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Comparative In Vitro Assessment of Marginal Microleakage and Caries-Like Lesions Around Common Restorative Materials

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ABSTRACT

Background: Secondary caries formation is still one of the main reasons of restorations fail, mostly caused by the material's resistance to microleakage and marginal sealing ability. The objective of this research was to assess compare the degree of secondary caries development next to restorations made of Glass Ionomer Cement (GIC), Composite Resin, and Amalgam.

Methods: The in-vitro study was conducted (March 2024 to August 2024) at Dentistry department of Akhtar Saeed Medical College, SMDC, Lahore with randomly selected groups (n = 30 each) created from 90 extracted human premolars: Group A (Composite Resin), Group B (Amalgam), and Group C (GIC). In accordance with the guidelines provided by the manufacturers, standardized Class I and II cavities were prepared and restored. The samples were subjected to artificial demineralization (pH cycling) and thermocycling in order to replicate oral conditions that are favourable for the development of marginal caries. In SPSS version 26.0, one-way ANOVA and chi-square tests were used to analyse the data ($p < 0.05$ as significant).

Results: The findings showed that Amalgam restorations had the most severe lesions and the highest leakage (0.87 ± 0.21 mm), while Composite Resin restorations had the lowest microleakage (0.58 ± 0.16 mm) and the lowest caries incidence. GIC exhibited results that were in between (0.72 ± 0.19). The groups differed significantly ($p = 0.01$ for caries severity and $p = 0.002$ for leakage).

Conclusion: In comparison to Amalgam and GIC, Composite Resin demonstrated better marginal adaptation and resistance to secondary caries. These results highlight the significance of choosing restorative materials to reduce restoration failures.

Keywords: Dental Caries, Composite Resins, Dental Amalgam, Glass Ionomer Cements, Dental Leakage, Tooth Demineralization.

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INTRODUCTION

Dental caries has remained one of the most common oral diseases in the world, affecting both adults and children and playing a major role in tooth loss and restoration failures [1]. A major cause of restoration replacement, secondary caries—defined as caries that develop at the edges of pre-existing restorations—increases the financial and health burden on patients [2]. A patient's diet, oral hygiene, microbial colonization, and the physical and chemical characteristics of restorative materials are some of the variables that affect the development of secondary caries [3].

Dental amalgams, glass ionomer cements (GICs), and composite resins are examples of restorative materials that vary in their ability to provide marginal sealing and inhibit bacterial penetration [4]. Because of their aesthetic appeal, composite resins are frequently used; however, if polymerization shrinkage takes place, they may be vulnerable to secondary caries and microleakage [5]. Glass ionomer cements have demonstrated promise in lowering cariogenic activity at restoration margins due to their fluoride-releasing characteristics [6]. Despite its waning use, amalgam exhibits marginal adaptation and long-term durability but lacks aesthetic benefits [7].

The longevity of restorations depends critically on the interplay between cariogenic challenges and restorative materials [8]. Depending on the type of material and cavity preparation methods, secondary caries incidences have varied in laboratory and clinical studies [9]. Additionally, new developments in bioactive restorative materials seek to improve remineralization and lessen bacterial adhesion, which may minimize the development of secondary caries [10].

The purpose of this study was to compare the prevalence and severity of secondary caries next to amalgam, glass ionomer, and composite resin restorations under controlled conditions. The goal was to find the materials that offer the finest protection against recurrent caries.

METHODS

This in-vitro experimental study (March 2024 to August 2024) was carried out at Dentistry department Akhtar Saeed Medical College, SMDC, Lahore (Ref. No. 2252/AST) after an informed consent. A total of 90 extracted human premolars that were free of restorations, caries, and cracks were collected. This sample size was obtained by calculating the sample size using OpenEpi version 3.0.0 (Atlanta, GA, USA) at a 95% confidence level and 80% power [11].

After being removed for orthodontic or medical purposes, the teeth were kept at room temperature in a 0.1% thymol solution until they were needed. Only teeth with complete roots and intact crowns were included. To maintain uniformity in preparation, teeth with developmental abnormalities, fractures, or structural flaws were not included. Three equal groups (n = 30 each) were randomly created such as Composite Resin, Dental Amalgam, and Glass Ionomer Cement (GIC) make up Groups A, B, and C respectively. A high-speed diamond bur with water cooling was used to create standardized Class I and II cavities. To avoid inter-operator variability, a single operator performed all cavity preparations. A periodontal probe and digital caliper were used to standardize the cavity dimensions, which were 3 mm for depth, 4 mm for width, and 2 mm for pulpal floor thickness.

Finishing and polishing procedures were performed for all restorative materials by following standard clinical protocols and the respective manufacturers' recommendations. Cavities were etched with 37% phosphoric acid for 15 seconds, rinsed, dried, and then bonded with a light-cured adhesive system for composite Resin. After being applied gradually, the composite resin was light-cured for 40 seconds at a time. Cavities were conditioned with 10% polyacrylic acid for 20 seconds, rinsed, dried, and then filled with regular glass ionomer cement (GIC). To avoid desiccation, a protective varnish coating was applied. Dental amalgam that had been combined in a mechanical amalgamator, condensed, carved, and burnished was used to fill cavities.

Each specimen was placed in distilled water at a temperature of 37ºC to allow the specimen to mature and stabilize its dimensional aspects; the specimen was then put back into the water and left to dry over 24 hours. To replicate intra-oral temperature variability, specimens were thermocycled at temperatures ranging between 5ºC to 55ºC at a dwell time of 30 sec in 500 cycles. The teeth were placed in an artificial demineralization solution (0.1 M lactic acid, pH 4.5) and the solution was left on the teeth 48 hours to simulate the formation of secondary caries. The demineralization produced initial caries-like alterations at the restoration margins, which were similar to the clinical conditions. The specimens were coated with nail varnish with a 1mm margin around the restoration margins and incubated in the 0.5% basic fuchsin dye after 24 hours. Immediately after the immersion, teeth were rinsed, longitudinally sectioned with the computer-controlled low-speed diamond saw through the center of the restoration.

Image Analysis software was used to determine the dye penetration depth (mm) to measure marginal microleakage. Adjacent carious lesions were evaluated under the same microscope and scored on a four-point ordinal scale based on the extent of demineralization such as None, Mild, Moderate, and Severe. Data were analyzed using SPSS version 26.0. Mean dye penetration depths were compared using One-way ANOVA followed by post-hoc Tukey's test. Chi-square test was used to assess the distribution of caries severity across groups. A p-value < 0.05 was considered statistically significant.

RESULTS

Table 1. Baseline Demographic and Cavity Characteristics (n = 90)

Variable	Composite Resin (n = 30) mean ± SD/ n (%)	Amalgam (n = 30) mean ± SD/ n (%)	GIC (n = 30) mean ± SD/ n (%)	Statistical Test	p-value
Tooth Type					
Premolar 1	18 (60)	17 (56.7)	16 (53.3)	$\chi^2 = 0.24^{df}$	0.88
Premolar 2	12 (40)	13 (43.3)	14 (46.7)		
Cavity Class (I/II)					
Class I	21 (70)	22 (73.3)	20 (66.7)	$\chi^2 = 0.28^{df}$	0.86
Class II	9 (30)	8 (26.7)	10 (33.3)		

GIC: Glass Ionomer Cement, df (degree of freedom): 1, ANOVA and Chi-square test was applied, p< 0.05 found to be statistically significant

There were 90 restored premolars (30 of each material group) being studied. The average age of the tooth donors was between 42 and 43 years of age, and no significant difference was observed (p > 0.05). Baseline parameters of donor demographic data were recorded such as gender distribution, type of teeth, and cavity type, which proved successful randomization and sample homogeneity, as shown in **Table 1.**

Table 2: Comparison of Dye Penetration Depth among Restorative Materials

Group	Mean ± SD (mm)	F-value	p-value
Composite Resin[a]	0.58 ± 0.16	$F = 6.93^{df}$	0.002
Amalgam[b]	0.87 ± 0.21		
GIC[ab]	0.72 ± 0.19		

GIC: Glass Ionomer Cement, df (degree of freedom): 1, ANOVA (F) was applied for statistical comparison, p<0.05 found to be statistically significant. Different superscript letters indicate statistically significant differences (Tukey HSD, p < 0.05).

The baseline parameters did not significantly differ between groups (p > 0.05). The mean dye penetration depth of the three restorative materials varied significantly (F = 6.93; p = 0.002) as demonstrated in **Table 2.** A post hoc pair comparison of the mean differences between the groups was carried out using honestly significant difference (HSD) Tukey's test. The findings revealed that composite resin had much less dye penetration than amalgam (p < 0.01). There were not significant differences between composite resin and GIC (p > 0.05) and between GIC and amalgam (p > 0.05).

Table 3: Severity of Secondary Caries Adjacent to Restorative Materials

Caries Severity	Composite Resin (n=30) n(%)	Amalgam (n=30) n(%)	GIC (n=30) n(%)	Statistical test	p-value
None	21 (70)	10 (33.3)	14 (46.7)	$\chi^2 = 11.27^{df}$	0.01
Mild	6 (20)	7 (23.3)	9 (30)		
Moderate	3 (10)	8 (26.7)	6 (20)		
Severe	0 (0)	5 (16.7)	1 (3.3)		

None: *No visible demineralization,* ***Mild:*** *Surface enamel affected,* ***Moderate:*** *Enamel and superficial dentin affected,* ***Severe:*** *Deep dentin involvement approaching the pulp, GIC: Glass Ionomer Cement, df (degree of freedom): 6, Chi-square test was applied, $p < 0.05$ found to be statistically significant.*

According to post-hoc analysis, GIC exhibited intermediate values with no statistically significant difference from either material ($p > 0.05$), whereas Composite Resin demonstrated significantly lower microleakage than Amalgam ($p = 0.001$). Additionally, there were significant differences in the distribution of secondary caries severity between groups ($\chi^2 = 11.27$; $p = 0.01$) which is shown in **Table 3**.

The highest percentage of caries-free margins was found in Composite Resin (n=21, 70%), and the most moderate-to-severe lesion were observed in Amalgam (n=13, 43.4%). The GIC showed a moderate preventive effect (n=14, 46.7% caries-free), probably because of the fluoride release

DISCUSSION

In this in vitro study, composite resin restorations had the lowest microleakage (mean = 0.58 mm) and lowest rate of secondary caries, whereas Amalgam had the highest microleakage (0.87 mm) and worst caries lesions. GIC gave moderate values both in leakage and caries. Significant differences in intergroup conditions were statistically proved in leakage ($p = 0.002$), and caries severity ($p = 0.01$). These results suggest that the kind of the restorative material is a significant determinant of retaining the marginal integrity and inhibiting the reoccurring caries under normal experimental conditions.

The findings of the current study revealed that composite resin had the lowest penetration of dye, which means that it has a better marginal sealing ability. The observation was in-line with the available literature that the low microleakage was closely linked with the decreased risk of the secondary caries around the composite restorations [12]. Mechanistically, there are better adhesive bonding and resin technologies that can be used to generate smaller marginal gaps, thereby restricting bacterial entry. Nevertheless, it is also known that polymerization shrinkage and surface roughness still require serious attention as they pose the risk of microleakage and secondary caries in resin-based materials and can negatively affect long-term clinical outcomes, despite their good results in the laboratory [13]. Our study also showed poorer performance of Amalgam, which is also correlated with previous research, indicated that the absence of adhesive bonding of amalgam restorations enhances the formation of marginal gaps and eventual penetration by bacteria [14]. The lack of a chemical bond may lead to peripheral cracks, which allows bacterial penetration. Glass ionomer cement (GIC) was found to have an intermediate capacity in micro leakage which suggested that fluoride release has a moderate protective ability against secondary caries. A recent meta-analysis established that GIC restorations were found to have lower caries secondary incidences in both primary and permanent teeth compared to amalgam [15, 16] This may partially offset the weak mechanical properties of the GIC through the fluoride-mediated remineralization potential of this material. Other studies, however, found no significant variation in marginal adaptation or the caries outcome between ion releasing materials and the composite resins suggesting that fluoride release might not be adequate to surmount the sensitivity of the techniques and the decay of the material with time [17]. Clinical follow up studies have also highlighted a good marginal integrity and absence of secondary caries in GIC restorations after one year and these results are in line with our average performance outcomes [18].

Also, local clinical trials have shown promising results of resin-modified GIC whereby less caries were reported in resin-modified GIC than the conventional restorations of composite resin after 12 months [19]. This indicates that changes in materials can be used to improve clinical performance, but more time is required to test their sustainability. Likewise, a more extensive systematic review found that microleakage is an essential experimental factor in the development of secondary caries, but there are uneven clinical association results [20,21]. In spite of these trends, there have been some long-term clinical studies that have had little or no difference between composites and ion-releasing material in caries occurrence which may be due to differences in patient-related factors, oral health and diet [22, 23]. Also, systematic reviews regarding secondary caries and marginal adaptation found no significant differences between these restorative materials at some follow-up times highlighting that in vitro outcomes would not represent full biofilm, salivary, and mechanical conditions in vivo [24].

There are multiple limitations to this study. Saliva buffering, masticatory stress, and microbial ecology are biological factors of the oral environment that are absent from this in vitro experiment. The model of artificial demineralization might not replicate the intricate and dynamic evolution of natural caries as reported in the previous literature where the caries process is compared in vitro and in vivo. Thus, associations between restorative materials and microleakage are to be viewed as an experimental as opposed to a conclusive clinical finding. Furthermore, the study did not assess contemporary nanocomposite or bioactive materials and only used a small number of removed premolars. Therapeutic trials with bigger sample sizes, longer observation durations, and the inclusion of behavioral and microbiological aspects to enhance therapeutic applicability should all be included in future studies [25].

CONCLUSION

This study showed that microleakage and the subsequent development of secondary caries are strongly influenced by the type of restorative material used. Amalgam restorations performed the worst because of increased microleakage and poor adhesion, whereas Composite Resin restorations had the best marginal sealing ability and the lowest incidence of recurrent caries. The intermediate results from Glass Ionomer Cement demonstrated the protective function of fluoride release. These results highlight how crucial it is to choose restorative materials with the best sealing and anti-cariogenic qualities. To confirm these in vitro results under actual oral circumstances and prolonged use, future clinical research is advised.

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CONFLICT OF INTEREST

None.

ETHICAL APPROVAL

This in-vitro experimental study (March 2024 to August 2024) was carried out at Dentistry department Akhtar Saeed Medical College, SMDC, Lahore **(Ref. No. 2252/AST)** after informed consent.

AUTHORS' CONTRIBUTION

All authors contributed equally as per ICMJE.

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