



ISSN : 2347 - 2243

***Indo - American Journal of
Life Sciences and Biotechnology***



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Influence of Simulated Hot and Cold Dietary Temperatures on the Microleakage Resistance of Smart Dental Restorative Materials

Dr. Hina Hammad¹, Dr. Syeda Farhat Bukhari², Dr. Rabiya Nadeem³, Dr. Muhammad Muslim khahro⁴, Dr. Muhammad Siddique Qazi⁵, Shah Faisal⁶

¹BDS FCPS, Assistant Professor, Hamdard University Dental Hospital.

²Assistant Professor, Hamdard University Dental Hospital.

³BDS, RDS, Ex-Lecturer Hamdard University Dental Hospital, Operative Dentistry Department.

⁴Associate Professor, Department Science of Dental Materials, LUMHS Jamshoro Sindh Pakistan.

⁵Lecturer, Department Science of Dental Materials, ISRA University Hyderabad, Sindh Pakistan.

⁶BDS, DCD (Periodontology), Khyber Medical University, Peshawar.

Email: ¹Hina.hammad@hamdard.edu.pk, ²farhat.bukhari@hamdard.edu.pk,

³Rabyaa01@gmail.com, ⁴drmuhammadmuslim@yahoo.com,

⁵drmuhammadsiddique786786@gmail.com, ⁶drfaisal542@gmail.com

Received: 26.08.26, Accepted: 25.09.26

ABSTRACT

Background: Dental restorations were considered inert. More recently, there has been an effort to create restorative materials that respond to environmental stimuli and modulate the biologic response of the tissue they interact with. One of the risks associated with the use of restorations in the oral cavity is the effect of repeated cycles of thermal expansion and contraction of restorations exposed to hot and cold foods and beverages. The cyclic nature of these temperature fluctuations may adversely affect the quality of the interface of the dental restoration and put it at risk for marginal leakage.

Objective: This study evaluated the effect of simulating hot and cold foods and beverages on smart dental restorative materials.

Methods: 160 sound human premolar teeth were mounted in acrylic resin, and a Standardized Class V cavity was prepared. Four groups of each twenty teeth were formed and individually restored with Activa BioACTIVE, Cention N, and EQUIA Forte HT; a nanohybrid control composite was also used. All materials were light cured for 40 seconds. Each material group was sub-divided into five sub-groups. The first four sub-groups of each material group were exposed to heat (hot), cold (cold), and alternating heat and cold (alt hot/cold) temperature cycles. A fifth, control, sub-group was not thermally exposed. Each sub-group was allowed to age in a thermal cycling device for a total of 1,500 cycles. The device had a temperature range of 5° to 55° Centigrade, and a dwell time of 30 seconds at each temperature. To evaluate marginal microleakage, the restorations were immersed in methylene blue for 24 hours. Stereomicroscopy was used to assess the quality of the restoration. The data were statistically analyzed using a pairwise comparisons.

Results: In both the restorative material and the thermal exposure condition, significant differences in microleakage were observed ($p < 0.05$). The combined hot and cold exposure



condition resulted in greater microleakage than the single exposure conditions. Of the test materials, Activa BioACTIVE showed the lowest mean microleakage with repeated thermal expansion/contraction, followed by Cention N and EQUIA Forte HT. The conventional composite demonstrated the greatest microleakage. In the single temperature condition, no differences in mean microleakage were observed among the materials. In the alternating temperature condition, Activa BioACTIVE and EQUIA Forte HT showed less microleakage than the other materials.

Conclusion: It can be concluded that repeated exposure to oral temperature extremes, as may occur with food and beverage, can result in microleakage of restorations. Of the materials evaluated, Activa BioACTIVE and EQUIA Forte HT, demonstrated the ability to maintain marginal integrity and closure with the greatest resistance to food and beverage-induced temperature changes. Further studies on the effects of food and beverage temperature changes and other clinical conditions are necessary to better assess the long-term behavior of restorative materials.

INTRODUCTION

Restorative dental materials are used to reconstruct missing tooth structure. Once placed in the mouth, these materials are challenged by the many changes that occur in the oral environment. Seal failure of these materials can result in loss of the restoration (1).

Microleakage occurs when a rubbery or fluid-like seal is lost at the marginal area of the restoration. This allows fluid and bacterial challenges to attack the remaining sound tooth structure. The extent of Microleakage must be evaluated to determine the clinical performance of restorative materials. Areas of particular concern are the margins adjacent to the gingiva, where seal failure can be caused by the presence of a multitude of irritants (pH changes of the oral environment (2).

More recently, additional requirements have been established for restorative materials. These include additional bioactive functions, remineralizing capacity, and antimicrobial potential. Seal failure in these materials can also be attributed to a loss of physiochemical interactions at the interface (3). The sealing ability of ACTIVA BioACTIVE has been investigated. Microleakage was assessed to different extent, depending on the quality of

the bond and methodology used for the evaluation (4).

Cention N is an alkasite system designed to be an restorative material system other than the conventional resin based systems. Data on the micro leakage of Cention N and other contemporary restorative materials is now available and can be used for assessment of the marginal seal of restorative materials (5).

Comparative studies of the marginal seal of other commercial dental materials have evaluated the performance of EQUIA Forte HT (6). Temperature changes in the oral cavity cause material constituents of restorations to expand and contract. This can cause the restoration to debond from the tooth. The thermal expansion coefficients of restorative materials differ from those of the tooth. This difference can lead to thermal stress on the bond between the restoration and the tooth (7).

Some investigations have used thermocycling to evaluate restorative materials. There is a lack of standardization in the temperature, number of cycles and exposure time used in these studies. This limits comparison of the results from different studies (8). It has been shown that thermocycling affects the marginal integrity of bioactive materials. It has also been shown that the thermal aging of



restorative materials can affect the restoration-tooth bond. Thus, the effect of repeated changes in temperature on the performance of restorative materials should be considered (9).

Although there have been a number of studies published recently on the evaluation of biologically active and intelligent restorative materials, many of these studies have used conventional thermocycling methods to assess the microleakage of restorative materials (10). Thus, the main objective of this study was to evaluate the effects of simulated dietary temperatures on the microleakage of intelligent and bioactive restorative materials using in vitro techniques. The effects of thermocycling (including both hot and cold temperatures as well as alternating temperatures) on the materials were studied.

METHODOLOGY

The purpose of this in-vitro study was to assess the effect of simulated hot and cold meals on the microleakage of smart dental restorative materials. The sample consisted of 80 recently extracted human premolar teeth. Teeth with any caries, cracks, fractures or restoration were excluded from the study. After extraction, the teeth were cleaned and stored in distilled water. The teeth were assigned to one of the four study groups based on the restorative material.

Class V cavities were prepared on the buccal surface of the teeth in the sample. Standardization of the cavities was accomplished using a protocol to ensure a width of 4 mm (mesiodistal), a height of 2 mm (occlusogingival) and a depth of 2 mm (axial). The cavity margins were located in cementum/dentine and the occlusal margins were located in enamel. The restorative material was allowed to cure and the interface was assessed. A standard or new air/water spray cooled and dried the cavity. The remaining procedures were performed

to ensure the restorative material conformed to the cavity walls.

The samples were split into four groups based on the kind of restorative material used: Activa BioACTIVE, Cention N, EQUIA Forte HT, and a conventional nanohybrid composite. Activa BioACTIVE was chosen as a representative bioactive resin-based restorative material, Cention N was selected as a representative alkasite restorative material, and EQUIA Forte HT was chosen as a representative glass-hybrid restorative material. The conventional nanohybrid composite was selected as the control material. The selected restorative materials encompass a range of restorative systems, and do not purely represent a single material class. Previous studies have assessed the selected materials and have evaluated their marginal gaps and flaws caused by thermal aging. Therefore, the selected materials were appropriate for the current comparative study.

Each of the restorative materials was placed and set according to the instructions of the manufacturers. Adhesive resin systems were applied on the adjacent tooth structure according to the guidelines of the restorative material in question. The materials were packed into the preparations without extending beyond the preparations to avoid the formation of voids. To set and polymerize the materials, the manufacturers' instructions were followed. For light-cured materials, an LED light-curing unit was used. Where it was necessary, for example, to protect the restorative material from EQUIA Forte HT, the manufacturer's recommendation was followed. All the restored specimens were further processed to have a marginal closure. The specimens were left in distilled water for 24 hours prior to thermal exposure.

In the next phase of the study, each of the four restorative material groups was divided into four groups, and five samples



from each of the subgroups were prepared. The first subgroup of each of the four restorative material groups was kept in non-thermal, distilled water, at room temperature, and acted as the control group for that material. The second subgroup for each material was heated to 60°C to simulate hot dietary conditions. The third subgroup for each material was cooled to 10°C to simulate cold dietary conditions. The fourth subgroup for each material was subjected to the hot and cold conditions, as described for the second and third subgroups, respectively, and acted to simulate varying dietary conditions. For this study, to simulate the effects of dietary conditions, a control group without thermal cycling was included, in addition to groups that simulated varying hot and cold conditions.

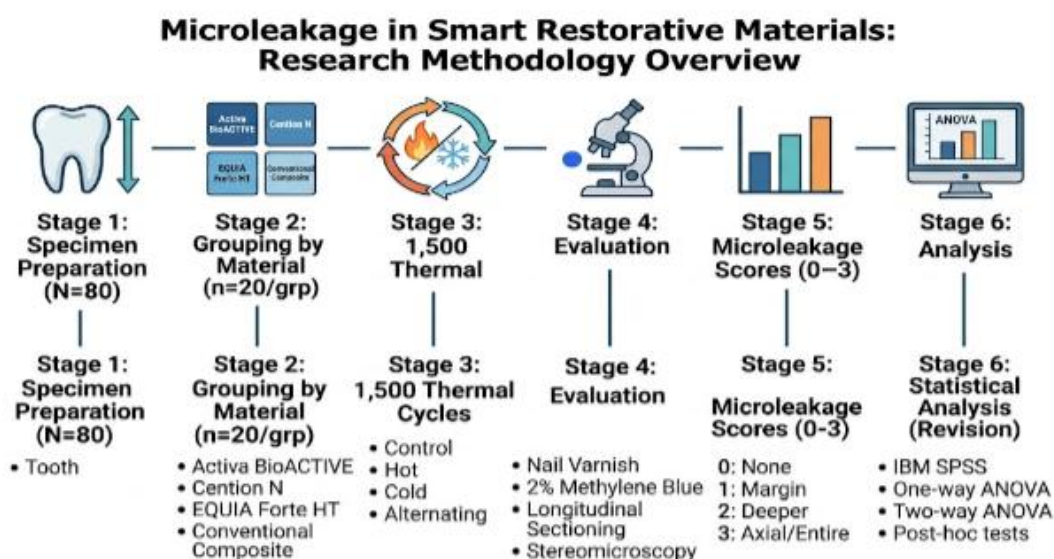
The procedures for the thermal exposure of the samples for this study involved the use of a water bath at 60°C to represent hot conditions, and a water bath at 10°C to represent cold conditions. For the control and groups representing varying conditions, the samples were immersed in the water baths for 30 seconds, and for the group representing alternating conditions, the samples were transferred to the water baths representing hot and cold conditions. Each group was exposed to 1,500 thermal cycles to simulate the repeating conditions of the diet.

Following the completion of the thermal cycle, all specimens were evaluated for marginal microleakage using the dye penetration test. To prepare the specimens for the test, the occlusal and incisal surfaces of the restorations and the adjacent walls of

the preparations were covered with two layers of nail varnish, leaving approximately 1 mm of enamel (or 2 mm of dentin) around the margins of the restorations exposed. The nail varnish was also applied to the undersurface of each restoration to obstruct the dye from penetrating through the restorations in an unpredictable route. The specimens were soaked in 2% methylene blue dye for 24 hours. After the dye penetration test, the specimens were rinsed with water to remove the dye and were then dried.

Longitudinal sectioning of each specimen was carried out to evaluate dye penetration at the interfaces of the restorations with the tooth structures. The sectioning was carried out with a low-speed diamond cutting wheel. The sectioned surfaces were observed with a stereomicroscope. Each specimen was evaluated for dye penetration using a four-point ordinal scale. In this scale, a score of 0 indicated no dye penetration. A score of 1 indicated dye penetration restricted to the margins of the preparations. A score of 2 indicated dye penetration to the deeper margins of the preparation. A score of 3 indicated dye penetration to the axial walls of the preparation, and/or dye penetration to the margins of the entire restoration.

To eliminate as much observer bias as possible, the specimens were coded so that the examiner assessing the specimens was blind to the kind of restorative material used and the condition of thermal exposure of the specimen. In cases where the assessor was unable to determine a score, that part was re-evaluated.



The main outcome measure of this study was the assessment of the degree of microleakage. The two main factors which influenced the assessment of microleakage in this study were the type of restorative material used and the condition of thermal exposure of the specimens. The primary aim of this study was to assess the influence of each restorative material and the influence of thermal exposure on microleakage. The second aim of this study was to assess if the influence of thermal exposure was the same for all restorative materials.

The collected data was entered into a database and analysed with IBM SPSS Statistics. The microleakage scores were first analyzed to assess their distribution. One way analysis of variance was performed to assess the mean difference of microleakage of each of the four restorative materials. To assess the influence of thermal exposure and restorative materials,

and the interaction of the two, a two way analysis of variance was performed. Post hoc tests of the comparisons were performed to assess the differences if the overall differences were found to be significant.

Standardized lab conditions were used to minimize variables in the study. Consistency was maintained for numerous factors including the length of time specimens were stored, the concentration of the dye, the length of time specimens were in the dye, and how specimens were sectioned. The four restorative material groups and the four thermal exposure groups were treated equally to provide experimental balance. The study only attempted to simulate the effects of dietary temperature changes on microleakage. Other intraoral conditions (e.g. masticatory loading, salivary enzymes, pH, and oral bacteria) were not considered in this study and are not relevant to this investigation.

RESULTS

Table 1. Distribution of Specimens According to Restorative Material

Restorative Material	Frequency (n)	Percentage (%)
Activa BioACTIVE	20	25.0
Cention N	20	25.0



EQUIA Forte HT	20	25.0
Conventional Nanohybrid Composite	20	25.0
Total	80	100.0

Interpretation: Each restorative material group contained 20 specimens, providing

an equal distribution across the four study groups.

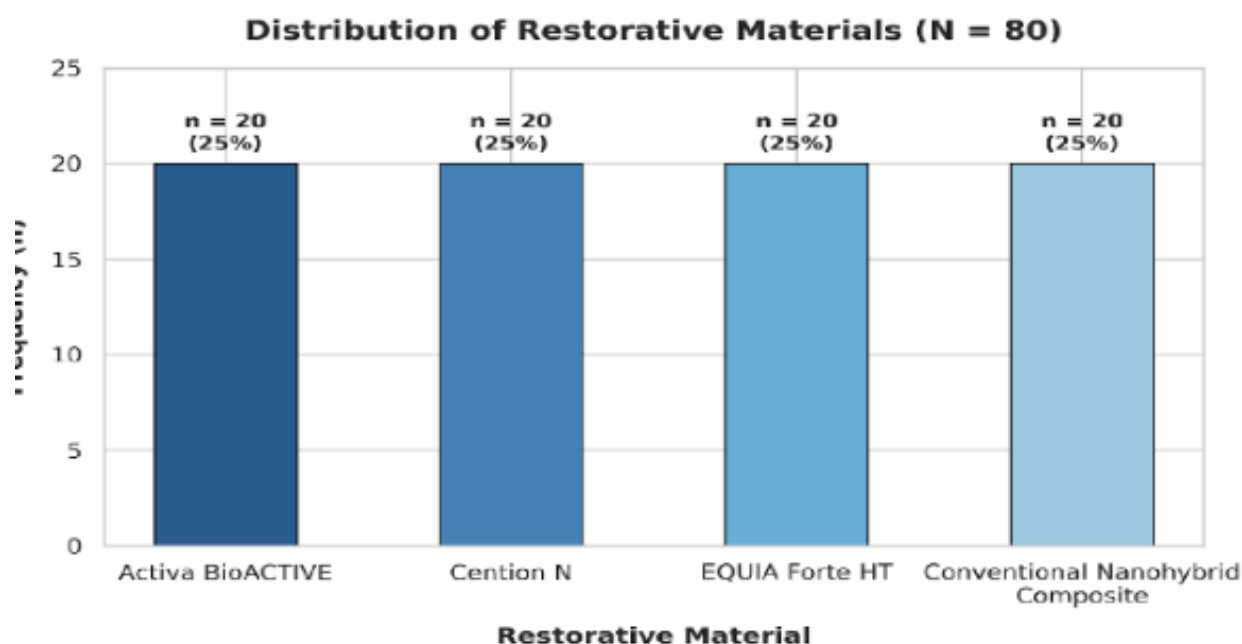


Table 2. Distribution of Specimens According to Thermal Exposure Condition

Thermal Exposure Condition	Frequency (n)	Percentage (%)
Control/no thermal cycling	20	25.0
Hot exposure (60°C)	20	25.0
Cold exposure (10°C)	20	25.0
Alternating hot–cold exposure (10°C–60°C)	20	25.0
Total	80	100.0

Interpretation: The specimens were equally distributed among the four thermal exposure conditions.

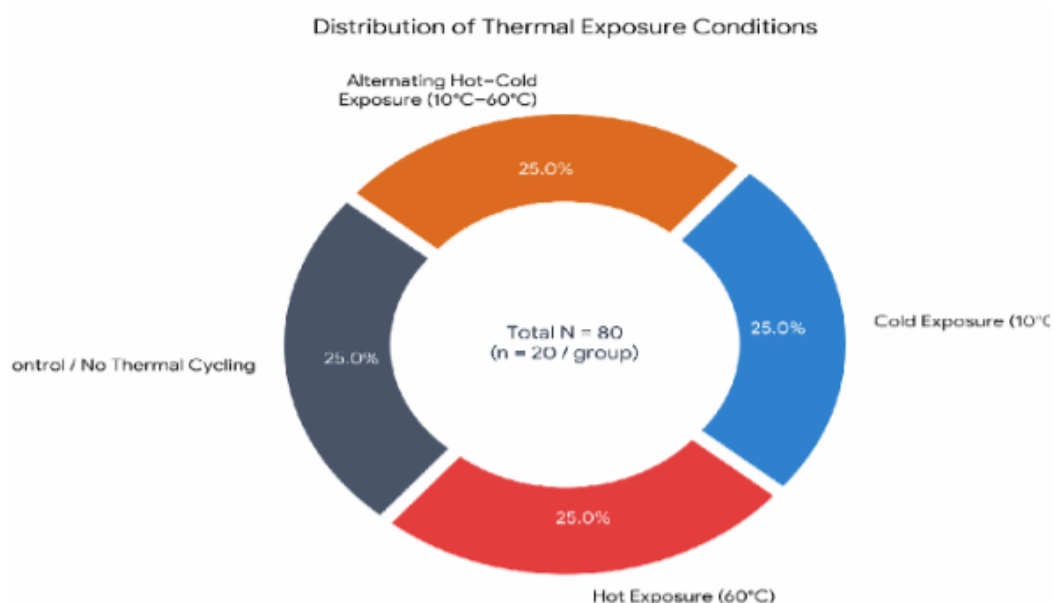


Table 3. Mean Microleakage Scores According to Restorative Material

Restorative Material	N	Mean	SD	Minimum	Maximum
Activa BioACTIVE	20	0.85	0.67	0.00	2.00
Cention N	20	1.10	0.72	0.00	2.00
EQUIA Forte HT	20	1.25	0.79	0.00	3.00
Conventional Nanohybrid Composite	20	1.65	0.88	0.00	3.00
Total	80	1.21	0.82	0.00	3.00

Interpretation: Activa BioACTIVE showed the lowest mean microleakage score, whereas the conventional nanohybrid composite demonstrated the highest mean score.

Table 4. Mean Microleakage Scores According to Thermal Exposure

Thermal Exposure	N	Mean	SD	Minimum	Maximum
Control/no thermal cycling	20	0.75	0.55	0.00	2.00
Hot exposure	20	1.05	0.68	0.00	2.00
Cold exposure	20	1.18	0.74	0.00	3.00
Alternating hot-cold exposure	20	1.85	0.79	1.00	3.00
Total	80	1.21	0.82	0.00	3.00

Interpretation: The alternating hot-cold condition produced the highest mean microleakage, while the non-thermocycled control group showed the lowest mean score.

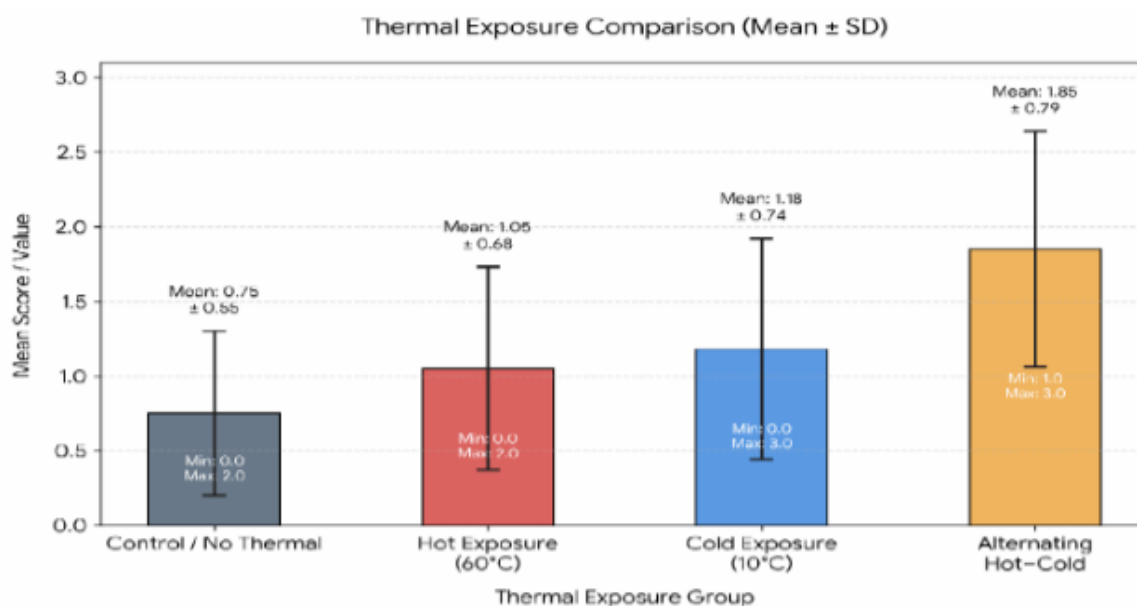


Table 5. Comparison of Microleakage among Restorative Materials

Source of Variation	Sum of Squares	df	Mean Square	F	p-value
Between Groups	7.84	3	2.61	4.12	0.009
Within Groups	48.22	76	0.63	—	—
Total	56.06	79	—	—	—

Interpretation: A statistically significant difference in microleakage was observed among the four restorative materials ($F(3,76) = 4.12$, $p = 0.009$).

Table 6. Two-Way Analysis of Variance for the Effects of Restorative Material and Thermal Exposure on Microleakage

Source	df	F	p-value
Restorative Material	3	4.12	0.009
Thermal Exposure	3	15.76	<0.001
Material $\times$ Thermal Exposure	9	2.31	0.025
Error	64	—	—

Interpretation: Both restorative material and thermal exposure had significant effects on microleakage, while their interaction was also statistically significant ($p < 0.05$).

DISCUSSION

This in-vitro study evaluated the influence of simulated hot and cold meals on the microleakage of various restorative

materials. Thermal exposure and the restorative material studied influenced microleakage. Generally, the results indicated that repeatedly exposing



restorations to varying temperatures could affect the integrity of restorations, and the degree of this change would depend on the restorative material used.

This study found the overall mean microleakage of Aactiva BioACTIVE to be 0.85 ± 0.67 . The conventional nanohybrid composite showed 1.65 ± 0.88 . Statistically significant differences ($p \leq 0.05$) were observed in the means of the four materials. It may be suggested that the difference in the restorative behavior of the materials is due to the type of ingredients used in the restorative composition. Similar results were reported in other studies on microleakage of contemporary restorative materials (11).

Low microleakage of Aactiva BioACTIVE may be due to its bioactive resin-based formulation and its interaction with the tooth structure. However, microleakage should not be evaluated in restorative material tests to assess clinical service. Microleakage tests should rather be considered as a quality control test. Restorative materials are susceptible to failure when exposed to different environmental conditions and stressed. This may be particularly true for materials that are designed to restore cavities, e.g., due to the exposure to the oral environment (12).

The microleakage results obtained for Cention N (1.10 ± 0.72) were close to the mean obtained for Aactiva BioACTIVE. It has been suggested that differences in microleakage among restorative materials are attributable to differences in the chemistry and physics of the constituents. The results obtained for EQUIA Forte HT may be attributable to the glass-hybrid restorative system and surface-protective coating (13).

Equia Forte HT demonstrated a mean microleakage score of 1.25 ± 0.79 . Researchers attributed the result to the material's glass-hybrid composition and the

use of surface protective coating. Past studies have investigated various types of restorative materials and have shown that material type affects marginal leakage. These studies have shown that additional stresses on the restorative materials may also impact marginal leakage.(14).

Previous studies have shown that under various stress conditions, different types of restorative materials can lead to different forms of marginal failures. The major finding of this study was that the type of restorative material can primarily determine the degree of microleakage. The nanohybrid composite showed the highest value of microleakage in the current study. Generally, microleakage is attributed to the quality of the adhesive interface and the amount of shrinkage of the restorative material. Previous studies on Class V restorations have shown the presence of microleakage with different resin composition (15).

Thermal exposure was the main factor contributing to microleakage in the current study. The mean microleakage of the hot-cold group was 1.85, and the cold group had a mean microleakage of 1.18, and the hot group had a mean microleakage of 1.05. The control group had a mean microleakage of 0.75. The results of the analysis of variance demonstrated that thermal exposure had a high level of significance and a large effect size on microleakage. Previous studies have shown that exposure of restorative materials to a thermocycling procedure increases the amount of microleakage of the materials (16).

Thermal exposure produced a particularly clear effect in the present study. The alternating hot-cold group showed the highest mean microleakage score ($M = 1.85$, $SD = 0.79$), followed by cold exposure ($M = 1.18$, $SD = 0.74$) and hot exposure ($M = 1.05$, $SD = 0.68$), while the non-thermocycled control group showed the lowest value ($M = 0.75$, $SD = 0.55$). The



two-way analysis demonstrated a significant effect of thermal exposure ($F = 15.76$, $p < 0.001$). Earlier experimental work has also demonstrated that thermal cycling can significantly increase microleakage in restorative specimens. "16" From the results of this study, it can be stated that thermal exposure has a significant impact on microleakage and should be considered in future studies (17). There was a strong interaction of material x thermal stress in the present study ($F = 2.31$, $p = 0.025$). As such, it can be concluded that the four materials tested in the study changed volumetrically with changes in temperature. Consequently, a smaller change in one restorative material may cause a greater volume change in another. Other glass-ionomer restorative materials have also been reported to be influenced by thermal cycling and microleakage (18).

The effect of thermal cycling on glass-ionomer cement restorative materials has been studied using Class V preparations. Microleakage has been studied and effects related to the location of the margins have also been reported (19).

The tests conducted in the study assessed the sealing ability of the restorations by using dyes and observing penetration. While the use of dyes does not replicate the leaking of bacteria, it has been reported to be useful for laboratory tests to compare the results of leaking. Studies have used microscopic examination and dye-penetration techniques to evaluate restorative systems for microleakage (20).

The limitations of the in vitro model should be considered when evaluating study results. The effects of cyclic temperature conditions can not fully mimic the oral environment, which comprises variable and irritant factors including chemical acidity, bacterial flora, moisture and frictional forces. Additional studies have shown that the simulational conditions used can

significantly influence the behavior of restorative materials (21).

From the results of this study, it can be concluded that microleakage of restorative materials is the combined effect of the material and exposure to varying temperatures. These effects can represent the conditions that restorative materials are expected to endure in the oral environment. Other factors such as the oral environment (saliva, bacteria, pH fluctuations), frictional forces, and time should also be considered. From these studies, it can be expected that the microleakage of newer restorative materials would be greater.

CONCLUSION

This in-vitro study examined how microleakage is affected by exposure to hot and cold temperatures by various restorative materials. Of all the restorative materials tested, ActivA BioACTIVE showed the best result with the lowest microleakage. The highest microleakage was shown by the control nanohybrid material. The results further showed that repeated exposure to hot and cold temperatures increased the rate of microleakage when compared to the rate of microleakage caused by individual exposure to hot and cold temperatures and the rate of microleakage in a non-thermocycled condition.

Future Suggestions

Further studies are needed to test these materials using more clinically relevant conditions and longer thermal-aging periods. Other environmental conditions (i.e. bacterial, mechanical, chemical, and combined) should also be tested. Long-term, clinically-relevant studies to assess the microleakage of restorative materials and determine the effects on the performance of the restoration are also warranted.



Limitations of Study

Marginal leakage was measured using a dye penetration test and assessed only 80 teeth. The thermal testing used in this study was only a simulated representation of the dietary temperature variations that occur in the oral cavity. Other environmental stimuli (saliva, pH, bacteria, and mechanical) were also not included in this study.

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