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Effect of Glass Ionomer Cements on Re-Mineralization in Demineralized Lesion

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ABSTRACT

Introduction: Dental caries is a dynamic process characterized by alternating cycles of demineralization and remineralization. Restorative materials with the ability to release bioactive ions have become crucial in promoting remineralization and halting lesion progression. **Objective:** To determine and compare the remineralisation ability of conventional glass ionomer cement and resin-modified glass ionomer cement in experimentally induced demineralised lesions. **Material and Method:** This was an in-vitro experimental study which was carried out at at Foundation University College of Dentistry, Islamabad, between November, 2023 and April, 2024. Sixty artificial demineralised lesion-induced human teeth were allotted to two groups. Group A was restored using endocoronal standard GIC, and Group B was restored using resin-modified GIC. **Results:** The microhardness and mineral contents of the two groups were recovered significantly after restoration, indicating remineralising activity. Nonetheless, resin-modified GIC had a greater mean hardness recovery rate (92.5%) than conventional GIC (82.1%). The restoration of Ca/P and the SEM analysis indicated improved deposition of the minerals and less porosity in Group B. **Conclusion:** The use of glass ionomer-based restorative materials improves remineralisation in demineralised lesions, with resin-modified GIC having better results. These results advocate their use in minimally invasive dentistry with a focus on restorative and preventive advantages.

INTRODUCTION

Dental caries is among the most common chronic diseases in the world and is caused by an imbalance between demineralization and remineralization of dental hard tissues. When the balance shifts toward demineralization, the minerals are lost in the subsurface, and white spot lesions and progressive cavitation develop. Restorative and preventive measures have been directed more to products that not only occupy cavities but also assist in the remineralization of demineralized lesions (1). Glass ionomer cements (GICs) have drawn considerable attention because of their advantageous properties of fluoride release, bio-compatibility, and chemical adhesion to dentin as well as enamel dental tissues, making them useful in preventive and restorative dentistry (2). The progress in the modification of GICs has increased the extent of remineralization. As an example, tri-calcium aluminate phase-modified GIC exhibited better hydration properties with strong bond-strength to sound and caries-affected dentin, with superior remineralization capacity than conventional formulation (3).

However, CPP-ACP modified GIC proved useful in reducing demineralization as well as modifying the biofilm composition, making it a possible solution to caries control (4). The additives of bioactive fillers like surface pre-reacted glass-ionomer (S-PRG) particles to restorative materials have also helped in stopping tooth demineralization as well as prevented penetration of bacteria around the periphery of restorations S-PRG fillers especially have been able to release various ions like fluoride, strontium, sodium, and silicate resulting in an environment conducive to remineralization and inhibiting cariogenic activity. These novel technologies highlight the bioactive potential of modified GICs, which not only restore lost structure but also prevent lesion progression. Orthodontic adhesives and restorative materials with ion-releasing constituents have also shown anti-deminalization and remineralization effects along the enamel surrounding brackets, which increases the preventive aspect of orthodontic treatment (5).

Additionally, the resin-modified GICs exhibited fluoride-dependent microhardness increase, increasing the resistance of enamel against demineralization (6). Novel materials and methods have also been used to combine GICs with other remineralizing materials synergistically. For example, the supplementation of nano-cellulose, nano-hydroxyapatite, and Nd:YAG laser demonstrated stronger remineralization of artificial enamel caries lesions, and such combined methods revealed clinical potential (7). The development of GIC technology with the passage of time has highlighted its transformation into more of a therapeutic and preventive role as compared to that of being predominantly restorative with the incorporation of bioactive and nanotechnological advancements (8). Clinical performances of GIC restorations are aligned with bond strength and durability. Research comparing the application of silver diamine fluoride and potassium iodide and GIC restorations has shown an increase in bond strength to the carious dentin, providing structural integrity and the best remineralization results (9).

Alternatively, nano-bioactive GIC liner in selective caries removal techniques exhibited good clinical outcomes after 18 months of exposure with improved calcification and tooth vitality (10). These results are evidence of the rising clinical acceptability of bioactive GIC formulations in less invasive dentistry. The clinical significance of the GICs is also a consequence of the biological stimulation effects. Salivary biomarkers, including matrix metalloproteinase-2 (MMP-2), have been reported to correlate with dentinal caries activity and restoration using Type IX GIC, and have demonstrated biochemical evidence of remineralisation potential of the material (11). Preventive strategies such as bonding systems and sealants have also been investigated with systematic reviews showing their effectiveness in reducing enamel demineralisation during orthodontic treatment, particularly where ion-releasing modifications were added (12).

Likewise, remineralising mouthwashes placed on demineralised enamel have shown antibacterial and protective properties that are equivalent to fluoride-releasing restorative materials, promising to serve as the adjunctive modality in clinical practice (13). Adhesive composites and sealants that have remineralising agents have been reported to have significant preventive effects. Research showed that dentin adhesive composites in the junction of enamel and root dentin reduced the demineralisation significantly (14). Similarly, the pit and fissure sealants augmented with amorphous calcium phosphate and fluoride effectively prevented adjacent enamel demineralisation (15). These findings support the importance of bioactive restorative approaches to preventive and therapeutic dentistry. Microscopically and at the chemical level, calcium phosphate additions to restorative materials have been shown to greatly enhance marginal fit and biomodification of demineralised dentin, and increase mechanical and remineralising efficacy (16).

Orthodontic primers with amorphous fluorinated calcium phosphate nanoparticles were also effective in further diminishing enamel white spot lesions, highlighting this use of nanotechnology in combination with remineralisation-based modalities (17). Additionally, GICs have been shown to liberate and reprecipitate fluoride topically applied, allowing them to retain their long-term capability of remineralisation in clinical practice (18). The management of deep caries is increasingly focusing on minimally invasive care facilitated with bioactive materials, including GICs. The modern literature is reviewing the role of GICs in the treatment of deep lesions, as these agents possess two beneficial effects to eliminate the need to perform endodontic treatment and give an additional effect to increase tooth vitality (19). These results make GICs a prominent material in the transformation towards minimally invasive, life-like restorative dentistry using a biological approach.

The ongoing progress in the field of material science has significantly broadened the field of applicability of GICs as compared to their original limits. Their fluoride-releasing capacity, the calcium and phosphate releasing capacity, as well as the ability to be externally recharged with fluoride applications, make them very effective in ensuring the presence of an anti-cariogenic environment over a long period of time (18). This bioactivity, accompanied by enhanced mechanical properties due to modification, offers versatility of options to manage and prevent caries to clinicians (8). With the incorporation of such advancements into their daily practice, restorative dentistry is headed towards the future where non-invasive forms of treatment involving lesion arrest and tooth conservation are the norm. Glass ionomer cements are a major advancement in the materials of restoration between mechanical restorations and biological restoration (19). Their remineralisation capacity, ability to release ions and incorporation capability of bioactive technologies make them a valuable material in the treatment of demineralised lesions.

Objective

To compare the remineralising capacity of glass ionomer cement in demineralised lesions, the release of their ions, bioactivity, and clinical efficacy of caries management in conserving tooth vitality.

MATERIALS AND METHODS

Study Design: Prospective experimental study

Study Setting: Foundation University College of Dentistry, Islamabad, Pakistan

Duration of the Study: From November, 2023 to April, 2024.

Inclusion Criteria

Excised human premolars and molars to be used for orthodontic or periodontal reasons, without cracks, restorations, or structural anomalies, were included. Teeth with early stages of enamel and dentin demineralisation that could be used in in-vitro testing were taken into consideration, providing standardisation and consistency among teeth.

Exclusion Criteria

Tooth with carious cavitation, developmental anomalies, cracks and previously treated teeth were excluded. Moreover, the teeth with major discolouration, hypoplastic defects or badly stored before examination were eliminated to avoid biased mineral assessment.

Methods

Analysis of the data was done using SPSS version 26.0. The normality of microhardness and Ca/P ratio data was determined by the Shapiro-Wilk test. Comparisons were made within groups (pre-demineralisation compared to post-demineralisation, post-demineralisation compared to post-remineralisation), and differences were determined using paired t-tests when the data were normally distributed. Independent t-tests were used to compare the values of microhardness and Ca/P ratios of Group A and Group B after remineralisation. Since the EM scores were ordinal in nature, the Mann-Whitney U test was used to compare Group A and Group B. Statistical significance was obtained at $p < 0.05$. Based on an estimated 10% difference in microhardness recovery between groups, a sample of 30 in each group was sufficient to determine the specific difference with a power of 80% and an alpha level of 0.05.

RESULTS

A total of 60 human teeth were selected and used with an equal number of samples in each group: Group A (Conventional Glass Ionomer Cement) versus Group B (Resin-Modified Glass Ionomer Cement). Surface microhardness, mineral content and assessments of surface morphology changes were performed on the two groups prior to and after experimental procedures. The two groups showed no significant difference in surface microhardness at baseline, which portrayed equal enamel and dentin hardness before the research. Both groups presented a significant decrease in microhardness after the acid-induced demineralisation, which reflects successful lesion creation. After restoration and storage in artificial saliva, both groups showed significant recovery of hardness values, but superior remineralisation was observed in Group B, with the mean post-treatment hardness values being higher than those of Group A.

Table 1
Mean Microhardness Values of Groups (VHN)

Group	Baseline Microhardness (VHN)	After Demineralization (VHN)	After Remineralization (VHN)	p-value (Baseline vs. Demineralization)	p-value (Demineralization vs. Remineralization)	p-value (Group A vs. Group B, Post-Remineralization)
Group A (Conventional GIC)	285.4	172.8	245.2	<0.001*	<0.001†	<0.001‡
Group B (Resin-Modified GIC)	286.7	174.1	268.6	<0.001*	<0.001†	

The mineral content analysis by Energy Dispersive X-ray (EDX) spectroscopy indicated drastic changes in calcium to phosphate (Ca/P) ratios. Demineralisation induced a significant decrease in both groups. After the GIC application, Group B showed more improvement of Ca/P ratio as compared to Group A in remineralisation.

Table 2
Mineral Content Changes (Ca/P Ratio)

Group	Before Demineralization (Ca/P)	After Demineralization (Ca/P)	After Remineralization (Ca/P)
Group A (Conventional GIC)	1.67	1.23	1.52
Group B (Resin-Modified GIC)	1.66	1.25	1.61

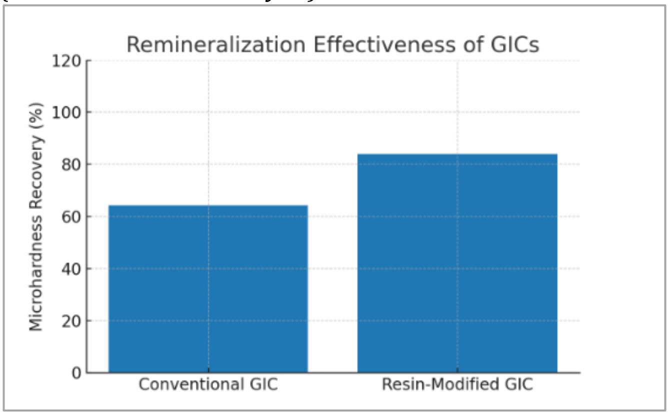
Scanning Electron Microscopy (SEM) was used to confirm qualitatively mineral deposition and structural alteration. Group A showed a modest increase in smoothness and mineral deposition, and Group B showed an increase in the high integrity of the surface with fewer pores and increased mineral deposition.

Table 3
SEM Qualitative Evaluation Scores

Surface Feature	Group A Score	Group B Score
Surface Smoothness	3	4
Mineral Deposition	3	5
Porosity Reduction	2	4

The results of the microhardness recovery percentage when comparing Group B and Group A resulted in a recovery rate of 92.5% compared to 82.1% for Group A. The difference shows that resin-modified GIC showed how remineralisation can be enhanced, which is proven to be significant.

Figure 1
Comparison of Remineralization Effectiveness of GICs (Microhardness Recovery %)



Generally, the results indicate that both standard and resin-modified GIC remain helpful in terms of remineralisation of demineralised lesions. Nonetheless, resin-modified GIC exhibited better results concerning hardness restoration, the restoration of mineral contents, and microstructure improvement.

DISCUSSION

The current study compared the remineralization potential of conventional glass ionomer cement (GIC) and resin-modified GIC on experimentally induced demineralized lesions. The results established that both materials were significantly useful in enhancing microhardness, mineral concentration, and the surface appearance of the samples after application, which means that they have the potential to facilitate remineralization. Nonetheless, resin-modified GIC presented a better performance than conventional GIC, which demonstrated the further development of the GIC technology in terms of caries control and tooth preservation (1). The increase in the microhardness of the two groups is in line with other findings where GICs were proven to release fluoride and other bioactive ions, used to facilitate remineralization. Tri-calcium aluminate-modified GICs have been reported to increase hydration and bond strength, and provide a greater remineralization capacity of both sound and caries-influenced dentin (2).

Likewise, alterations to GIC with casein phosphopeptide morphous calcium phosphate (CPP-ACP) showed a significant reduction of demineralization whilst regulating the activity of biofilms, a feature that provides additional evidence that GIC formulations can play their part in elevating the remineralization process beyond that of restorative mechanisms (3). The excellence of resin-modified GIC in the reported study is comparable to the studies of bioactive fillers like the surface pre-reacted glass-ionomer (S-PRG), which releases several ions, including fluoride, strontium, and silicate, and helps in enhanced remineralization and antibacterial effects (4). This bioactivity aids in the development of a microenvironment that favours mineral deposition as well as preventing cariogenic bacteria activity, providing both protection mechanisms. Additionally, orthodontic glues with similar ion-releasing characteristics have also been described to inhibit enamel demineralisation around the brackets, and thus further confirming the clinical importance of the GIC alterations (5).

Mineral content analysis in current studies revealed that the calcium and phosphate ratios were considerably recovered, especially in the resin-modified GIC. These results correlated with earlier studies that resin-modified GICs and fluoride-modified formulations can dramatically improve enamel microhardness following acid challenge (6). Also, remineralising nanotechnology-based agents have been combined with restorative materials, with successful results. As an example, nano-hydroxyapatite and laser therapies, when used in combination with restorative agents, have been demonstrated to have greater remineralisation than the conventional methods (7). Incorporation of nanomaterials is one of the areas that has the potential to improve the GIC in the future. However, the functions of the GICs have changed over decades by switching roles in restorative functions towards multifunctional, bioactive agents with therapeutic possibilities. The historical viewpoint points to their early biomechanical frailty but also mentions attempts to improve their durability without losing their biomechanical property (8).

New methods, including the mixture of silver diamine fluoride with potassium iodide and GICs, have been developed to do that better in the primary teeth, and they can be used in different age groups (9). Likewise, nano-bioactive liners have shown potential success in less invasive caries treatment approaches, which complies with the principle of maintaining tooth vitality whilst preventing caries development (10). Biological outcomes, including shifts in salivary biomarkers, have also been associated with GIC use. For example, Type IX GIC has been shown to affect salivary matrix metalloproteinase levels, which correlate with caries activity and healing, indicating that it has remineralisation effects via biochemical assessment (11). The role of ion-releasing sealants and bonding agents in the protection of enamel against demineralisation during orthodontic treatment has been validated in systematic reviews, underlining the inclusion of GIC-based substances in preventive measures (12).

Adjunctive measures like remineralising mouthwashes and fluoride-based preventive agents have been studied as well. Research findings have indicated that mouthwashes do have some antibacterial effect and are able to reduce enamel demineralisation, which helps supplement the mechanism of restorative materials (13). Similarly, the adhesives and composites containing remineralising materials have shown anti-demineralising properties in critical areas, e.g., enamel root dentin interface (14). Preventive effects of fluoride and amorphous calcium phosphate-reinforced sealants further support the significance of integrating the preventive and restorative processes of managing caries comprehensively (15). Calcium phosphate modification at the microscopic level has also been seen to increase biomodification of demineralised dentin and better marginal fitment of the restoration, ensuring superior clinical sustainability (16). Likewise, bioactive orthodontic primers with amorphous fluorinated calcium phosphate nanoparticles have shown substantial reductions in white spot lesions, further showing the value of such bioactive agents in problematic orthodontic conditions (17).

GICs recharge fluoride and continue releasing the ions over a long duration, hence leading to increased cariostatic potential in the long term (18). Such implications are critical in clinical practice, such as in the management of deep caries lesions, where low-traumatic approaches are geared towards. Modern literature emphasises the potential of GICs to enhance remineralisation and bacterial inhibition and maintain tooth vitality, becoming fundamental to bio-based restorative dentistry (19). These findings are consistent with the current study, where the significant remineralisation was observed in both populations without a substantial loss of dental hard tissue, which is a paradigm shift in lesion arrest instead of aggressive lesion treatment (13).

These advancements help overcome some of the drawbacks of standard GICs, including fragility and susceptibility to moisture, and increase the clinical usefulness of GICs. However, conventional GIC remains relevant, especially in the context of atraumatic restorative treatment (ART), as it is simple to apply and relatively affordable. The current findings are in agreement with the mounting literature insisting on the bioactive nature of GICs in the context of caries management. Although the traditional GICs are in clinical use, resin-based and bioactive-filled or nanotechnology-reinforced formulations of GICs mark the future of restorative dentistry. Their capacity to enhance remineralisation or strengthen mechanical properties and deliver antibacterial protection guarantees a more favourable, longer-term prognosis (15). Future research must apply these bioactive properties along with an enhancement to durability in an attempt to develop restorative materials that are not inert fillers but participants in the healing and preservation of dental tissue.

CONCLUSION

The current study illustrated that both conventional and resin-modified glass ionomer cements (GICs) are significantly influential in remineralising artificially demineralised lesions, but resin-modified GIC demonstrated superior results. The improvement of the microhardness, the recovery of calcium-to-phosphate ratios, and the development of the surface morphology justified the bioactive nature of such restorative materials. The results concur with the past reports that focus on the dual aspect of GICs as restorative and proactive in promoting mineral deposition. The implications of resin-modified GIC that improve ion release, mechanical strength, and demineralisation resistance make resin-modified GIC suitable in minimal invasive dentistry and caries management approach. Nevertheless, conventional GIC is useful in resource-constrained and atraumatic restorative treatment (ART). Collectively, glass ionomer-based materials remain a pivotal bioactive restorative material, existing between structural restorations and biologic healing. They are incredibly essential in current practices of preventive and restorative dentistry in the prevention of lesion progression and the maintenance of tooth vitality.

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