material

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Introduction

Dental caries is a highly prevalent chronic disease in children, particularly affecting primary teeth. Its rapid progression can impair nutrition, growth, and quality of life, leading to pain, infection, premature tooth loss, and malocclusion. Effective prevention includes oral hygiene, dietary control, fluoride use, and regular dental care.[1,2]

Successful restorative treatment in primary teeth depends on selecting materials with good mechanical properties, biocompatibility, fluoride release, and strong marginal sealing ability. Microleakage, defined as the passage of bacteria and fluids at the tooth–restoration interface, is a major cause of restoration failure, leading to secondary caries, sensitivity, and pulpal irritation. This is particularly critical in primary teeth due to their thinner structure and the difficulties of achieving proper isolation in children.[3]

Dental amalgam, historically used for its durability, has recently declined in use due to esthetic concerns and its mercury content.[4] Composite resins are now preferred for their adhesion and esthetics, but they have limitations, such as polymerization shrinkage and technique sensitivity.[5] Bulk-fill composites, such as SDR® (Dentsply Sirona, USA), were developed to improve adaptation and reduce shrinkage stress.[6] Newer self-curing materials, such as STELA® (SDI, Australia), offer additional bioactive benefits, including ion release and remineralization potential.[7] A systematic review concluded that universal adhesives exhibit clinical performance comparable to that of total-etch and self-etch systems in resin composite restorations, with no significant differences in retention or secondary caries over time.[8]

The oral environment also plays a critical role in caries development. An imbalance in the oral biofilm, particularly the proliferation of cariogenic bacteria such as Streptococcus mutans, leads to acid production and demineralization of tooth structure. Secondary caries commonly occurs at the tooth–restoration interface, often due to microleakage and biofilm accumulation. Fluoride-releasing restorative materials can help counteract this process by promoting remineralization and maintaining a favorable pH environment.[9]

Despite advances in restorative materials, comprehensive studies comparing newer materials such as STELA® (SDI, Australia) and SDR® (Dentsply Sirona, USA) remain limited, particularly regarding both microleakage and their influence on environmental pH. This study aims to evaluate STELA® (SDI, Australia), SDR® (Dentsply Sirona, USA), and a conventional composite (Neo Spectra® ST Universal) in primary teeth, focusing on microleakage and their influence on environmental pH.

Materials and Methods

Ethics approval

This *in vitro* study was carried out in the Biomaterial Unit of the Craniofacial Research Laboratory of Saint Joseph University of Beirut. The protocol was approved by the ethics committee of the same university (CER-2025-351).

Sample for microleakage

To determine the minimum required sample size, a G*Power analysis using normalized values yielded a large effect size (w=0.61). Based on this, a minimum sample of 26 specimens (≈9 per group) was required to achieve 80% power at a 5% significance level. To improve reliability and account for potential specimen loss and variability, the sample size was increased to 15 specimens per group, resulting in a total of 45 specimens.

The extracted primary teeth were obtained following approval from the parents or legal guardians, who provided informed consent for the use of the teeth in the present experimental study. The teeth were stored in distilled water and mounted in stone molds before standardized Class I cavities were prepared using carbide burs under water cooling. The samples were randomly divided into three groups (n=15) and restored with Neo Spectra® ST Universal (Dentsply Sirona, USA), STELA® (SDI, Australia), or SDR® (Dentsply Sirona, USA) using an etch-and-rinse protocol and their respective adhesive systems. All procedures were performed by a single operator to reduce bias, and restorations were finished and polished (Fig 1).

The specimens were subjected to thermocycling according to ISO standards 11405 for 500 cycles at 5°C–55°C with a dwell time of 30 seconds, then immersed in 1% methylene blue dye to evaluate microleakage for 24 hours. The tooth specimens were then sectioned in the mesiodistal direction using a high-speed diamond blade (Isomet® Diamond Wafering Blades, No. 11-4244, Buehler Ltd., Lake Bluff, USA) under water cooling (Fig 2). The presence or absence of microleakage was determined by evaluating the extent of dye penetration along the restoration-tooth interface using a stereomicroscope at ×20 magnification.[3] Dye penetration observed under the stereomicroscope was measured according to the following scoring system (Figs. 3, 4):

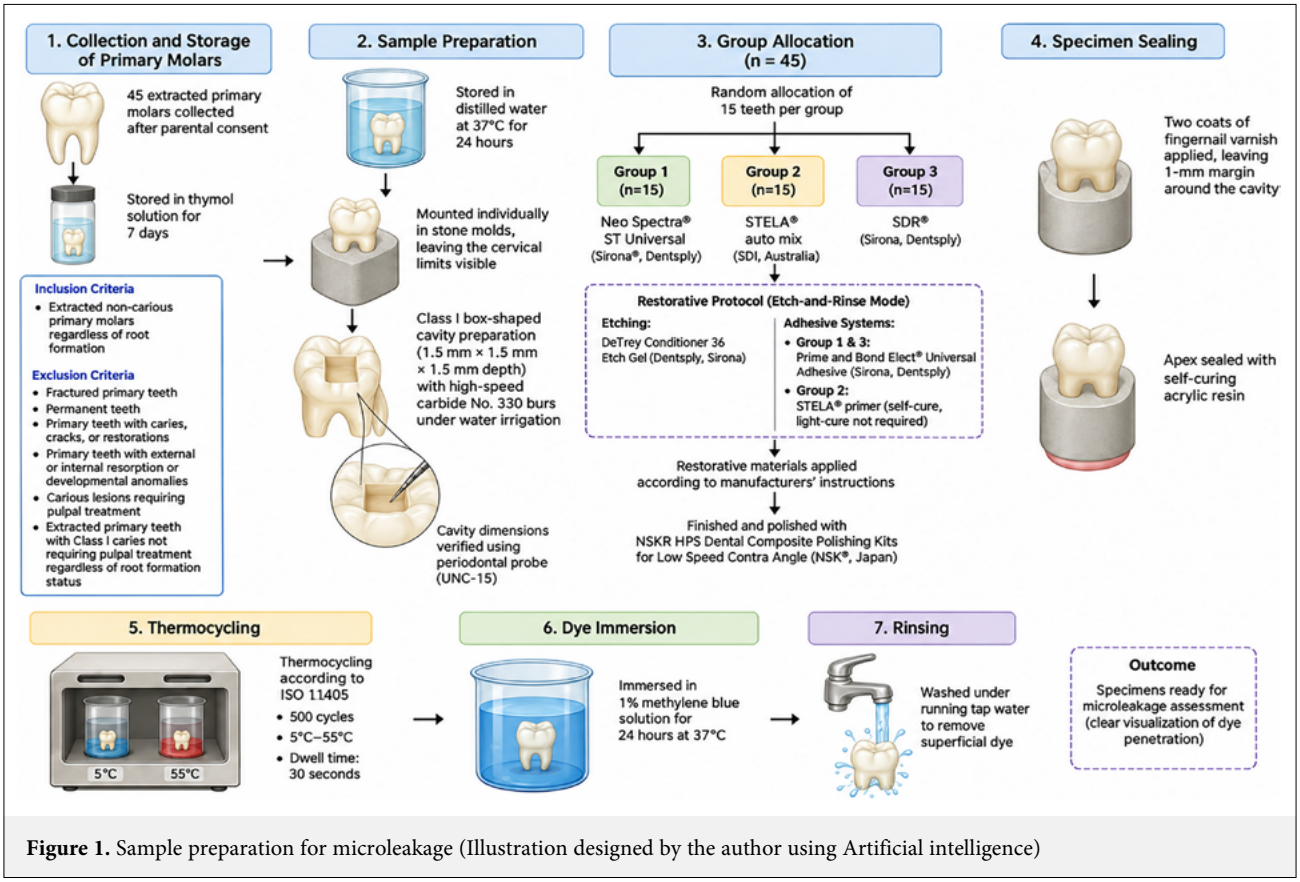

Figure 1. Sample preparation for microleakage (Illustration designed by the author using Artificial intelligence)

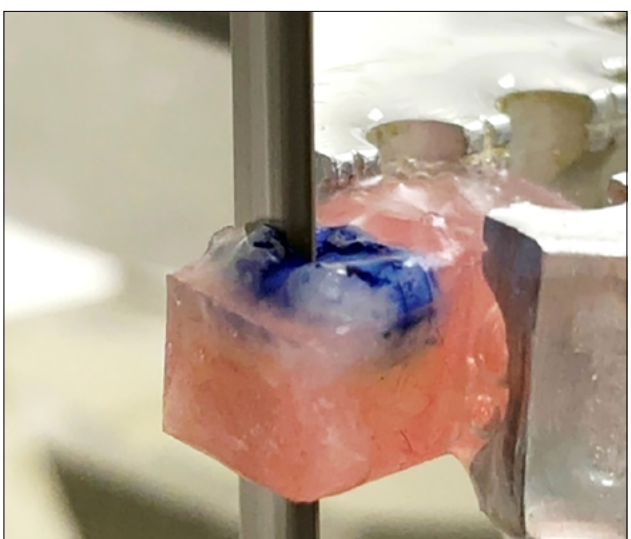

Figure 2. Shows sectioning in a mesiodistal direction



Figure 3. Shows score 1

1. Dye penetration up to one-third of the cavity
2. Dye penetration up to two-thirds of the cavity
3. Dye penetration up to the full cavity depth

Sample for pH evaluation

The sample size calculation was performed using the GPower software (version X.X), applying a one-way ANOVA (fixed effects, omnibus). The parameters entered were: group means=5.3 / 5.4 / 5.5, standard deviation=0.2, alpha=0.05, power=0.80, and number of groups=3. The resulting effect size was f=0.408. GPower indicated that a total of 63 samples would be required to achieve the desired power, or 21 disks per material. To account for potential specimen loss, damage, or measurement exclusion, two additional disks were prepared per group, bringing the total to 23 disks per material.

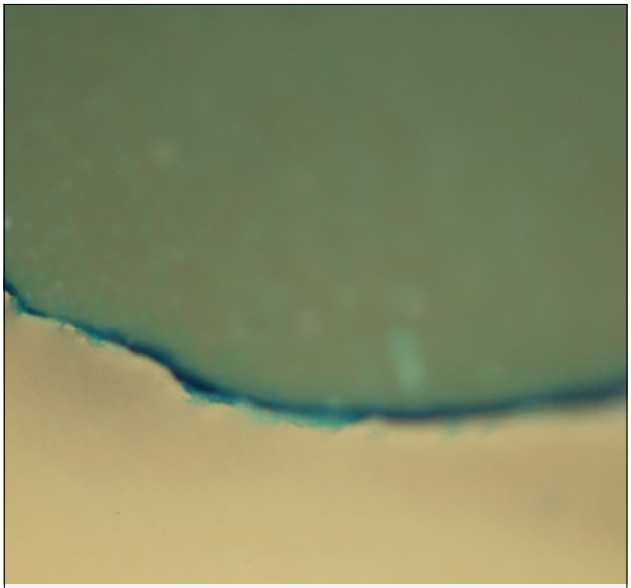

Figure 4. Shows score 3

Standardized cylindrical specimens (6 mm diameter and 2 mm thickness) were prepared using custom-made Teflon molds. The molds were placed on a glass plate and filled with each material. For the conventional composite and SDR®, the molds were light-cured for 30 seconds according to the manufacturers' instructions (light intensity of 1200 mW/cm², Woodpecker®, China). For STELA®, the mold surfaces were pre-coated with STELA® Primer (SDI Ltd., Bayswater, VIC, Australia) prior to filling. STELA® was left to set chemically for 4 minutes to ensure complete polymerization. Each sample was stored individually in saline-filled containers at 37°C. Saline was selected as a standardized and reproducible experimental medium, while recognizing that it represents only a simplified model of the oral environment.[9] The pH was measured using a calibrated electrode at multiple time intervals ranging from 1 hour to 15 days, with measurements performed in duplicate to ensure accuracy (Fig. 5).

Results

Microleakage evaluation

Fisher's Exact test was performed to evaluate the microleakage score within the three restorative materials and revealed a significant association between this score and the type of material ($p=0.004<0.05$).

Within the SDR® and STELA® groups, the most observed microleakage score was score 2 (53.4% and 66.7%, respectively), while the least displayed one was 3 (13.3% and 14.3%, respectively). However, Neo Spectra® ST Universal predominantly exhibited score 3 (66.7%), while the remaining samples showed a score of 2 (33.3%) (Table 1).

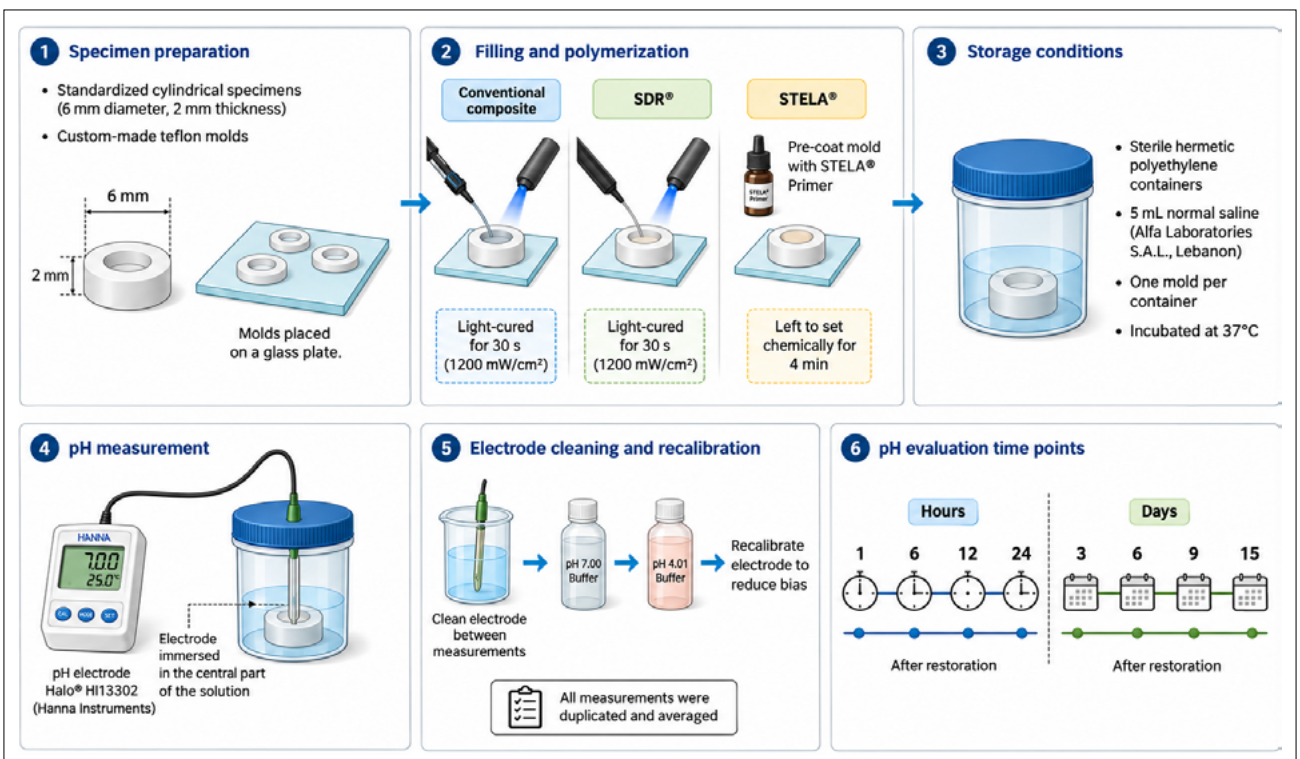

Figure 5. Material and method for pH evaluation (Illustration designed by the author using Artificial intelligence)

Table 1. Fisher Exact analysis to evaluate the association between the type pf restorative material and microleakage score

	Composite n=15 n (%)	SDR® n=15 n (%)	STELLA® n=15 n (%)	p
Microleakage score	5 (33.3)	-	3 (20)	0.004
1				
2	8 (53.4)	5 (33.3)	10 (66.7)	
3	2 (13.3)	10 (66.7)	2 (14.3)	
Total	15 (100)	15 (100)	15 (100)	

p<0.05 is significant. n: Number of samples per group.

Figure 6 illustrates the distribution of restorative materials within each microleakage score. For score 1, the majority of samples belonged to the SDR® group (62.5%), followed by STELA® (37.5%), while Neo Spectra® ST Universal showed no representation. Score 2 demonstrated a more balanced distribution, with STELA® being the most prevalent (43.5%), followed by SDR® (34.8%) and Neo Spectra® ST Universal (21.7%). In contrast, score 3 was predominantly displayed by Neo Spectra® ST Universal (71.4%), while SDR® and STELA® exhibited a minor contribution (14.3% each).

Influence of restorative materials on the environmental pH:

A mixed repeated measures ANOVA was run to assess the effect of time and the type of composite upon pH. Since the assumption of sphericity was violated (based on Mauchly's test), Greenhouse-Geisser corrections were applied (Table 2). The effect of time upon pH was statistically significant (F(4.61, 304.54)=340.29, p<0.0001). Moreover, the effect of the interaction between time and composite type was statistically significant (F(9.23, 304.54)=36.61, p<0.0001), suggesting that pH variations over time were significantly different among the tested composite types.

Table 2. Repeated measures ANOVA evaluating ph changes across time and composite materials

Effect	Df (GG)	F	p
Time	(4.61, 304.54)	340.29	<0.0001**
Time x Composite type	(9.23, 304.54)	36.61	<0.0001**

**: p<0.0001 is highly significant. Df: Degrees of freedom, GG: Greenhouse-Greisser.

For a better interpretation, all results are presented in the form of graphs. Figure 7 show the differences in pH changes over time depending on the dental materials used.

The estimated marginal means of pH values for the three restorative materials were evaluated across eight time points (Table 3). The estimated marginal mean pH values (±standard deviation) of the tested restorative materials were evaluated at 1 hour, 6 hours, 12 hours, 24 hours, 3 days, 6 days, 9 days, and 15 days. Overall, a time-dependent change in pH was observed for all tested materials, indicating a temporal effect on the environmental pH.

The conventional composite Neo Spectra® ST Universal (Dentsply, USA) demonstrated the highest pH values at all time points, with a progressive increase from

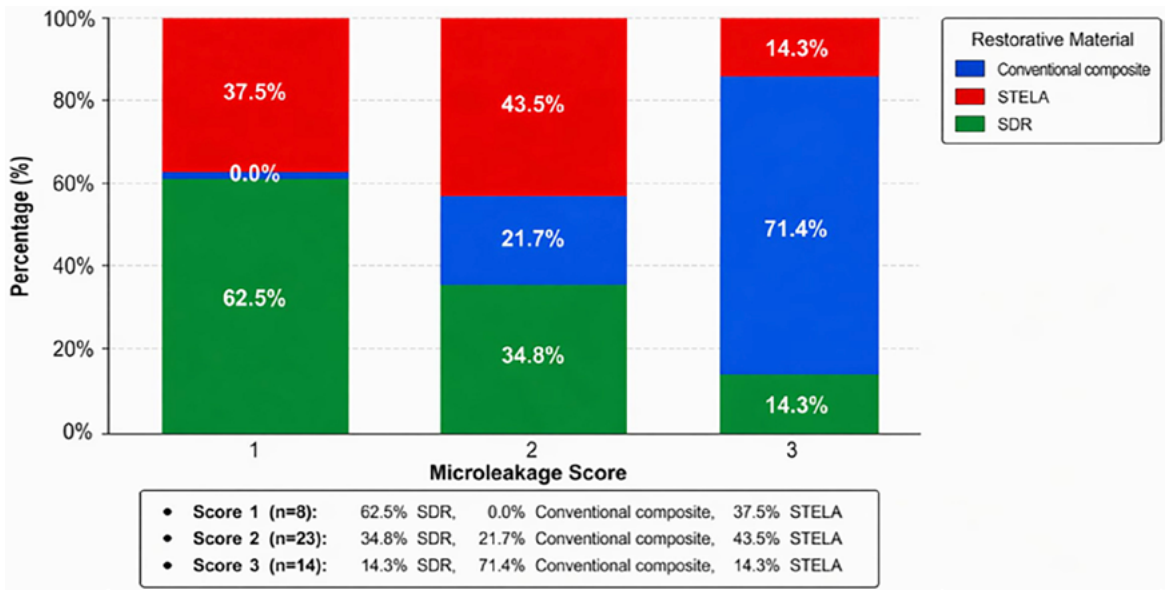

Figure 6. Stacked Bar Chart illustrating the distribution of restorative materials within each microleakage score group

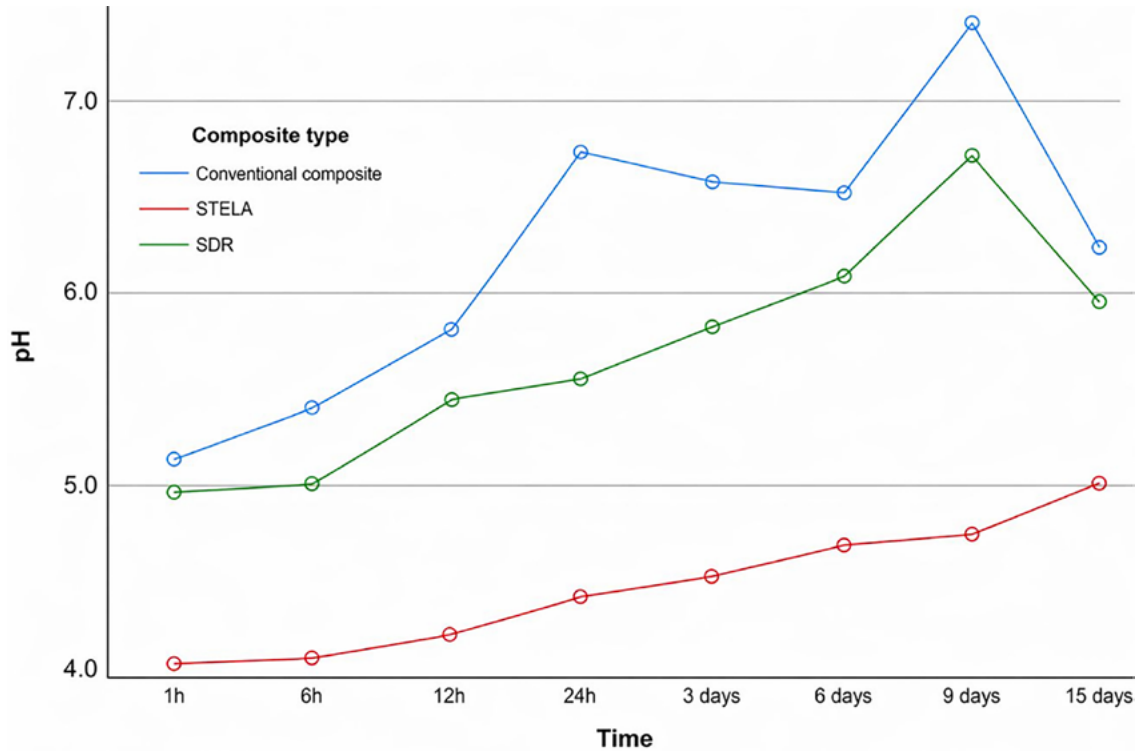

Figure 7. Comparison of pH variation over time among Neo Spectra® ST Universal, STELA®, and SDR®

the initial measurements to approximately the ninth day point, where the highest value was observed. After this peak, a slight decrease in pH was noted at the final measurement.

Table 3. Descriptive statistics of the mean pH values for each composite type across the different time dots

Mean pH values (SD) at	Neo Spectra® ST Universal	STELA®	SDR®
1h	5.14 (0.24)	4 (0.23)	4.97 (0.25)
6h	5.41 (0.14)	3.99 (0.2)	4.99 (0.24)
12h	5.83 (0.2)	4.07 (0.31)	5.44 (0.13)
24h	6.76 (0.2)	4.32 (0.35)	5.56 (0.28)
3 days	6.63 (0.52)	4.38 (0.25)	5.87 (0.35)
6 days	6.59 (0.11)	4.66 (0.52)	6.12 (0.4)
9 days	7.48 (0.21)	4.73 (0.4)	6.82 (0.39)
15 days	6.27 (0.2)	5 (0.41)	5.99 (0.35)

SD: Standard deviation.

Smart Dentin Replacement SDR® (Dentsply Sirona, USA) showed intermediate pH values compared with the other materials. The pH increased gradually over time, reaching its maximum around the 9th day point, followed by a slight decrease toward the end of the observation period.

In contrast, STELA® (SDI, Australia) exhibited the lowest pH values throughout the experiment. However, a gradual and consistent increase in pH was observed over time, indicating a progressive rise in environmental pH. Despite this increase, the values remained lower than those recorded for the conventional composite Neo Spectra® ST Universal (Dentsply, USA) and SDR® (Dentsply Sirona, USA) at all measurement points.

Table 4 displays the results of the post-hoc comparison between composites, using Bonferroni correction, in terms of pH mean difference values with their respective confidence intervals. pH values differed significantly between all composite groups ($p<0.0001$ for all comparisons).

Table 4. Post-hoc comparison between composites with Bonferroni correction

Pairwise comparison	Mean difference (95% CI)	p
Neo Spectra® ST Universal vs SDR®	0.542 (0.378–0.707)	<0.0001**
Neo Spectra® ST Universal vs STELA®	1.868 (1.704–2.032)	<0.0001**
SDR® vs STELA®	1.326 (1.161–1.49)	<0.0001**

**: $p<0.0001$ is highly significant. CI: Confidence intervals.

pH values for Neo Spectra® ST Universal were significantly higher than the ones exhibited by SDR® (mean difference=0.542, CI=0.378–0.707) and STELA® (mean difference=1.868, CI=1.704–2.032). Similarly, SDR® showed significantly higher pH values compared to STELA® (mean difference=1.326, CI=1.161–1.49).

Discussion

In pediatric dentistry, preserving primary teeth until natural exfoliation is a main objective, requiring restorative materials capable of withstanding mechanical wear, bacterial challenges, and environmental variations such as pH fluctuations and temperature changes, while also maintaining aesthetic integrity.[10] However, the longevity of restorations is often compromised by microleakage and secondary caries, which are closely linked to the physicochemical properties of restorative materials.

Secondary caries may develop due to increased bacterial adhesion and biofilm accumulation, particularly at restoration margins where plaque control is difficult. Additionally, polymerization shrinkage and masticatory forces can induce interfacial stresses, especially in deep Class I restorations in primary teeth, leading to marginal gaps, postoperative sensitivity, and eventual restoration failure.[11] In this context, the development of bioactive restorative materials has introduced a promising approach, as these materials can release therapeutic ions such as calcium and fluoride, contributing to antibacterial activity, reduced plaque accumulation, and enhanced remineralization.[12]

The present study aimed to evaluate both microleakage and the influence of restorative materials on environmental pH among three different materials: conventional composite Neo Spectra® ST Universal (Dentsply Sirona, USA), SDR® (Dentsply Sirona, USA), and STELA® (SDI, Australia). Based on the findings, both null hypotheses were rejected, as significant differences were observed among the tested materials in terms of microleakage (p=0.004) and their effect on environmental pH (p<0.0001).

Regarding microleakage, the results demonstrated a clear variation in marginal sealing ability among the materials. SDR® and STELA® predominantly exhibited score 2, indicating moderate microleakage, whereas Neo Spectra® ST Universal showed a significantly higher proportion of score 3, reflecting greater dye penetration and inferior marginal adaptation. This difference can be explained by the inherent characteristics of conventional resin composites, which are associated with higher polymerization shrinkage stress and increased technique sensitivity due to incremental placement. These factors may result in gap formation at the tooth-restoration interface, facilitating microleakage.[4]

In contrast, SDR® demonstrated improved performance, particularly with the highest proportion of score 1 in some samples, suggesting better marginal adaptation. This can be attributed to its flowable consistency and stress-relieving polymerization modulator, which reduces shrinkage stress and enhances cavity adaptation. Similarly, STELA® showed favorable distribution toward lower microleakage scores, likely due to its self-curing mechanism and bioactive composition, which may contribute to improved marginal sealing through physicochemical interaction with the tooth structure.[4,13]

The proportional distribution further confirmed that Neo Spectra® ST Universal was predominantly associated with the highest microleakage score, while SDR® and STELA® were more frequently linked to lower scores. These findings highlight the advantage of bulk-fill and bioactive materials in minimizing microleakage compared to traditional composites.

In addition to marginal integrity, the influence of restorative materials on environmental pH represents another critical factor affecting bacterial activity and caries progression. In the present study, saline was used as the experimental medium to better simulate oral conditions, as distilled water does not adequately reflect the ionic composition of the oral environment. Although artificial saliva is commonly used, its lack of standardization remains a limitation.[14]

The results demonstrated statistically significant differences among the tested materials in their effect on environmental pH, leading to the rejection of the second null hypothesis. All materials exhibited acidic pH values ranging between 5 and 6 after 15 days, with a general trend of gradual increase over time. This behavior may be attributed to ongoing interactions such as water sorption, ion release, and post-polymerization reactions, eventually reaching a stabilization phase.

Among the materials tested, conventional composite (Neo Spectra® ST Universal) consistently exhibited the highest pH values. This can be explained by its chemically stable and highly cross-linked resin matrix, which limits water sorption and ion release, thereby maintaining a relatively neutral environment. These findings are consistent with previous studies reporting minimal environmental interaction and stable pH behavior in Neo Spectra® ST Universal conventional composites.[15,16]

SDR® demonstrated intermediate pH values, reflecting its modified resin matrix and bulk-fill composition. The presence of a polymerization modulator allows controlled shrinkage and improved depth of cure, while also enabling limited water sorption and ion diffusion. This results in moderate interaction with the surrounding medium, explaining the gradual increase in pH over time while remaining lower than Neo Spectra® ST Universal. Similar observations have been reported in the literature, where bulk-fill composites exhibit altered physicochemical behavior compared to traditional composites.[12]

In contrast, STELA® exhibited the lowest pH values throughout the experimental period, which can be attributed to its bioactive nature and enhanced ion-releasing capacity. The material's composition promotes ion exchange processes, including the release of calcium and other reactive species, which may initially lower the pH. Over time, however, this ion release contributes to buffering and remineralization processes, resulting in a gradual increase toward neutral pH. This dynamic behavior reflects the fundamental difference between bioactive and conventional materials. While Neo Spectra® ST Universal remain chemically inert, bioactive materials exhibit time-dependent interactions with their environment, characterized by an initial acidic phase followed by stabilization.[17]

From a clinical perspective, the ability of the restorative material to interact with and potentially modulate its surrounding environment may be relevant in the management of caries-prone primary teeth. Environmental pH is closely associated with the balance between demineralization and remineralization and can influence the activity of cariogenic microorganisms. Therefore, differences in pH behavior among restorative materials may represent an additional factor to consider when evaluating their biological performance. However, the present findings should be regarded as preliminary because the experimental saline model does not reproduce the dynamic and biologically complex oral environment, including salivary buffering, salivary flow, dietary challenges, bacterial biofilms, and host-related factors. Further *in vitro* biofilm studies and clinical investigations are required to determine whether the observed pH differences translate into clinically meaningful effects.

Despite the study's significant findings, several limitations should be considered. The evaluation of microleakage was performed using the dye penetration method, which, although widely used, is a semi-quantitative technique dependent on visual interpretation and may not fully represent clinical conditions. Furthermore, the small molecular size of dye particles may lead to an overestimation of leakage compared to bacterial penetration. In addition, this study was conducted under *in vitro* conditions, which cannot fully replicate the complexity of the oral environment, including salivary flow, occlusal forces, and microbial activity. Therefore, caution should be exercised when extrapolating these findings to clinical scenarios. Moreover, the assessment of environmental pH was limited to a relatively short observation period. Considering the time-dependent nature of ion release and buffering capacity, particularly in bioactive materials, longer-term evaluations would provide a more comprehensive understanding of material behavior. In addition, increasing the sample size in future studies would enhance statistical power and improve reliability.

Overall, the findings of this study demonstrate that restorative materials differ significantly in both their marginal sealing ability and their influence on environmental pH. SDR® and STELA® showed improved microleakage performance compared to Neo Spectra® ST Universal, while STELA® exhibited the most pronounced effect on environmental pH due to its bioactive properties. These results highlight the importance of selecting restorative materials not only based on mechanical properties but also on their biological and chemical interactions within the oral environment.

From a clinical perspective, materials that combine reduced microleakage with beneficial bioactive properties may offer enhanced protection against secondary caries, particularly in pediatric patients where long-term restoration success is critical. Nevertheless, further *in vivo* studies are required to validate these findings and to assess the long-term clinical performance of these materials under functional conditions.

Conclusion

Conventional resin composites in primary teeth are associated with higher microleakage and poorer marginal sealing due to polymerization shrinkage and technique sensitivity, increasing the risk of secondary caries. In contrast, bulk-fill materials like SDR® (Dentsply Sirona, USA) show improved marginal adaptation and reduced microleakage. Self-curing bioactive materials such as STELA® (SDI, Australia) appear promising, combining good sealing ability with ion release that may influence pH, offering potential antibacterial and remineralization benefits. However, further clinical studies are needed to evaluate their long-term performance, underlying mechanisms, and effectiveness under conditions simulating the oral environment.

Disclosures

Ethics Committee Approval: The study was approved by the Saint Joseph University of Beirut Ethics Committee (no: CER-2025-351, date: 11/11/2025).

Informed Consent: Informed consent was obtained from all participants.

Conflict of Interest Statement: The authors declare no conflict of interest.

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