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Article

A Calcium Chloride Gel as a Chemocatalytic Surface Treatment for Conventional Glass Ionomer Cement: Effects on Water Sorption and Solubility

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ABSTRACT

Objectives: This in vitro study aimed to evaluate a newly formulated calcium chloride ($CaCl_2$) gel as a chemocatalytic surface treatment for conventional glass ionomer cement (GIC) and to compare its effect on water sorption and solubility with that of a $CaCl_2$ solution and of radiant heat treatment using LED and Plasma Arc light curing units. **Methods:** Fifty GIC specimens (GC Fuji IX GP® FAST) were fabricated using a split Teflon mold (6 mm diameter, 2 mm thickness) and randomly assigned to five groups (n=10): Group 1 (Control, no treatment); Group 2 (LED, 1000 mW/cm², 40 s); Group 3 ($CaCl_2$ solution, 42.7 wt%, 2 min); Group 4 ($CaCl_2$ gel, 2 min); and Group 5 (Plasma Arc, 1975–2320 mW/cm², 10 s). Water sorption (WSP) and solubility (WSL) were assessed at baseline (24-h immersion in distilled water) and after a 14-day pH cycling protocol in 5% acetic acid (pH 3.0). Statistical analysis used the Kruskal–Wallis test with Steel–Dwass pairwise comparisons and Wilcoxon signed-rank test ($\alpha = 0.05$). **Results:** At baseline, all four treatments produced significantly lower WSL than the control group, whereas WSP was significantly reduced by $CaCl_2$ gel, $CaCl_2$ solution and Plasma Arc but not by LED. Plasma Arc produced the lowest WSP values at baseline (25.4 ± 17.7 μg/mm³) and after pH cycling (25.7 ± 17.4 μg/mm³), significantly lower than all other groups. $CaCl_2$ gel and solution did not differ significantly from each other in WSP or WSL at either time point. After pH cycling, the control group showed significant increases in WSP ($p = 0.005$) and WSL ($p < 0.001$), and the $CaCl_2$ solution group showed a significant increase in WSL ($p = 0.002$); no significant within-group change was detected in the LED, $CaCl_2$ gel or Plasma Arc groups. **Conclusions:** Within the limitations of this in vitro study, Plasma Arc irradiation and $CaCl_2$ surface treatment (in either solution or gel form) reduced the water sorption and solubility of the tested conventional GIC, whereas LED irradiation significantly reduced solubility but not sorption. The newly developed $CaCl_2$ gel performed comparably to the conventional $CaCl_2$ solution. Unlike the solution, it did not show a statistically significant increase in solubility after pH cycling, although the post-cycling values of the two forms did not differ significantly. The gel may therefore be a practical vehicle for $CaCl_2$ surface treatment, but its clinical relevance requires confirmation in further laboratory and clinical studies.

Keywords: glass ionomer cement; water sorption; solubility; LED curing; plasma arc; calcium chloride; pH cycling; setting enhancement

1. Introduction

Glass ionomer cements (GICs) occupy a unique position in restorative dentistry, combining several advantageous properties including chemical adhesion to tooth tissues, fluoride ion release with recharging ability, good biocompatibility, and a coefficient of thermal expansion comparable to dentin [1,2]. These attributes make GICs clinically attractive for the management of early carious lesions, non-stress-bearing restorations, and atraumatic restorative treatment (ART) [3–6].

Despite decades of development, conventional GICs continue to exhibit inferior mechanical and physical properties compared to resin-based restorative materials, which limits their application in posterior stress-bearing areas [7]. Among the most critical limitations are their relatively high water sorption (WSP) and solubility (WSL). These properties are fundamentally linked to the composition and kinetics of the acid-base setting reaction between the polyalkenoic acid liquid and the alumina-silicate glass powder [8,9].

Water sorption compromises the structural integrity of GIC restorations by initiating degradation, swelling, and lamination of the cement matrix [9,10]. Solubility, defined as the dissolution of the material in a solvent, leads to mass loss, marginal microleakage, and eventual restoration failure, predisposing teeth to recurrent caries [8]. Early moisture contamination during the initial stages of setting is particularly detrimental, resulting in a soft, porous surface susceptible to cracking and reduced fracture toughness [11,12].

Several strategies have been investigated to enhance and accelerate the GIC setting reaction, thereby improving its physical properties. Thermocatalytic methods exploit the delivery of radiant heat to catalyze ion mobility and accelerate cross-linking during setting. Dionysopoulos et al. demonstrated that radiant heat using LED and blue diode laser (445 nm) units significantly reduced WSP and WSL of conventional GICs [13,14]. Plasma arc light curing units, which operate at substantially higher irradiances (1975–2320 mW/cm^2) compared to LED units (~1000 mW/cm^2), have been proposed as a more efficient source of radiant heat [15,16], yet their specific effects on conventional GIC properties remain poorly characterized.

Chemocatalytic approaches utilizing calcium chloride ($CaCl_2$) solution have also demonstrated efficacy in enhancing GIC properties. The mechanism involves augmentation of the acid-base setting reaction through the supply of Ca^{2+} ions that cross-link the carboxylate groups of polyalkenoic acids, thereby reducing surface porosity, hydrophilicity, WSP, and WSL [17,18]. However, to our knowledge, $CaCl_2$ has so far been studied only in solution form, which presents practical challenges for clinical application. Dionysopoulos et al. recommended investigating a gel formulation as a more user-friendly alternative [17].

To the best of our knowledge, no previous study has investigated a calcium chloride gel formulation for enhancing the setting reaction and resistance to water degradation of conventional glass ionomer cement. Therefore, the present study evaluated a newly developed $CaCl_2$ gel and compared its performance with established thermocatalytic (LED and Plasma Arc) and chemocatalytic ($CaCl_2$ solution) approaches under simulated oral aging conditions. The null hypothesis tested was that no significant difference would exist in WSP or WSL between untreated GIC and any of the four treatment modalities.

2. Materials and Methods

2.1. Ethical Approval

This study was approved by the Research Ethics Committee of the Faculty of Oral and Dental Medicine, Misr International University (IRB No. MIU-IRB-2122-148). All procedures were conducted in accordance with relevant institutional guidelines.

2.2. Sample Size Calculation

Sample size was calculated based on data from a previous study [19], with a mean ± SD of 1.62 ± 0.73, an estimated mean difference of 1.0, statistical power of 0.8, and a Type I error rate of 0.05 (G*Power v3.1.9.2). A minimum of 9 specimens per group was required; 10 specimens per group were used (total n = 50).

2.3. Specimen Preparation

Fifty disc-shaped specimens were fabricated from conventional GIC (GC Fuji IX GP® FAST, GC Corp., Tokyo, Japan; Lot: 2111241) using a split Teflon mold (6 mm diameter, 2 mm thickness) [14,17]. Capsules were triturated using an amalgamator (IMIX-M3, Macao, China) for 10 s at high speed per manufacturer instructions. The material was loaded and injected into the mold, sandwiched between two polyester matrix strips (TOR-VM, 0.05 mm) and glass slabs to ensure standardized surface finish and excess removal. After setting, specimens were demoulded and trimmed with a surgical blade. Each specimen was examined under an optical microscope (10×) to exclude specimens containing air bubbles or cracks [17].



Figure 1. Teflon Mold.

2.4. Experimental Groups and Treatments

The 50 specimens were randomly allocated to five groups (n = 10 per group):

- Group 1 (Control): Specimens were allowed to set without any surface treatment.
- Group 2 (LED): After 2 min of setting, specimens were irradiated for 40 s using a cordless LED curing unit (Woodpecker, 1000 mW/cm², wavelength 420–480 nm), verified with a radiometer (Woodpecker LM-1).
- Group 3 ($CaCl_2$ Solution): A freshly prepared 42.7 wt% $CaCl_2$ solution was applied to the specimen surface for 2 min, then rinsed with 5 mL deionized water.
- Group 4 ($CaCl_2$ Gel): A novel $CaCl_2$ gel formulation (Carbopol 940 polymer 0.4% w/v, gelatin 5 g/100 mL, 21.35 g anhydrous $CaCl_2$/100 mL, sodium benzoate 15 mg/100 mL; prepared at the Inorganic Chemistry Laboratory, Faculty of Science, Suez Canal University) was applied to the specimen surface for 2 min, then rinsed with 5 mL deionized water. It should be noted that the $CaCl_2$ content of the gel (21.35 g/100 mL) was lower than that of the 42.7 wt% solution used in Group 3.
- Group 5 (Plasma Arc): After 2 min of setting, specimens were irradiated for 10 s using a Plasma Arc curing unit (Sapphire® Plus; wavelength 400–500 nm, irradiance 1975–2320 mW/cm²).

All specimens were stored in sealed plastic containers for 24 h to allow completion of the primary GIC setting reaction [17].

Table 1. Materials composition, manufacturer, and lot number.

No.	*Materials*	*Composition*	*Manufacturer*	*Lot Number*
1	**Fuji IX GP FAST**	**Powder:** 90-100% fluoroaluminosilicate glass, 5-10% polyacrylic acid	GC, Tokyo, Japan	2111241

		liquid: 30-40% polyacrylic acid, polycarboxylic acid, 40% distilled water.		
2	**Calcium Chloride Solution**	42.7 weight % $CaCl_2$ (chemically prepared)	Inorganic chemistry lab, Faculty of Science, Suez Canal University, Cairo, Egypt	
3	**Calcium Chloride gel**	- 200mg (0.4%) of Carbopol 940 polymer. - 5 g of gelatin powder. - 100 ml distilled water. - 21.35 g of anhydrous $CaCl_2$. - sodium benzoate.	Inorganic chemistry lab, Faculty of Science, Suez Canal University, Cairo, Egypt	
4	**Acetic Acid**	5% concentration of Acetic Acid with pH 3.0	HIMEDIA Laboratories company	RM/065/16



Figure 2. Sapphire® Plus Plasma Arc Light Cure

2.5. Water Sorption and Solubility Assessment

Specimens were weighed to four decimal places using a precision electronic balance (Sartorius, Germany; readability 0.1 mg). The initial dry weight was recorded as W_1. Each specimen was immersed in 10 mL distilled water at 37 ± 1°C in individual sealed containers for 24 h, blot-dried, waved in air for 15 s, and weighed within 1 min (W_2). Specimens were then transferred to a desiccator containing dehydrated silica gel at 37 ± 1°C until a constant mass was achieved (W_3). Specimen volume (V) was calculated as $V = \pi r^2 h$ ($V = 56.52\ mm^3$). WSP and WSL were calculated as [13,14,17]: WSP ($\mu g/mm^3$) = $(W_2 - W_3) / V$ WSL ($\mu g/mm^3$) = $(W_1 - W_3) / V$



Figure 3. Electronic Balance with four digits precision.



Figure 4. Incubated samples in glass containing dehydrated silica gel.

2.6. pH Cycling Protocol

To simulate the oral environment and assess material durability, a pH cycling protocol was applied. Specimens were exposed to 5% acetic acid solution (pH 3.0; HIMEDIA Laboratories) twice daily for 10 min over 14 days (at 10:00 am and 6:00 pm), stored in distilled water at 37°C between cycles [20,21]. After 14 days, post-pH cycling weights were obtained (W_4 wet; W_5 after re-desiccation) and WSP and WSL recalculated: $WSP_p{}^T$ ($\mu g/mm^3$) = ($W_4 - W_5$) / V $WSL_p{}^T$ ($\mu g/mm^3$) = ($W_1 - W_5$) / V



Figure 5. Waterproof pH Meter and Temperature Tester.



Figure 6. Mean pH of Acetic Acid was 3.0.

2.7. Statistical Analysis

Data were presented as mean ± standard deviation (SD), median, and minimum–maximum values. Negative solubility values, which indicate a net mass gain relative to the initial dry mass, were retained in the analysis as recorded. Normality was assessed using the Kolmogorov–Smirnov test. As data were not normally distributed, the Kruskal–Wallis test was used for intergroup comparisons, followed by Steel–Dwass pairwise post-hoc tests. The Wilcoxon signed-rank test was used for within-group comparisons between baseline and post-pH cycling values. The significance level was set at $p \leq 0.05$. Statistical analysis was conducted using IBM SPSS Statistics v26.0 (IBM Corp., Armonk, NY, USA).

3. Results

3.1. Water Sorption

At baseline, a statistically significant difference in WSP was observed across all five groups ($p < 0.001$). The control group exhibited the highest mean WSP (83.2 ± 4.0 μg/mm³), significantly greater than the $CaCl_2$ gel, $CaCl_2$ solution, and Plasma Arc groups ($p < 0.05$). The difference with the LED group was not statistically significant. Plasma Arc produced the lowest mean WSP (25.4 ± 17.7 μg/mm³), significantly lower than all other groups. No significant difference was observed between $CaCl_2$ solution and $CaCl_2$ gel groups.

After pH cycling, the control group showed a significant increase in WSP ($p = 0.005$), whereas no significant change from baseline was detected in any of the treated groups (Table 2, Figure 7). After pH cycling, the intergroup pattern was unchanged: Plasma Arc remained significantly lower than all other groups, $CaCl_2$ gel and $CaCl_2$ solution remained significantly lower than the control, and LED did not differ significantly from the control.

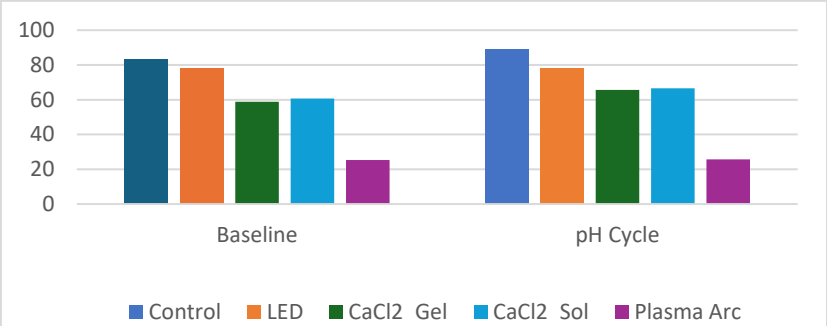


Figure 7. Bar chart showing the mean Water Sorption Values for different tested group.

3.2. Water Solubility

At baseline, the control group showed significantly higher WSL (30.0 ± 6.8 μg/mm³) compared to all treated groups ($p < 0.0001$). Plasma Arc yielded the lowest values (4.4 ± 1.2 μg/mm³), with no significant difference between $CaCl_2$ solution, $CaCl_2$ gel, and Plasma Arc groups at baseline. LED treatment produced a significantly lower WSL than the control but significantly higher WSL than the $CaCl_2$ solution and Plasma Arc groups (Table 3, Figure 8).

After pH cycling, the control group exhibited significantly higher WSL than all treated groups ($p < 0.0001$), and Plasma Arc maintained the lowest values, significantly lower than all other groups; the LED, $CaCl_2$ gel and $CaCl_2$ solution groups did not differ significantly from each other. Significant increases in WSL after pH cycling were observed only in the control group ($p < 0.001$) and the $CaCl_2$ solution group ($p = 0.002$), whereas the increases in the LED, $CaCl_2$ gel ($p = 0.083$) and Plasma Arc groups were not statistically significant (Table 3, Figure 8).

Table 2. Mean, SD, and median water sorption values (μg/mm³) at baseline and after pH cycling.

p-value*	Min–Max	Median	Post-pH Mean±SD	Min–Max	Median	Baseline Mean±SD	Group
0.005*	65.5–100.8	92.0	88.9±11.8[a]	76.1–90.2	83.2	83.2±4.0[a]	Control
0.744 NS	40.7–107.9	86.7	78.0±23.7[ab]	60.2–118.5	76.1	77.8±17.6[ab]	LED
0.256 NS	44.2–86.7	63.7	65.6±13.6[b]	38.9–72.5	61.9	58.8±12.4[b]	$CaCl_2$ Gel
0.436 NS	53.1–90.2	61.9	66.5±11.5[b]	35.4–88.5	61.9	60.7±17.2[b]	$CaCl_2$ Sol.
0.902 NS	10.6–56.6	17.7	25.7±17.4[c]	8.8–56.6	17.7	25.4±17.7[c]	Plasma Arc

*Different superscript letters indicate significant difference between groups. *p-value for Wilcoxon signed-rank test (baseline* vs. *post-pH cycling). NS = not significant.*

Table 3. Mean, SD, and median water solubility values (μg/mm³) at baseline and after pH cycling.

p-value*	Min–Max	Median	Post-pH Mean±SD	Min–Max	Median	Baseline Mean±SD	Group
<0.001*	40.7–72.5	60.2	55.4±11.0[a]	17.7–42.5	30.1	30.0±6.8[a]	Control
0.285 NS	5.3–51.3	24.8	28.9±15.3[b]	10.6–31.8	23.0	21.8±6.0[b]	LED
0.083 NS	8.8–37.2	24.8	23.0±10.4[b]	−3.5–33.6	13.3	14.0±12.1[bc]	$CaCl_2$ Gel
0.002*	3.5–51.3	24.8	26.5±14.8[b]	0.0–28.3	7.1	11.0±9.3[c]	$CaCl_2$ Sol.
0.880 NS	−5.3–37.2	3.5	5.9±9.1[c]	3.5–7.1	3.5	4.4±1.2[c]	Plasma Arc

*Different superscript letters indicate significant difference between groups. *p-value for Wilcoxon signed-rank test (baseline* vs. *post-pH cycling). NS = not significant. Negative solubility values indicate a net mass gain relative to the initial dry mass (W_3 or $W_5 > W_1$).*

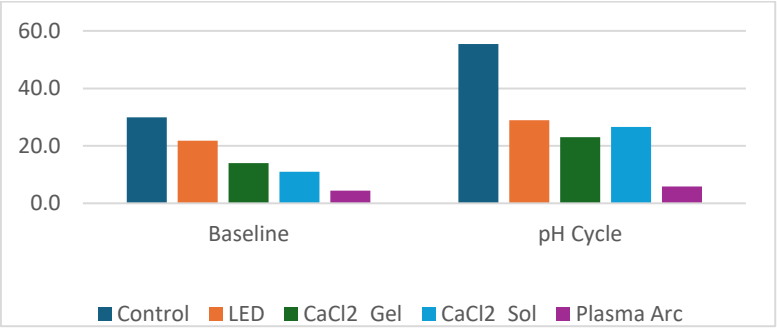


Figure 8. Bar chart showing the mean Water Solubility Values for different tested groups.

4. Discussion

The principal novelty of the present study lies in the development and evaluation of a calcium chloride gel formulation as a chemocatalytic enhancer for conventional glass ionomer cement. Previous investigations have focused exclusively on calcium chloride solutions, which are clinically less convenient because of their low viscosity and limited surface retention. By incorporating calcium chloride into a gel formulation, prolonged contact between the material and the cement surface may be achieved, potentially enhancing ion diffusion during the early stages of the acid-base reaction while simplifying clinical application. To the best of our knowledge, this is the first study to evaluate this approach experimentally.

The present study evaluated the influence of four GIC surface treatment modalities—LED light curing, Plasma Arc light curing, $CaCl_2$ solution, and $CaCl_2$ gel—on WSP and WSL at baseline and after pH cycling. The null hypothesis was therefore partially rejected: all four treatments significantly reduced WSL compared with the untreated control, and $CaCl_2$ gel, $CaCl_2$ solution and Plasma Arc also significantly reduced WSP, whereas the WSP reduction produced by LED was not statistically significant.

The setting reaction of GIC proceeds in two stages. The initial (3–5 min) stage involves calcium polyacrylate cross-linking, while the later stage (24–48 h) involves aluminum polyacrylate cross-links, which are more hydrolytically stable [21]. Incomplete maturation of these cross-links results in a porous, water-permeable cement surface, rendering the material susceptible to WSP and WSL. All four treatment modalities targeted acceleration of this setting reaction through either thermocatalytic or chemocatalytic mechanisms, consistent with the literature [13,14,17,18].

Plasma Arc yielded the lowest WSP and WSL values among all groups (although its baseline WSL did not differ significantly from that of the $CaCl_2$ groups), a finding

consistent with its high irradiance output (1975–2320 mW/cm²), which substantially exceeds that of LED units. Plasma arc systems generate their operating light spectrum by passing high-voltage current through electrodes to produce a continuous spectrum, which is filtered to a band around 470 nm. Plasma arc units have been reported to produce greater temperature rises than LED systems, which rely on doped semiconductor junctions that emit light with lower heat output [15,16]. A greater thermocatalytic effect of the Plasma Arc may have increased ion mobility and accelerated polyacrylate cross-linking to a greater extent than LED, producing a denser, less porous cement surface. However, surface temperature was not measured in the present study, and the radiant exposure delivered by the Plasma Arc (approximately 20–23 J/cm² over 10 s) was lower than that delivered by the LED unit (approximately 40 J/cm² over 40 s). The superior performance of the Plasma Arc therefore cannot be explained by the total energy delivered alone; differences in irradiance, emission spectrum and heat generation between the two units may be involved, and this explanation remains to be verified by direct temperature measurement. Notably, the effect was maintained after the 14-day pH cycling protocol, suggesting resistance of the treated surface to the acidic challenge applied in this study. These findings differ from those of Sfondrini et al. [22], who did not report an advantage for plasma arc curing; however, that study assessed the shear bond strength of a resin-modified GIC, which differs in both the property evaluated and the setting chemistry from the conventional GIC used here.

LED treatment reduced WSP and WSL compared to the control, though the WSP reduction did not reach statistical significance. This may reflect the lower irradiance of the unit employed, which produced less thermal energy at the cement surface. Prior studies by Dionysopoulos et al. using higher-irradiance LED and diode laser units reported statistically significant reductions in WSP [13,14], which may suggest that the thermocatalytic effect depends on the irradiance and heat output of the curing unit; this could not be verified here because temperature was not measured.

$CaCl_2$ solution and gel treatments produced comparable reductions in WSP and WSL, with no significant difference between the two forms either at baseline or after pH cycling. From a practical perspective, a gel vehicle may offer advantages over a solution because its higher viscosity is expected to improve retention on the glass ionomer cement surface during the early stages of the setting reaction and to facilitate chairside application. In the present study, the gel produced improvements in water sorption and solubility comparable to those of the solution, despite its lower $CaCl_2$ content. However, the viscosity, surface retention, handling and storage stability of the gel were not measured, so these potential clinical advantages remain to be demonstrated. Long-term laboratory and clinical studies are required before the gel can be recommended for clinical use.

The mechanism involves the provision of exogenous Ca^{2+} ions that augment the acid-base setting reaction by cross-linking the free carboxylate groups of polyalkenoic acids, reducing surface porosity and hydrophilicity [17,18]. A difference was also observed in the within-group response to pH cycling: $CaCl_2$ solution exhibited a significant increase in WSL after pH cycling ($p = 0.002$), whereas the increase in the $CaCl_2$ gel group did not reach statistical significance ($p = 0.083$). This observation should be interpreted with caution. The absence of a significant within-group change does not demonstrate equivalence or superiority; the gel group also showed a numerical increase in mean WSL (from 14.0 to 23.0 μg/mm³); the post-pH cycling WSL values of the gel and solution groups did not differ significantly; and with ten specimens per group, the study may have been underpowered to detect smaller changes. One possible, but speculative, explanation is that the gel vehicle maintained more prolonged contact with the GIC surface and thereby promoted a more acid-resistant surface layer; surface characterization (e.g., SEM/EDX or FTIR analysis) would be required to test this. To the best of our knowledge, this is the first study

to evaluate experimentally a $CaCl_2$ gel formulation, which had been proposed by Dionysopoulos et al. [17].

No significant change in WSP was observed between baseline and post-pH cycling for any treated group, whereas the control showed significant increases in both WSP and WSL. These findings suggest that the treatments improved the resistance of the cement to the acidic challenge used in this study. However, the $CaCl_2$ solution group showed a significant increase in WSL, and the 14-day protocol represents only a short-term simulation; whether these effects translate into improved clinical durability cannot be determined from the present data.

This study has several limitations. First, as an in vitro study, it cannot reproduce the oral environment, including saliva, pellicle formation, thermal fluctuations, masticatory loading and biofilm challenge. Second, only one conventional GIC (Fuji IX GP FAST), one specimen geometry and a single aging protocol were tested, so the results may not apply to other GIC formulations or clinical cavity configurations. Third, the pH cycling protocol consisted of 5% acetic acid (pH 3.0) alternated with distilled water over 14 days; this is an aggressive but short-term erosive challenge that does not include artificial saliva or a remineralizing solution, and longer aging periods are needed. Fourth, the temperature generated at the cement surface by the LED and Plasma Arc units was not measured, and the two units differed in irradiance, exposure time, radiant exposure and emission spectrum; the proposed thermocatalytic mechanism therefore remains inferential. Fifth, the $CaCl_2$ gel and solution differed not only in vehicle but also in $CaCl_2$ concentration, and the gel contained additional components (Carbopol 940, gelatin and sodium benzoate) whose individual effects on the cement surface were not assessed; differences between the two forms therefore cannot be attributed to the vehicle alone. The viscosity, surface retention and storage stability of the gel were also not characterized. Sixth, no surface or chemical characterization (e.g., SEM, EDX or FTIR) was performed to confirm the proposed mechanisms. Seventh, the sample size was calculated from the water sorption data of a previous study for a two-group comparison; with ten specimens per group and the high variability observed in some groups (e.g., Plasma Arc WSP, SD 17.7 $\mu g/mm^3$), the study may have been underpowered to detect smaller differences, particularly for within-group changes after pH cycling. Eighth, a mass difference of 0.1 mg (the readability of the balance) corresponds to approximately 1.8 $\mu g/mm^3$ for the specimen volume used, which is close to the low WSL values recorded in the Plasma Arc group; small differences at this level should be interpreted cautiously. Similarly, the negative solubility values recorded for some specimens indicate a net mass gain, possibly owing to retained water or ion uptake, which the gravimetric method cannot distinguish from material loss. Finally, other clinically relevant properties were not evaluated, including fluoride release, which has been reported to decrease after $CaCl_2$ and radiant heat treatments [13,17], as well as surface hardness, compressive and flexural strength and color stability.

5. Conclusions

Within the limitations of this in vitro study, the following conclusions are drawn:

1. All four treatment modalities—LED, Plasma Arc, $CaCl_2$ solution, and $CaCl_2$ gel—significantly reduced the water solubility of the tested conventional GIC compared with untreated controls; water sorption was significantly reduced by Plasma Arc, $CaCl_2$ solution and $CaCl_2$ gel, but not by LED.

2. Plasma Arc light curing produced the greatest reduction in WSP and WSL, which may reflect a greater thermocatalytic effect on the GIC setting reaction than that of the LED unit used; this requires confirmation by temperature measurement.

3. The newly developed $CaCl_2$ gel showed effects on water sorption and solubility comparable to those of the conventional $CaCl_2$ solution. Unlike the solution, the gel did

not show a statistically significant increase in solubility after pH cycling; however, the post-cycling values of the two forms did not differ significantly, and this observation requires confirmation in larger studies. The gel may be a practical vehicle for $CaCl_2$ surface treatment of conventional GIC, but its clinical benefit has yet to be established.

4. None of the treated groups showed a significant change in water sorption after 14 days of pH cycling, suggesting short-term resistance of the treatment effects to the acidic challenge applied; longer-term aging studies are needed to establish their durability.

Further clinical and in vitro studies evaluating the effects of these modalities on other GIC properties (fluoride release, surface hardness, compressive strength) and over longer aging periods are recommended.

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S.A: resources; data curation; editing; visualization, R.H: writing—review and editing; visualization; supervision; project administration

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