Comparative Evaluation of Commercial Glass Ionomer Cements Comparative Evaluation of Three Commercially Available Conventional Glass Ionomer Cements Based on Physicomechanical Properties, Surface Microhardness, And Antibacterial Activity: An In Vitro Study

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ABSTRACT

Background

Conventional glass ionomer cements (GICs) are widely used restorative materials owing to their chemical adhesion to tooth structure, fluoride-releasing ability, biocompatibility, and cariostatic properties. Differences in the composition and formulation of commercially available conventional GICs may influence their physicomechanical, surface, and antibacterial characteristics, thereby affecting their clinical performance.

Aim

To compare the setting time, flexural strength, compressive strength, surface microhardness following a demineralization-remineralization challenge, and antibacterial activity of three commercially available conventional glass ionomer cements.

Materials and Methods

Three commercially available conventional glass ionomer cements (Crysta Restorative II, Lute Glass, and Prism Cem Type II) were evaluated under standardized laboratory conditions. Setting time was determined according to ISO 9917-1-2007. Flexural strength and compressive strength were evaluated using a universal testing machine in accordance with ISO standards. Surface microhardness was assessed using the Vickers microhardness test at baseline, after demineralization, and after remineralization. Antibacterial activity against *Streptococcus mutans* and *Staphylococcus aureus* was evaluated using the agar well diffusion method. Statistical analysis was performed using one-way ANOVA, repeated measures ANOVA, and two-way ANOVA, followed by appropriate post hoc tests ($p < 0.05$).

Results

Statistically significant differences were observed among the evaluated glass ionomer cements with respect to setting time, flexural strength, compressive strength, surface microhardness, and antibacterial activity ($p < 0.05$). All materials demonstrate difference was found between *Streptococcus mutans* and *Staphylococcus aureus*.

Conclusion

Within the limitations of this in vitro study, the three commercially available conventional glass ionomer cements demonstrated significant differences in their physicomechanical, surface, and antibacterial properties, indicating that their overall performance is material dependent. These findings may assist clinicians in selecting appropriate GICs for specific clinical applications and provide bassline data for future long-term laboratory and clinical investigations.

Keywords

Conventional glass ionomer cement, Setting time, Flexural strength, Compressive strength, Surface microhardness, Antibacterial activity

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INTRODUCTION

Dental caries remains one of the most prevalent chronic oral diseases worldwide and continues to represent a major challenge in restorative dentistry. Despite considerable advances in preventive strategies, the demand for durable restorative materials capable of preserving tooth structure and maintaining long-term clinical function remains high. The success of restorative treatment depends not only on the removal of diseased tissue but also on the selection of a material with appropriate mechanical, biological, and physicochemical properties that can withstand the oral environment (1,2).

Glass ionomer cements (GICs), introduced by Wilson and Kent in 1972, have become an integral part of restorative dentistry because of their unique combination of desirable properties. Unlike many restorative materials, conventional GICs chemically bond to enamel and dentin, exhibit a coefficient of thermal expansion similar to that of natural tooth structure, demonstrate acceptable biocompatibility, and continuously release fluoride ions that contribute to the prevention of secondary caries and remineralization of adjacent dental tissues. Owing to these advantages, GICs are widely used in paediatric dentistry, atraumatic restorative treatment (ART), cervical restorations, and other minimally invasive restorative procedures (3–6).

The setting reaction of conventional GICs involve an acid-base reaction between fluoroaluminosilicate glass powder and aqueous polyalkenoic acid, resulting in the formation of a rigid cross-linked polysalt matrix. The composition of the glass particles, characteristics of the polyacid, powder-to-liquid ratio, particle size distribution, and the presence of additives collectively influence the setting characteristics and overall performance of the material. Consequently, commercially available conventional GICs manufactured by different companies often differ in their handling characteristics, mechanical behaviour, surface properties, and biological performance (1,3,7).

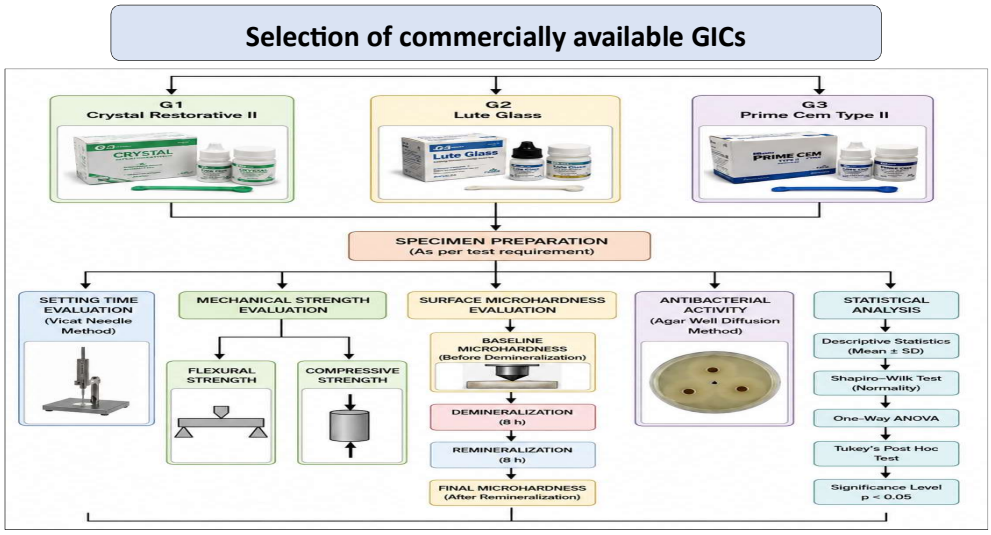
Among the various properties influencing the clinical longevity of GICs restorations, setting time is particularly important because it determines the working characteristics and early maturation of the material. Mechanical properties such as flexural and compressive strengths reflect the ability of the restoration to resist functional masticatory forces and structural failure under clinical conditions. Likewise, surface microhardness is widely considered an indirect indicator of surface mineral integrity and resistance to demineralization. Evaluation of microhardness following demineralization and remineralization provides valuable information regarding the ability to restorative materials to maintain and recover their surface characteristics after exposure to cariogenic conditions. In addition, the intrinsic antibacterial activity of GICs, primarily attributed to fluoride release and the initial acidic environment during setting, paus an important role in suppressing bacterial growth and reducing the risk of recurrent caries at the tooth-restoration interface (8–11).

Several commercially available conventional glass ionomer cements are currently available for clinical use; however, differences in their formulation may result in considerable variations in their physicomechanical and biological performance. Although previous studies have investigated individual properties of these materials, most have focused on isolated parameters such as compressive strength, fluoride release, or antibacterial activity. Comprehensive comparative studies evaluating setting characteristics, flexural strength, compressive strength, surface microhardness following a demineralization-remineralization challenge, and antibacterial activity under standardized experimental conditions remain limited. Such comparative information is clinically valuable, as it enables clinicians to select restorative materials based on an overall assessment of their performance rather than relying on a single property or manufacturers' specifications (7,12–16).

Therefore, the present in vitro study aimed to comparatively evaluate the setting time, flexural strength, compressive strength, surface microhardness following demineralization-remineralization challenge, and antibacterial activity against *Streptococcus mutans* and *Staphylococcus aureus* of three commercially available conventional glass ionomer cements under standardized laboratory conditions.

Fig. 1 Experimental workflow illustrating the comparative evaluation of the commercially available conventional glass ionomer cements.

1.



2. MATERIALS AND METHODS

2.1 Study Design

The present investigation was designed as an in vitro comparative experimental study to evaluate the physicomechanical properties, surface microhardness, and antibacterial activity of three commercially available conventional glass ionomer cements under standardized laboratory conditions as shown in figure 1. The evaluated properties included setting time, flexural strength, compressive strength, surface microhardness following a demineralization-remineralization challenges, and antibacterial activity against *Streptococcus mutans* and *Staphylococcus au*

2.2 Materials

Three commercially available conventional glass ionomer cements were selected based on their routine clinical use and availability in the Indian dental market. The materials evaluated in the present study are listed in **Table 1.**

Table 1. Commercially available conventional glass ionomer cements evaluated in the study

Group	Material	Type	Manufacturer
G1	Crysta Restorative II	Conventional Glass Ionomer Cement	Prevest DenPro Pvt. Ltd., India
G2	Lute Glass	Conventional Glass Ionomer Luting Cement	A-Tech, India
G3	Prime Cem Type II	Conventional Glass Ionomer Cement	Prime Dental Products Pvt. Ltd., India

All materials were handled strictly according to the manufacturers recommended instructions.

2.3 Setting Time Evaluation

The setting time was determined according to ISO 9917-1-2007 for water-based dental cements under standardized laboratory conditions.

Each glass ionomer cement was hand-mixing according to the manufacturer's recommended powder-to-liquid ratio on a clean mixing pad using a plastic spatula until a homogeneous consistency was obtained. Immediately after mixing, the cement was transferred into a split stainless-steel mould and the surface was levelled using a glass slide to obtain a smooth and uniform specimen surface.

The setting time was determined using a Vicat needle apparatus fitted with a (1.0 ± 0.1) mm diameter needle weighing (400 ± 5) g. Timing was initiated from the beginning of mixing. At regular intervals, the Vicat needle was lowered vertically onto the specimen surface at different locations, and the needle was cleaned after each application to prevent residual cement from affecting subsequent measurements.

The setting time was recorded as the elapsed time from the start of mixing until the Vicat needle failed to produce a complete indentation on the cement surface, indicating completion of the initial setting reaction. Five specimens were evaluated for each material (**n = 5**), and the mean setting time was used for statistical analysis.

The experimental setup used for setting time determination is illustrated in Figure 2.

Figure 2. Vicat needle apparatus used for determination of the setting time

2.4 Flexural Strength Evaluation

The flexural strength of the commercially available conventional glass ionomer cements was evaluated using the three-point bending test in accordance with ISO 9917-2-2007 under standardized laboratory conditions.

Bar-shaped specimens measuring 25 mm × 2 mm × 2 mm were prepared using stainless-steel moulds. Each glass ionomer cement was hand-mixed according to the manufacturer's recommended powder-to-liquid ratio and immediately packed into the moulds. A polyester strip followed by a glass slide was placed over the mould to obtain smooth and uniform specimen surfaces. After complete setting, the specimens were carefully removed from the moulds and visually inspected. Specimens exhibiting visible defects such as voids, cracks, or surface irregularities were discarded and replaced.

The specimens were stored in distilled water at 37 ± 1 °C for 24 hours prior to mechanical testing.

Flexural strength was determined using a Universal Testing Machine (UTM) by the three-point bending method. Each specimen was positioned on two supporting rollers with a support span of 20 mm, and a compressive load was applied at the midpoint at a crosshead speed of 1mm/min until fracture occurred. The maximum fracture load (F, N) was recorded automatically by the testing system.

The flexural strength (**σ**, MPa) was calculated using the following equation:

$$\textbf{Flexural Strength (MPa)} = \frac{3PL}{2bd^2}$$

Where:

- **σ** = Flexural strength (MPa)
- **P** = Maximum load at fracture (N)
- **L** = Support span (20 mm)
- **b** = Specimen width (mm)
- **d** = Specimen thickness (mm)

Ten specimens of each material (n =10) were tested, and the mean flexural strength was calculated for statistical analysis. The preparation of standardized specimens and the three-point bending test setup are illustrated in Figure 3.

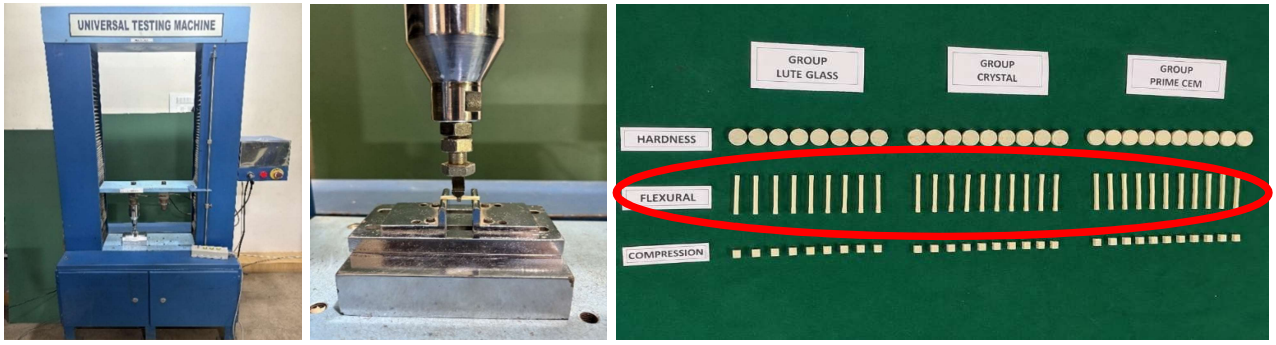


Fig. 3 Flexural strength evaluation. (A) Standardized bar-shaped specimens. (B) Three-point bending test performed using a universal testing machine

2.5 Compressive Strength Evaluation

The compressive strength of the commercially available conventional glass ionomer cements was

evaluated in accordance with ISO 9917-1-2007 for water-based dental cements.

Cylindrical specimens measuring 3 mm in diameter and 6 mm in height were prepared using stainless-steel moulds. The materials were hand-mixed according to the respective manufacturers' instructions and immediately packed into the moulds. A polyester strip followed by a glass slide was placed over the mould surface to obtain smooth and flat specimens. After complete setting, the specimens were carefully removed from the moulds and inspected for visible defects. Specimens exhibiting voids, cracks, or surface irregularities were discarded and replaced. The specimens were stored in distilled water at 37 ± 1 °C for 24 hours prior to mechanical testing. Compressive strength was determined using a Universal Testing Machine (UTM). Each specimen was positioned vertically between the compression platens, and a compressive load was applied along its long axis at a crosshead speed of 1mm/min until fracture occurred.

The maximum fracture load (F, N) was recorded by the universal testing machine.

The compressive strength (**CS**, MPa) was calculated using the following equation:

$$\textbf{Compression strength} = F/\pi\, r^2$$

Where:

- **F** = Load Applied in N
- π = 3.1416
- r^2 = Radius of the specimen

Ten specimens of each material (n = 10) were tested, and the mean compressive strength was calculated for statistical analysis. The compressive strength testing procedure is illustrated in Figure 4.

(A) (B) (C)

Fig. 4 Compressive strength evaluation. (A) Cylindrical specimen, (B) Compression testing, (C) Representative fractured specimen after testing.

2.6 Surface Microhardness Evaluation

Surface microhardness was evaluated using the Vickers microhardness test to determine the resistance of the investigated conventional glass ionomer cements to surface indentation before and after a demineralization-remineralization challenge.

Disc-shaped specimens measuring 15 mm in diameter and 2 mm in thickness were prepared using stainless-steel moulds. The materials were hand-mixed according to the respective manufacturers' instructions and transferred into the moulds. A polyester strip followed by a glass slide was placed over the mould surface to obtain smooth and uniform specimens. After complete setting, the specimens were carefully removed from the moulds.

Baseline surface microhardness was determined using a Vickers Microhardness Tester (Reichert, Austria; Serial No. 363798) equipped with a 136 ° diamond pyramid indenter. A load of 50 g was applied for a dwell time of 15 s. Two indentations were made at different locations on each specimen, and the mean Vickers Hardness Number (VHN) was recorded as the baseline surface microhardness.

Following baseline evaluation, the specimens were immersed in a demineralizing solution for 8 h. The demineralizing solution was prepared using 48.5 mg calcium chloride, 45.5 mg sodium dihydrogen phosphate, and 0.43 mL acetic acid. The pH was adjusted to 4.1-4.5 using sodium dihydrogen, and the final volume was made up to 150 mL with distilled water.

Following demineralization, the specimens were rinsed with distilled water, gently air-dried, and the surface microhardness was re-evaluated under identical testing conditions.

The specimens were subsequently immersed in a remineralizing solution for 8 h. The remineralizing solution was prepared using 48.5 mg calcium chloride, 18.4 mg potassium dihydrogen phosphate, 1.68 mg potassium chloride, 252 mg sodium

bicarbonate, and 0.0075 mg sodium fluoride, and the final volume was adjusted to 150 mL with distilled water. Following remineralization, the specimens were rinsed with distilled water, gently dried, and subjected to a final surface microhardness evaluation using the same testing parameters.

The Vickers Hardness Number (VHN) was calculated using the following equation:

$$(\text{VHM}) = \frac{1.8544F}{d^2}$$

Where:

- **VHN** = Vickers Hardness Number (kgf /mm^2)
- **F** = Applied load (kgf)
- **d** = Mean length of the two indentation diagonals (mm)

Ten specimens of each material (n = 10) were evaluated. The mean Vickers Hardness Number obtained at baseline, after demineralization, and after remineralization was used for statistical analysis. The Vickers microhardness testing procedure is illustrated in Figure 5.

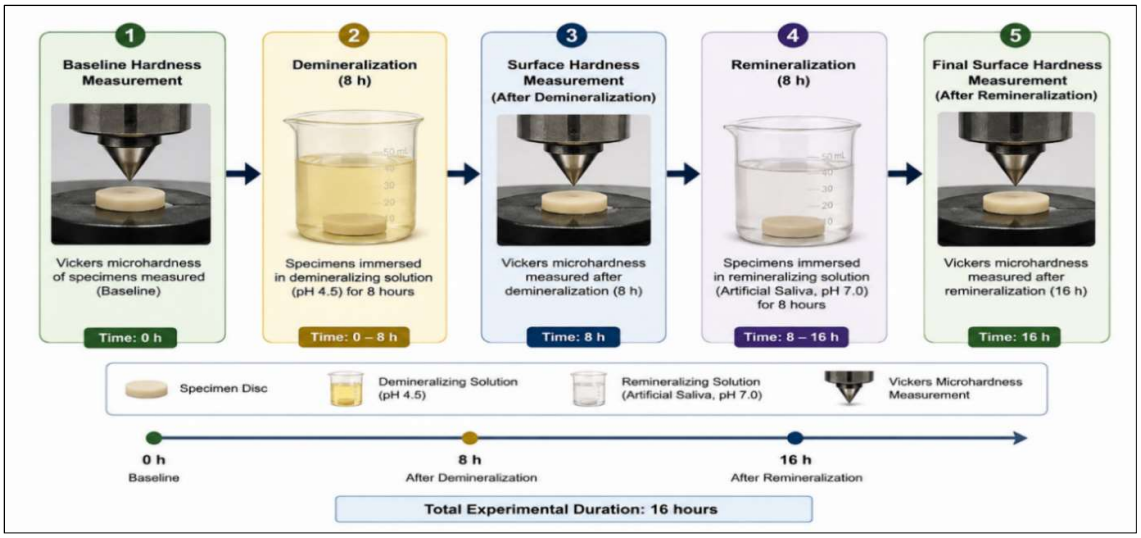


Fig. 5 Schematic representation of the demineralization-remineralization protocol used for surface microhardness evaluation

(A) **(B)**

Fig. 6 Surface microhardness evaluation (A) Prepared disc-shaped specimens (B) Vickers microhardness tester used for hardness measurement

2.7 Antibacterial Activity Evaluation

The antibacterial activity of the commercially available conventional glass ionomer cements was evaluated using the agar well diffusion method against *Streptococcus mutans* and *Staphylococcus aureus* under standardized laboratory condition. The antibacterial efficacy was determined by measuring the zone of inhibition (ZOI) surrounding the test material.

Sterile nutrient agar plates were prepared, and the test microorganisms were uniformly inoculated onto the agar surface using sterile cotton swabs to obtain a confluent bacterial lawn. Wells measuring 6 mm in diameter were aseptically prepared in the inoculated agar plates using a sterile cork borer.

Each glass ionomer cement was hand-mixed according to the respective manufacturer's recommended powder-to-liquid ratio. Immediately after mixing, the freshly prepared cement was transferred into the agar wells before completion of the setting reaction. The inoculated plates were incubated at 37 °C for 24 h.

Following incubation, the antibacterial activity of each material was assessed by measuring the diameter of the zone of inhibition (mm) surrounding each well using a standard antibiotic zone measuring scale. A large zone of inhibition indicated greater antibacterial efficacy.

Antibacterial activity was evaluated separately against *Streptococcus mutans* and *Staphylococcus aureus.* Five independent specimens were evaluated for each material against each microorganism (n = 5), and the mean zone of inhibition was calculated for statistical analysis. The agar well diffusion method used for antibacterial evaluation is illustrated in Figure 7.

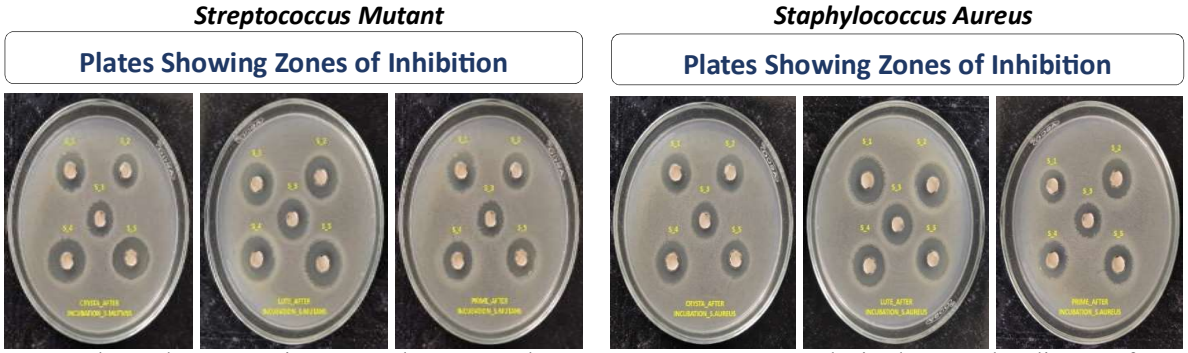


Fig. 7 Agar well diffusion method for antibacterial evaluation showing the experimental setup before incubation and representative inhibition zone produced

2.8 Statistical Analysis

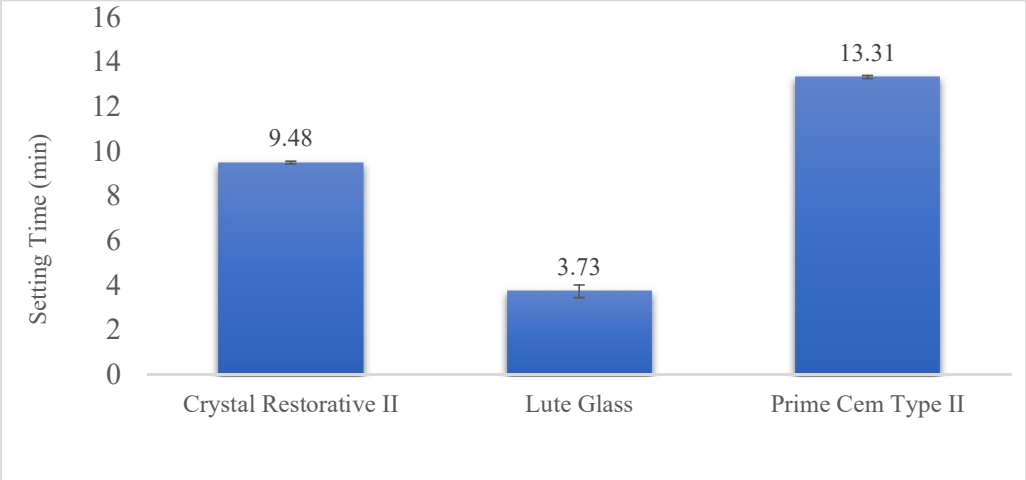
Statistical analysis was performed using Jamovi statistical software (Version 2.3.28). Quantitative data were expressed as mean ± standard deviation (SD). The normality of data distribution was assessed using the Shapiro-Wilk test.

Intergroup comparisons of setting time, flexural strength, and compressive strength among the commercially available conventional glass ionomer cements were performed using one-way analysis of variance (one-way ANOVA). Antibacterial activity was analyzed using two-way analysis of variance (two-way ANOVA), with glass ionomer cement type and bacterial species as fixed factors. Whenever a statistically significant difference was observed, Tukey's post hoc test was performed for pairwise comparisons.

For the surface microhardness evaluation, measurements obtained at baseline, after demineralization, and after remineralization from the same specimens were analyzed using repeated measures analysis of variance (repeated measures

ANOVA). Since Mauchly's test indicated violation of the assumption of sphericity, the Greenhouse-Geisser correction was applied, followed by Bonferroni-adjusted pairwise comparisons, where appropriate.

A p-value < 0.05 was considered statistically significant for all analyses.



3. RESULTS

3.1 Setting Time

The mean setting times of the commercially available conventional glass ionomer cements are presented in Table 2. Among the evaluated materials, Lute Glass demonstrated the shortest mean setting time (3.73 ± 0.28 min), followed by Crysta Restorative II (9.48 ± 0.06 min), whereas Prime Cem Type II exhibited the longest mean setting time (13.31 ± 0.07 min).

The data satisfied the assumption of normality according to the Shapiro-Wilk test (W = 0.957, p = 0.643). As the assumption of homogeneity of variances was violated (Levene's test, p < 0.001), Welch's one-way ANOVA was performed. The analysis demonstrated a statistically significant difference in setting time among the three commercially available conventional glass ionomer cements (Welch's F(2, 7.14) = 5148, p < 0.001).

Pairwise comparisons using the Games-Howell post hoc test revealed statistically significant differences between all study groups (p < 0.001). The means setting time differed significantly between Crysta Restorative II and Lute Glass (mean difference = 5.76 min), Crysta Restorative II and Prime Cem Type II (mean difference = -3.83 min), Lute Glass and Prime Cem Type II (mean difference = -9.58 min).

Table 2. Comparison of mean setting time among commercially available conventional glass ionomer cements

Glass ionomer cement	**Mean ± SD (min)**
Crysta Restorative II	**9.48 ± 0.06**
Lute Glass	**3.73 ± 0.28**
Prime Cem Type II	**13.31 ± 0.07**

Statistical analysis: Welch's one-way ANOVA, **F(2, 7.14) = 5148, p < 0,001.** Games-Howell post hoc analysis demonstrated statistically significant pairwise differences between all study groups **(p < 0.001).** The comparative mean setting times are illustrated in Figure 8.

Fig. 8 Mean setting time of commercially available conventional glass ionomer cements. Data are expressed as mean ± standard deviation (SD)

3.2 Flexural Strength

The mean flexural strengths of the commercially available conventional glass ionomer cements are presented in Table 3. Lute Glass demonstrated the highest mean flexural strength (41.60 ± 3.44 MPa), whereas Prime Cem Type II exhibited the lowest mean flexural strength (25.60 ± 4.15 MPa).

The data satisfied the assumptions of normality according to the Shapiro-Wilk test (W = 0.932, p = 0.054) and homogeneity of variances according to Levene's test (F = 0.688, p = 0.511). Therefore, one-way ANOVA was performed, which demonstrated a statistically significant difference in flexural strength among the study groups (F(2,27) = 31.30, p < 0.001).

Pairwise comparisons using Tukey's post hoc test revealed statistically significant differences between all study groups. Lute Glass exhibited significantly

higher flexural strength than Crysta Restorative II (mean difference = 9.56 MPa, p <0.001) and Prime Cem Type II (mean difference = 16.01 MPa, p < 0.001). Furthermore, Crysta Restorative II demonstrated significantly higher flexural strength than Prime Cem Type II (mean difference = 6.45 MPa, p = 0.010). The comparative flexural strength values are presented graphically in Figure 9.

Table 3. Mean flexural strength of commercially available conventional glass ionomer cements

Glass ionomer cement	**Mean ± SD (MPa)**
Crysta Restorative II	**32.10 ± 5.76**
Lute Glass	**41.60 ± 3.44**
Prime Cem Type II	**25.60 ± 4.15**

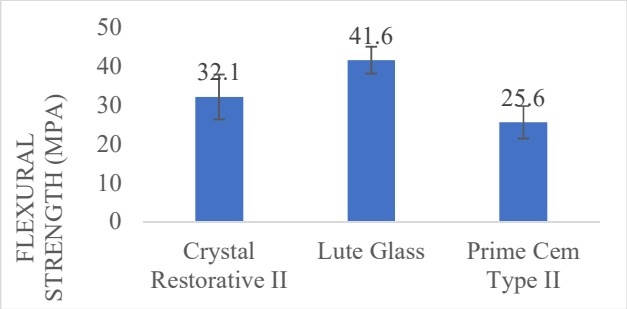


Fig. 9 Mean flexural strength of the commercially available conventional glass ionomer cements

3.3 Compressive Strength

The mean compressive strengths of the commercially available conventional glass ionomer cements are presented in Table 4. Lute Glass demonstrated the highest mean compressive strength (53.30 ± 5.62 MPa), followed by Crysta Restorative II (25.10 ± 4.72 MPa), whereas Prime Cem Type II exhibited the lowest mean compressive strength (22.10 ± 4.89 MPa).

The data satisfied the assumptions of normality according to the Shapiro-Wilk test (W =0.985, p = 0.932). Therefore, one-way ANOVA was performed, which demonstrated a statistically significant difference in compressive strength among the study groups (F (2,27) = 115.00, p < 0.001).

Pairwise comparisons using Tukey's post hoc test revealed that Lute Glass exhibited significantly higher compressive strength than both Crysta Restorative II (mean difference = 28.30 MPa, p < 0.001) and Prime Cem Type II (mean difference =31.28 MPa, p < 0.001). However, no statistically significant difference was observed between Crysta Restorative II and Prime Cem Type II (mean difference = 3.02 MPa, p = 0.392). The comparative compressive strength values are presented in Figure 10.

Table 4. Mean compressive strength of commercially available conventional glass ionomer cements

Glass ionomer cement	**Mean ± SD (MPa)**
Crysta Restorative II	**25.10 ± 4.72**
Lute Glass	**53.30 ± 5.62**
Prime Cem Type II	**22.10 ± 4.89**

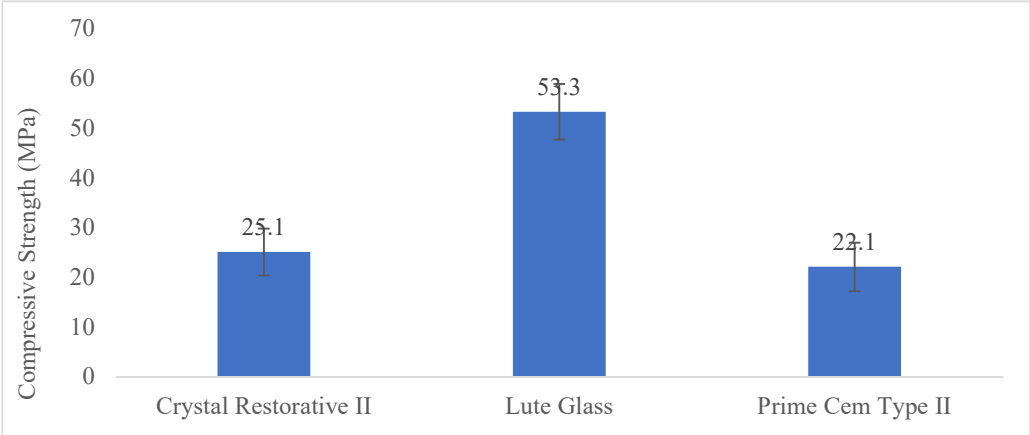


Fig. 10 Mean compressive strength of the commercially available conventional glass ionomer cements

3.4 Surface Microhardness

The mean surface microhardness values of the commercially available conventional glass ionomer cements at baseline, after demineralization, and after remineralization are presented in Table 5. At baseline, Lute Glass demonstrated the highest mean surface microhardness (79.6 ± 3.94 VHN), followed by Prime Cem Type II (71.4 ± 1.66 VHN) and Crysta Restorative II (61.6 ± 2.74 VHN). Following demineralization, all materials exhibited a reduction in surface microhardness, whereas remineralization resulted in a partial recovery of microhardness values in all groups.

The assumptions of normality were satisfied for all study groups at each evaluation stage according to the Shapiro-Wilk test ($p > 0.05$). Mauchly's test indicated a violation of the assumption of sphericity ($W = 0.351$, $p < 0.001$); therefore, Greenhouse-Geisser corrected values were used for the repeated measures analysis. Repeated measures ANOVA demonstrated a significant main effect of stage (Greenhouse-Geisser corrected $F = 1544.4$, $p < 0.001$), indicating significant changes in surface microhardness across the three evaluation stages. A significant stage × group interaction was also observed ($F = 15.0$, $p < 0.001$), demonstrating that the magnitude of microhardness changes differed among the evaluated glass ionomer cements. Furthermore, a significant between-group effect was observed ($F = 359$, $p < 0.001$).

Pairwise comparisons using the Bonferroni correction demonstrated statistically significant differences between baseline and demineralization, baseline and remineralization, and demineralization and remineralization (all $p < 0.001$). Intergroup comparisons also revealed statistically significant differences among Crysta Restorative II, Lute Glass, and Prime Cem Type II ($p < 0.001$).

The changes in surface microhardness following demineralization and remineralization are summarized in Table 6. The mean reduction, percentage reduction, mean recovery, and percentage recovery were calculated to facilitate comparison of the changes in surface microhardness following the demineralization-remineralization cycle without drawing comparative conclusions. The changes in surface microhardness across the three evaluation stages are illustrated in Figure 11.

Table 5. Surface microhardness (VHN) of commercially available conventional glass ionomer cements at baseline, after demineralization, and after remineralization

Glass ionomer cement	Baseline (Mean ± SD)	Demineralization (Mean ± SD)	Remineralization (Mean ± SD)
Crysta Restorative II	61.6 ± 2.74	35.2 ± 0.81	43.0 ± 0.76
Lute Glass	79.6 ± 3.94	53.1 ± 2.20	62.0 ± 1.52
Prime Cem Type II	71.4 ± 1.66	52.2 ± 1.53	56.7 ± 1.95

Table 6. Changes in surface micro hardness following demineralization and remineralization

Material	Baseline → Demineralization		Demineralization → Remineralization	
	Mean Reduction (VHN)	% Reduction from Baseline	Mean Recovery (VHN)	% Recovery

Crysta Restorative II	26.40	42.86 %	7.80	29.55%
Lute Glass	26.50	33.29 %	8.90	33.58%
Prime Cem Type II	19.20	26.89%	4.50	23.44%

- **Mean Reduction (VHN)**
  Mean Reduction = Baseline – Demineralization
- **% Reduction from Baseline:**
  % Reduction = [(Baseline – Demineralization) / Baseline] × 100
- **Mean Recovery (VHN)**
  Mean Recovery = Remineralization – Demineralization
- **% Recovery from Baseline**
  % Recovery = (Remineralization – Demineralization) / (Baseline – Demineralization) × 100

Fig. 11 Surface microhardness of the commercially available conventional glass ionomer cements at baseline, after demineralization, and after remineralization.

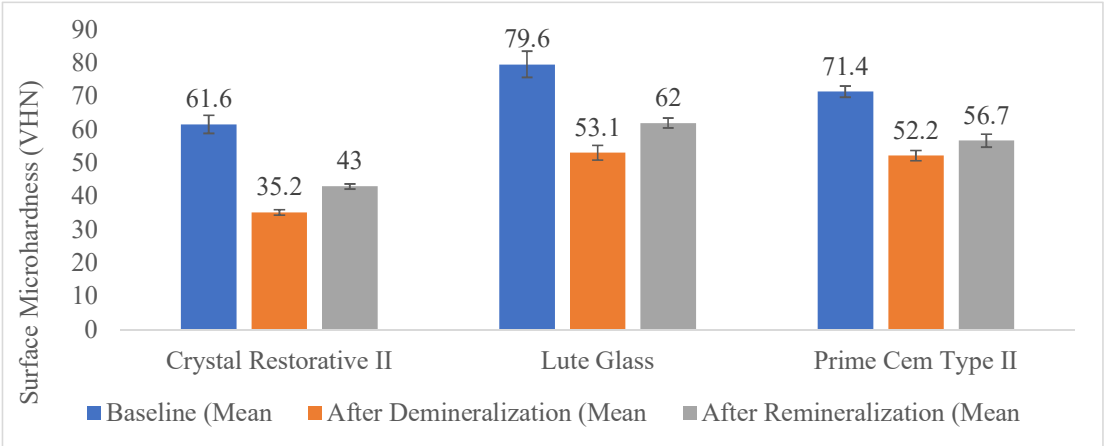
3.5 Antibacterial Activity

The antibacterial activity of the commercially available conventional glass ionomer cements against *Staphylococcus aureus (S. aureus)* and *Streptococcus mutans (S. mutans)* was evaluated by measuring the diameter of the inhibition zone (mm). The descriptive statistics are presented in Table 7. Against *S. aureus,* the mean inhibition zones were 14.3 ± 1.63 mm, 15.5 ± 1.84 mm, and 12.2 ± 0.90 mm, respectively.

The assumptions of normality and homogeneity of variances were satisfied according to the Shapiro-Wilk test (W = 0.982, p = 0.877) and Leven's test (F (5,24) = 1.15, p = 0.360). Therefore, a two-way ANOVA was performed to evaluate the effects of glass ionomer cement type, bacterial species, and their interaction on the inhibition zone. A statistically significant group effect was observed (F (2,24) = 11.397, p < 0.001), whereas neither the bacterial species effect (F (1,24) = 0.840) was statistically significant.

Post hoc analysis using Tukey's multiple comparison test demonstrated statistically significant differences between Crysta Restorative II and Prime Cem Type II (mean difference = 3.14 mm, p < 0.001). However, no statistically significant difference was observed between Crysta Restorative II and Lute Glass (mean difference = 1.43 mm, p = 0.097). Furthermore, no statistically significant difference was observed between *S aureus* and *S. mutans* (mean difference = 0.293 mm, p = 0.590). The mean inhibition zones for both bacterial species are illustrated in Figure 12.

Table 7. Mean inhibition zone (mm) of commercially available conventional glass ionomer cements against *S. aureus* and *S . mutans*



Glass ionomer cement	***S. aureus* (Mean ± SD**	***S. mutans* (Mean ± SD)**
Crysta Restorative II	13.6 ± 0.99	14.3 ± 1.63
Lute Glass	15.2 ± 2.10	15.5 ± 1.84

Prime Cem Type II	12.3 ± 0.87	12.2 ± 0.90

Fig. 12 Mean inhibition zones (mm) of the commercially available conventional glass ionomer cements against ***S. aureus*** and ***S. mutans***

4. DISCUSSION

4.1 Overall Findings

Glass ionomer cements remain among the most widely used restorative materials in contemporary dentistry because of their ability to chemically bond to tooth structure, release fluoride, and promote remineralization. However, considerable variations in their physicomechanical and biological properties have been reported owing to differences in material composition and manufacturing processes. Therefore, the present in vitro study comparatively evaluated the setting time, flexural strength, compressive strength, surface microhardness following a demineralization-remineralization challenges, and antibacterial activity of three commercially available conventional glass ionomer cements under standardized laboratory conditions.

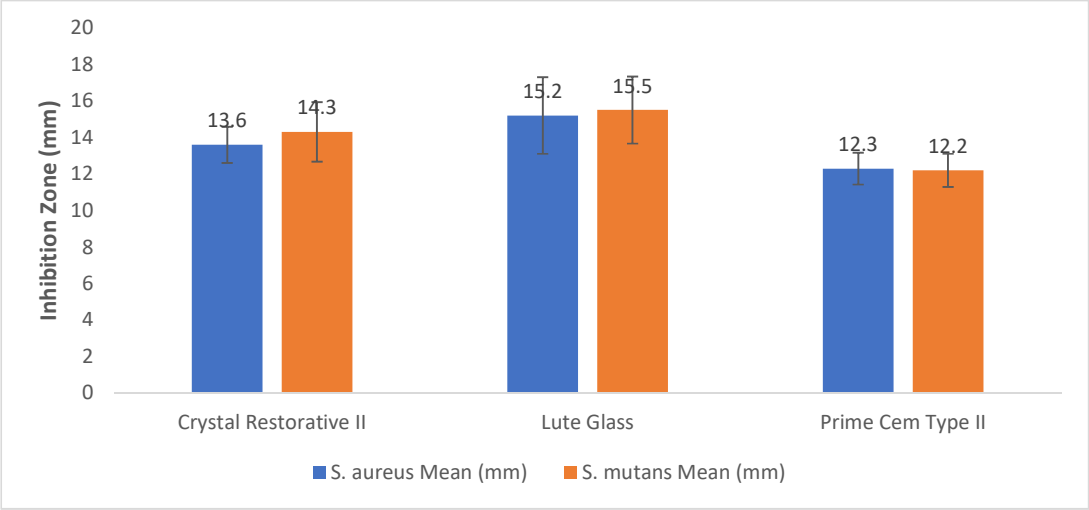
The findings of the present study demonstrate significant differences in the performance of the evaluated materials. **Lute Glass** exhibited the shortest setting time and superior flexural and compressive strengths, indicating favourable handling characteristics and greater resistance to mechanical loading. In contrast, **Prime Cem Type II** demonstrated the longest setting time and comparatively lower mechanical strength. Surface microhardness analysis revealed that all materials underwent a reduction in hardness following demineralization and exhibited partial recovery after remineralization, although the magnitude of these changes differed among the tested glass ionomer cements. Furthermore, all materials demonstrated antibacterial activity against ***Streptococcus mutans*** and ***Staphylococcus aureus,*** with significant differences observed among the tested materials, whereas no significant difference was found between the two bacterial species.

Overall, these findings indicate that the physicomechanical properties, resistance to demineralization, remineralization potential, and antibacterial performance of conventional glass ionomer cements are material-dependent. Such differences are likely attributable to variations in glass particle characteristics, powder-to-liquid ratio, polyacid composition, fluoride-releasing capacity, and setting reaction kinetics. Consequently, careful selection of the restorative material based on its overall performance may contribute to improved clinical longevity and restorative success.

4.2 Setting Time

Setting time is an important clinical property of conventional glass ionomer cements, as it directly influences the working characteristics of material, resistance to early moisture contamination, and the time required before finishing and polishing procedures. An ideal glass ionomer cement should exhibit an adequate working time while achieving a sufficiently rapid setting reaction to minimize the risk of dissolution or surface degradation during the early maturation phase (17,18).

In the present study, significant differences in setting time were observed among the evaluated conventional glass ionomer cements. Lute Glass exhibited the shortest mean setting time, followed by Crysta Restoration II, whereas Prime Cem Type II demonstrated the longest setting time. These findings suggest that the setting characteristics of conventional glass ionomer cements are highly dependent on their formulation and manufacturing process.



The setting reaction of conventional glass ionomer cements is governed by an acid-base reaction between fluoroaluminosilicate glass particles and aqueous polyalkenoic acid. The rate of this reaction is influenced by several factors, including glass particles generally exhibit faster ion release, resulting in accelerated cross-linking of the polyacid matrix and a shorter setting time. Similarly, optimized tartaric acid concentration improves handling characteristics while promoting rapid hardening after placement.

The observed differences among the tested materials may therefore be attributed to variations in their chemical composition, particle size distribution, and proprietary manufacturing processes. These factors influence the kinetics of the acid-base reaction and consequently affect the clinical setting behaviour of the restorative material. A shorter setting time may reduce chairside treatment duration and decrease the susceptibility of the restoration to moisture contamination during the initial setting stage. However, excessively raped setting may increase the risk of early surface dissolution before complete maturation.

The findings of the present study are consistent with previous investigation reporting that commercially available conventional glass ionomer cements exhibit significant variations in setting time because of differences in composition and formulation. Earlier studies have demonstrated that modifications in glass chemistry, polyacid composition, and tartaric acid content significantly influence the setting characteristics and maturation behaviour of conventional glass ionomer cements. These observations support the results of the present study, emphasizing that material composition remains one of the principal determinants of setting performance.

4.3 Flexural Strength

Flexural strength is one of the most important mechanical properties of glass ionomer cements because it reflects the material's ability to resist tensile and compressive stresses simultaneously during functional loading. In clinical practice, restorative materials are frequently subjected to complex multidirectional forces, particularly in stress-bearing areas. Therefore, adequate flexural strength is considered essential for minimizing crack initiation and propagation, thereby improving the longevity of restorations (7,19–21).

In the present study, significant differences in flexural strength were observed among the commercially available conventional glass ionomer cements. Lute Glass demonstrated the highest mean flexural strength, followed by Crysta Restorative II, whereas Prime Cem Type II exhibited the lowest values. These findings indicate that the flexural performance of conventional glass ionomer cements is influenced by differences in their composition and manufacturing characteristics.

The flexural strength of glass ionomer cements depends primarily on the integrity of acid-base reaction matrix, the powder-to-liquid ratio, glass particle characteristics, porosity, and the degree of maturation following setting. A more homogeneous matrix with fewer internal voids facilitates efficient stress distribution throughout the material, thereby reducing stress concentration and delaying crack propagation. In addition, finer and more reactive fluoroaluminosilicate glass particles promote improved ionic cross-linking within the polysalt matrix, contributing to enhanced mechanical performance.

The superior flexural strength observed for Lute Glass may be attributed to a more optimized formulation that promotes efficient matrix formation and improved particle-matrix interaction. Conversely, the comparatively lower flexural strength of Prime Cem Type II may be related to differences in particle characteristics, matrix density, or the presence of microscopic structural defects that reduce resistance to bending stresses. Since the manufacturers do not fully disclose the proprietary composition of these materials, the precise contribution of individual of individual components cannot be determined; however, variations in formulation are likely responsible for the observed differences.

These findings are in agreement with previous studies reporting that commercially available conventional glass ionomer cements exhibit considerable variation in flexural strength owing to differences in glass composition, particle size distribution, powder-to-liquid ratio, and maturation characteristics. Previous investigators have also reported that improvements in matrix homogeneity and reduced internal porosity are associated with enhanced flexural properties and greater resistance to fracture under functional loading.

From a clinical perspective, materials with higher flexural strength may provide improved resistance to fracture in restorations exposed to repeated occlusal loading, particularly in stress-bearing regions. Nevertheless, flexural strength represents only one aspect of clinical performance and should be interpreted together with other physicomechanical and biological properties when selecting an appropriate restorative material.

4.4 Compressive Strength

Compressive strength is critical mechanical property of conventional glass ionomer cements because these restorative materials are predominantly subjected to compressive forces during mastication. Adequate compressive strength enables the material to withstand functional occlusal loads, thereby reducing the risk of bulk fracture and improving the long-term clinical performance of restorations. Consequently, compressive strength is considered one of the primary criteria for evaluating the

suitability of glass ionomer cements for clinical applications, particularly in stress-bearing areas (7,21–23).

In the present study, statistically significant differences in compressive strength were observed among the commercially available conventional glass ionomer cements. Lute Glass demonstrate the highest compressive strength, followed by Crysta Restorative II, whereas Prime Cem Type II exhibited the lowest values. These findings indicate that the compressive behaviour of conventional glass ionomer cements is strongly influenced by differences in their composition and structural characteristics.

The compressive strength of glass particle characteristics, degree of matrix maturation, and the presence of internal porosities or voids. During the setting reaction, calcium and aluminium ions released from the fluoroaluminosilicate glass particles cross-link the polyalkenoic acid chains to form a rigid three-dimensional matrix. A dense and homogeneous matrix with minimal structural defects provides greater resistance to compressive loading by facilitating porosity and incomplete matrix maturation may act as stress concentration sites, thereby reducing compressive strength.

The superior compressive strength observed for Lute Glass may therefore be attributed to a more optimized formulation that promotes efficient ionic cross-linking and improved matrix integrity. In contrast, the comparatively lower values obtained for Prime Cem Type II may reflect differences in material composition, particle size distribution, or matrix density. Since the detailed proprietary formulations of commercially available glass ionomer cements are not publicly disclosed, the exact mechanisms responsible for these differences cannot be conclusively established; however, variations in formulation and manufacturing processes are likely to play a major role.

The findings of the present study are consistent with previous investigations demonstrating significant differences in compressive strength among commercially available glass ionomer cements. Earlier studies have reported that improvements in glass composition, optimized powder-to-liquid ratios, enhanced matrix maturation, and reduced internal porosity contribute to increased compressive strength and improved resistance to occlusal loading. These observations support the present findings and further emphasize the importance of material formulation in determining the mechanical performance of conventional glass ionomer cements.

From a clinical perspective, restorative materials with higher compressive strength may be expected to better withstand functional masticatory forces and exhibit improved durability in posterior restorations. However, compressive strength alone does not determine the overall clinical success of a restorative material and should be interpreted together with other physicomechanical characteristics, fluoride-releasing ability, remineralization potential, and antibacterial properties.

4.5 Surface Microhardness

Surface microhardness is widely regarded as an indicator of the structural integrity, mineral stability, and wear resistance of restorative materials. In glass ionomer cements, changes in surface microhardness reflect alterations in the integrity of the polysalt matrix following exposure to acidic and remineralizing environments. Consequently, evaluation of surface microhardness before and after a demineralization-remineralization challenge provides valuable information regarding the resistance of restorative materials to mineral loss and their ability to recover following exposure to remineralizing conditions (24–27).

In the present study, all evaluated glass ionomer cements exhibited a significant reduction in surface microhardness following demineralization, followed by partial recovery after remineralization. This pattern is consistent with the established behaviour of conventional glass ionomer cements when exposed to cyclic acidic and neutral environments. Acidic conditions promote hydrogen ion diffusion into the cement matrix, resulting in partial dissolution of the polysalt matrix and leaching of calcium, aluminium, fluoride, and other ions from the material. This process weakens the superficial structure of the cement and consequently reduces its resistance to indentation, leading to lower surface microhardness values.

Following immersion in the remineralizing solution, all materials demonstrated an increase in surface microhardness, although none recovered completely to their respective baseline values. This incomplete recovery is expected because demineralization produces irreversible structural alterations within the superficial matrix that cannot be fully restored during a relatively short remineralization period. Nevertheless, the observed increase in hardness suggests that mineral deposition and continued maturation of the glass ionomer matrix partially compensated for the mineral loss induced during the demineralization phase.

The differences observed among the evaluated materials may be attributed to variations in glass composition, fluoride release, particle size distribution, powder-to-liquid ratio, and the rate of acid-base maturation. Glass ionomer cements capable of maintaining a more stable polysalt matrix while releasing sufficient bioactive ions are expected to exhibit greater resistance to demineralization and improved recovery following remineralization. Since the exact proprietary formulations of the investigated materials are not publicly available, the individual contribution of each compositional factor cannot be determined;

however, differences in formulation are likely responsible for the variations observed in the present study.

An important strength of the present investigation is that changes in surface microhardness were evaluated using repeated measurements on the same specimens throughout the demineralization-remineralization cycle. This experimental design minimized inter-specimen variability and enabled a more reliable assessment of changes occurring during the different experimental stages. In addition, the calculation of percentage reduction and percentage recovery provided a quantitative representation of the extent of hardness loss and subsequent recovery, thereby facilitating comparison of the behaviour of the evaluated materials throughout the experimental cycle.

The findings of the present study are consistent with previous investigations reporting significant reductions in the surface microhardness of conventional glass ionomer cements following acidic challenge, with subsequent partial recovery after exposure to remineralizing media or artificial saliva. Earlier studies have attributed this recovery to continued maturation of the cement matrix together with the release and reprecipitation of calcium, phosphate, and fluoride ions, which contribute to partial restoration of the superficial mineral phase. However, most authors have similarly reported that complete recovery to baseline hardness is rarely achieved after a single demineralization-remineralization cycle, particularly when the duration of remineralization is limited.

From a clinical perspective, the ability of glass ionomer cements to retain surface hardness after acidic challenge and subsequently recover part of the lost hardness is of considerable importance. Restorative materials placed in the oral cavity are continuously exposed to repeated episodes of demineralization and remineralization associated with dietary acids, bacterial metabolism, and saliva. Therefore, materials capable of maintaining greater surface integrity under these cyclic conditions may be expected to demonstrate improved wear resistance, surface durability, and long-term clinical performance.

4.6 Antibacterial Activity

The antibacterial activity of restorative materials plays an important role in minimizing bacterial colonization at the tooth-restoration interface and reducing the risk of secondary caries. The antibacterial properties of restorative materials have gained increasing attention because residual microorganisms remaining beneath restorations may contribute to restoration failure and the development of recurrent caries. Unlike restorations materials that merely replace lost tooth structure, conventional glass ionomer cements possess an intrinsic antibacterial effect, primarily because of their fluoride-releasing ability and the transient acidic environment generated during the early stages of the acid-base setting reaction. Consequently, evaluation of antibacterial activity provides valuable information regarding the biological performance of these materials in addition to their mechanical properties (28–31).

In the present study, all three commercially available conventional glass ionomer cements exhibited measurable antibacterial activity against both *Streptococcus mutans* and *Streptococcus aureus,* confirming that conventional glass ionomer cements possess inherent antibacterial properties. The statistically significant differences observed among the evaluated materials indicate the antibacterial performance is influenced by material composition and formulation. In contrast, no statistically significance difference was observed between the two bacterial species, suggesting that the antibacterial effect of the investigated materials was generally consistent against both microorganisms under the experimental conditions employed.

The antibacterial activity of conventional glass ionomer cements has been primarily attributed to fluoride ion release, which interferes with bacterial metabolism by inhibiting several intracellular enzymatic pathways, reducing acid production, and suppressing bacterial growth. Fluoride ions have also been reported to inhibit bacterial glycolysis by interfering with enzymes such as **enolase**, thereby reducing acid production and impairing bacterial metabolism. During the initial setting reaction, the temporary acidic pH created by the acid-base reaction may further contribute to bacterial inhibition. In addition to fluoride release, the diffusion of other ions released from the fluoroaluminosilicate glass particles may also influence the antibacterial behaviour of the material. The overall antibacterial effect therefore represents the combined influence of material composition, ion release kinetics, and the maturation characteristics of the cement.

The differences observed among the investigated materials are likely related to variations in fluoride release, glass particle composition, powder-to-liquid ratio, and matrix permeability, all of which may influence the diffusion of antibacterial ions into the surrounding medium. Because the detailed formulations of commercially available glass ionomer cements are proprietary, the precise contribution of individual components cannot be established. Nevertheless, the present findings support the concept that formulation-dependent differences play an important role in determining the antibacterial performance of conventional glass ionomer cements.

The findings of the present study are in agreement with previous investigations demonstrating that conventional glass ionomer cements exhibit measurable antibacterial activity against cariogenic

microorganisms, particularly *Streptococcus mutans.* Earlier studies have also reported antibacterial effects against other Gram-positive bacteria, including *Staphylococcus aureus,* although the magnitude of inhibition varies among commercially available products because of differences in fluoride release and material composition. However, variations in antibacterial efficacy reported in the literature may also be influenced by differences in experimental methodology, including the agar well diffusion technique, specimen dimensions, storage conditions, incubation period, and the diffusion characteristics of antibacterial ions within the agar medium. These observations are consistent with findings of the present study, which demonstrated significant differences among the evaluated materials while showing no statistically significant difference in the overall response of the two tested bacterial species.

From a clinical perspective, the intrinsic antibacterial activity of conventional glass ionomer cements may contribute to suppression of residual microorganisms remaining after cavity preparation and may assist in reducing bacterial recolonization adjacent to the restoration. Although antibacterial activity alone cannot prevent the development of recurrent caries, it represents an additional biological advantage when considered together with fluoride release, chemical adhesion to tooth structure, and remineralization potential. Therefore, the selection of a restorative material should be based on a comprehensive evaluation of its mechanical, physicochemical, and biological properties rather than antibacterial activity alone.

4.7 Clinical Implications

The findings of the present study have important clinical implications for the selection of conventional glass ionomer cements in restorative dentistry. Since no single material property is sufficient to predict the overall, clinical performance of a restorative material, clinicians should consider a combination of physicomechanical and biological characteristics during material selection. Properties such as setting time, flexural strength, compressive strength, surface microhardness, remineralization potential, and antibacterial activity collectively influence the clinical longevity and functional success of restorations.

The observed differences among the evaluated materials indicate that commercially available conventional glass ionomer cements cannot be considered interchangeable despite belonging to the same material category. Variations in formulation, glass composition, and setting characteristics may influence their performance under clinical conditions. Consequently, material selection should be based on the specific clinical requirements of each case, including the location of the restoration, anticipated occlusal loading, caries risk of the patient, and the need for fluoride release and antibacterial activity.

Although the present investigation was conducted under standardized laboratory conditions, the findings provide valuable baseline information regarding the comparative performance of commercially available conventional glass ionomer cements. Such information may assist clinicians in selecting restorative materials that offer an appropriate balance between mechanical performance and biological properties for different clinical situations.

4.8 Strengths, Limitations, and Future Directions

The present study possesses several strengths. All materials were evaluated under standardized experimental conditions using identical specimen dimensions, testing protocols, and environmental conditions. Mechanical, surface, and biological properties were assessed using internationally accepted methodologies, thereby enabling a comprehensive comparison of the investigated conventional glass ionomer cements. Furthermore, repeated measures analysis was employed for surface microhardness evaluation, allowing assessment of changes within the same specimens during the demineralization-remineralization cycle and minimizing inter-specimen variability.

Despite these strengths, certain limitations should be acknowledged. As an **in vitro** investigation, the experimental conditions cannot completely replicate the complex oral environment, where factors such as salivary composition, pH fluctuations, masticatory loading, thermal cycling, biofilm formation, and patient-related variables may influence the long-term clinical performance of restorative materials.

In addition, only three commercially available conventional glass ionomer cements were evaluated, and the observation period was limited to the experimental conditions of the present study. Therefore, the findings should be interpreted within the limitations of the study design.

Future investigation should include long-term aging protocols, thermal cycling, wear evaluation, fluoride release kinetics, bond strength assessment, and biofilm-based antibacterial models to better simulate clinical conditions. Furthermore, randomized clinical trials and long-term clinical follow-up studies are required to validate the laboratory findings and establish the clinical performance of conventional glass ionomer cements under intraoral conditions.

5. CONCLUSION

Within the limitations of this in vitro study, statistically significant differences were observed among the three commercially available conventional glass ionomer cements with respect to their physicomechanical properties, surface microhardness, and antibacterial activity. The

evaluated materials exhibited variable performance in terms of setting time, flexural strength, compressive strength, resistance to demineralization, recovery following remineralization, and antibacterial efficacy, demonstrating that the overall behaviour of conventional glass ionomer cements is highly dependent on their material composition and formulation.

The findings further indicate that commercially available conventional glass ionomer cements cannot be considered clinically equivalent despite belonging to the same materials category. Differences in composition, setting characteristics, and matrix maturation may substantially influence their mechanical performance, resistance to acidic challenge, remineralization behaviour, and biological properties. Therefore, the selection of a conventional glass ionomer cement should be based on a comprehensive evaluation of its physicomechanical and biological characteristics rather than on a single material property.

The present investigation provides comparative baseline data regarding the performance of three commercially available conventional glass ionomer cements under standardized laboratory conditions. These findings may assist clinicians in selecting restorative materials according to specific clinical requirements while also serving as a reference for future investigations involving newly developed or modified glass ionomer formulations. Nevertheless, further long-term in vitro studies and well-designed clinical trials are required to validate the present findings under conditions that more closely simulated the oral environment.

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- Investigation
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- Supervision
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