Variables affecting conventional glass ionomer cement surface roughness after exposure to Coca-Cola®

P B Sari1, E Herda1* and M Damiyanti1

1Department of Dental Materials, Faculty of Dentistry, Universitas Indonesia, Jakarta 10430, Indonesia

*E-mail address: ellyza_herda@yahoo.com

Abstract. This research investigated variables that may affect the surface roughness of conventional glass ionomer cement (GIC), including the immersion of specimens in Coca-Cola®, applying CPPACP paste and then immersing in Coca-Cola® directly or after 30 min, or immersing the specimens in Aqua Bidest (control group). Results showed that the surface roughness of conventional GIC increased significantly after immersion in Coca-Cola®, whereas applying CPP–ACP paste and then immersing in Coca-Cola® decreased the surface roughness of conventional GIC. Furthermore, the surface roughness of conventional GIC was significantly decreased after applying CPP–ACP paste and then immersing in Coca-Cola® after 30 min. It was concluded that decreasing the surface roughness of conventional GIC was not significantly different after applying CPP–ACP paste when immersed in Coca-Cola® immediately or after 30 min.

1. Introduction
In recent years, carbonated drink consumption has become increasingly popular. One of the most popular carbonated beverages today is Coca-Cola®. Coca-Cola® production levels in Indonesia have improved year to year, with sales growth in Indonesia currently averaging 7%–8% per year [1]. According to earlier research, Coca-Cola® has a pH of 2.37 and has the lowest pH compared to other carbonated beverages [2].

Drinks with low pH, including Coca-Cola®, can dissolve tooth minerals and increase the roughness of the tooth surface. Surface roughness above 0.2 μm significantly encourages bacterial adhesion, maturation, and acidity of plaque, thus increasing the risk of dental caries [3]. Caries is a hard tissue disease caused by enamel dye dissolution from an acid produced from the metabolism of food carbohydrates by oral bacteria [4].

Conventional glass ionomer cement (GIC) is a commonly used restoration material because of its superior properties compared to other materials such as composites and amalgam. Conventional GICs are dental restorative materials and have a good adaptation to dentin compared to composites and amalgams because conventional GICs and dentin are chemically bonded [5]. In addition, conventional GIC also has anti-caries capabilities that make it a popular restoration material. This restoration material prevents demineralization and improves remineralization of enamel and dentin while inhibiting the growth of bacteria that cause dental caries. Conventional GIC releases fluoride that is deposited in the tooth tissue surrounding the GIC, making it more resistant to acid [6].

Casein phosphopeptide–amorphous calcium phosphate (CPP–ACP) has been shown to provide acid protection against tooth decay. Previous research has shown that CPP binding with ACP acts as a reservoir of CaHPO4 ions formed when acid is present. Acid can be formed by dental plaque bacteria, and under such conditions, CPP binds with ACP to act as a buffer (buffer) plaque pH and produces calcium and phosphate ions, especially CaHPO4. Increased CaHPO4 compensates for the decrease in pH, thus preventing demineralization of enamel [7]. In one study, micro-tensile bond strength and
compressive strength were measured on conventional GIC and GIC with added CPP–ACP. This research showed that conventional GIC which has CPP–ACP added has 33% higher micro-tensile bond strength and 23% more compressive strength. However, there has been very little research showing CPP–ACP protection against acids in restoration materials, especially conventional GICs [7]. Therefore, the current study investigated the effect of CPP–ACP paste application on conventional GIC surface roughness as a protective effect against acid. It is important to understand how to minimize rough surfaces on structural restoration materials which may accelerate the formation of bacterial colonization and increase the risk of caries [3].

2. Methods
2.1. Preparation of conventional GIC specimen
Conventional GIC (Fuji IX, G C Corporation, Tokyo, Japan) was stirred on a paper pad and placed in a stainless steel mold of 6 mm diameter and 3 mm in height using plastic filling. Before GIC hardened, the GIC surface was coated with mylar strips and glass objects on the surface and given a weight of 500 g to obtain a smooth surface. All 24 conventional GIC specimens were immersed in Aqua Bidest (double-distilled water) and stored in an incubator at 37°C.

2.2. Measurement of surface roughness values
Initial surface roughness was measured in different locations using the Mitutoyo SJ-301 Surface Roughness Tester (Japan).

2.3. Application of CPP–ACP paste
The 24 GIC specimens were divided into four equal groups. Group 1 and Group 2 specimens were not treated with CPP–ACP application. Group 3 and Group 4 specimens were treated with a thin layer of CPP–ACP paste on a standardized surface weighing 8.3 mg of paste for each specimen. Group 4 specimens were held for 30 min before the next stage.

2.4. Soaking conventional GIC in carbonated beverage (Coca-Cola®)
The four GIC groups were immersed in chilled Coca-Cola® (9°C) for 30 min. The 30-min immersion simulated Coca-Cola® consumption for six days, estimating that a drink is generally consumed in 5 min once per day. The 30-min immersion was done three times for a total of 90 min of immersion, simulating Coca-Cola® consumption for 18 days. Before and after the immersion, a measurement of Coca-Cola® pH was taken using a pH indicator. Measurements were made by matching the colors with the pH indicator.

2.5. Measurement of surface finite roughness value
The roughness of the final surface was measured in three different locations using the Mitutoyo SJ-301 Surface Roughness Tester.

2.6. Repetition treatment
Application of CPP–ACP paste, Coca-Cola® immersion, and measurement of surface roughness were performed three times in each treatment group.

2.7. Data analysis
Repeated ANOVA and one-way ANOVA statistical testing were used in the data analysis.

3. Results
The results are shown in Table 1. There was a difference in GIC roughness values after being subjected to different treatments: soaking in Aqua Bidest, soaking in Coca-Cola®, applying CPP–ACP paste and immediately soaking in Coca-Cola®, and applying CPP–ACP paste 30 min before soaking in Coca-Cola®.
Table 1. Surface roughness measurements (ΔRa) for conventional GIC

| Group                        | Surface Roughness/Ra ± SD (µm) | Initial     | 1st 30 minutes | 2nd 30 minutes | 3rd 30 minutes |
|------------------------------|---------------------------------|-------------|----------------|----------------|----------------|
| Aqua Bidest                  |                                 | 0.774 ± 0.147 | 0.805 ± 0.139 | 0.867 ± 0.185 | 0.962 ± 0.176  |
| Coca-Cola®                   |                                 | 0.774 ± 0.147 | 0.923 ± 0.227 | 1.167 ± 0.220 | 1.453 ± 0.403  |
| CPP–ACP + Coca-Cola®         |                                 | 0.774 ± 0.147 | 0.711 ± 0.144 | 0.613 ± 0.149 | 0.591 ± 0.147  |
| CPP–ACP (30 minutes) + Coca-Cola® |                               | 0.774 ± 0.147 | 0.652 ± 0.128 | 0.557 ± 0.132 | 0.480 ± 0.072  |

For specimens soaked in Aqua Bidest, conventional GIC surface roughness values showed a change, but it was not significant (p > 0.05). A statistically significant difference (p < 0.05) in surface roughness was observed between the initial measurement and the third 30-min treatment and between the second 30-min treatment and the third 30-min treatment.

For specimens soaked in Coca-Cola®, conventional GIC surface roughness values indicated a change, but it was not significant overall (p > 0.05). A statistically significant difference (p < 0.05) in surface roughness was observed between the initial measurement and the second and third 30-min treatments, between the first 30-min treatment and the second and third 30-min treatments, and between the second 30-min treatment and the third 30-min treatment.

Changes in conventional GIC surface roughness values were not significantly different (p > 0.05) for the two groups where CPP–ACP paste was applied and then soaked in Coca-Cola®. There was a significant change in surface roughness value between the initial surface roughness and the second and third 30-min treatments (p < 0.05).

Table 2. Mean differences in surface roughness among groups at the first 30-min measurement

|                  | Aqua Bidest ΔRa (µm) | Coca-Cola® ΔRa (µm) | CPP–ACP + Coca-Cola® ΔRa (µm) | CPP–ACP (30 minutes) + Coca-Cola® ΔRa (µm) |
|------------------|----------------------|----------------------|--------------------------------|--------------------------------------------|
| Aqua Bidest      | -                    | 0.118                | 0.097                          | 0.150                                      |
| Coca-Cola®       | 0.118                | -                    | 0.215*                         | 0.268*                                     |
| CPP–ACP + Coca-Cola® | 0.097               | 0.215*                | -                              | 0.053                                      |
| CPP–ACP (30 minutes) + Coca-Cola® | 0.150               | 0.268*                | 0.053                          | -                                          |

(*) statistically different value means using one-way ANOVA test (p < 0.05)

Table 2 shows a significant difference in mean surface roughness between the group immersed in Coca-Cola® and the group where CPP–ACP paste was applied and immediately soaked in Coca-Cola® and between the group immersed in Coca-Cola® and the group where CPP–ACP paste was applied and then soaked in Coca-Cola® after waiting for 30 min.
Table 3. Mean differences in surface roughness among groups at the second 30-min measurement

|                  | Aqua Bidest \( \Delta Ra \) (µm) | Coca-Cola\(^*\) \( \Delta Ra \) (µm) | CPP–ACP + Coca-Cola\(^*\) \( \Delta Ra \) (µm) | CPP–ACP (30 minutes) + Coca-Cola\(^*\) \( \Delta Ra \) (µm) |
|------------------|-----------------------------------|--------------------------------------|-----------------------------------------------|-------------------------------------------------|
| Aqua Bidest \( \Delta Ra \) (µm) | -                                 | -                                    | 0.553*                                        | 0.610*                                          |
| Coca-Cola\(^*\) \( \Delta Ra \) (µm) | 0.298*                           | -                                    | 0.553*                                        | -                                               |
| CPP–ACP + Coca-Cola\(^*\) \( \Delta Ra \) (µm) | 0.255*                           | 0.553*                              | -                                             | 0.057                                           |
| CPP–ACP (30 minutes) + Coca-Cola\(^*\) \( \Delta Ra \) (µm) | 0.312*                           | 0.610*                              | 0.057                                         | -                                               |

(*) statistically different value means using one-way ANOVA test (p < 0.05)

Table 3 shows significant differences in mean surface roughness between the group immersed in Aqua Bidest and the groups immersed in Coca-Cola\(^*\), CPP–ACP paste applied and immediately soaked in Coca-Cola\(^*\), and CPP–ACP paste applied and soaked in Coca-Cola\(^*\) after waiting for 30 min. In addition, significant differences in surface roughness values were also observed in the group immersed in Coca-Cola\(^*\) and the group with CPP–ACP paste applied and immediately soaked in Coca-Cola\(^*\), the group immersed in Coca-Cola\(^*\), and the group immersed in Coca-Cola\(^*\) 30 min after the CPP–ACP paste was applied.

Table 4. Mean differences in surface roughness among groups at the third 30-min measurement

|                  | Aqua Bidest \( \Delta Ra \) (µm) | Coca-Cola\(^*\) \( \Delta Ra \) (µm) | CPP–ACP + Coca-Cola\(^*\) \( \Delta Ra \) (µm) | CPP–ACP (30 minutes) + Coca-Cola\(^*\) \( \Delta Ra \) (µm) |
|------------------|-----------------------------------|--------------------------------------|-----------------------------------------------|-------------------------------------------------|
| Aqua Bidest \( \Delta Ra \) (µm) | -                                 | 0.180*                              | 0.297*                                        | 0.403*                                          |
| Coca-Cola\(^*\) \( \Delta Ra \) (µm) | 0.180*                           | -                                    | 0.477*                                        | 0.583*                                          |
| CPP–ACP + Coca-Cola\(^*\) \( \Delta Ra \) (µm) | 0.297*                           | 0.477*                              | -                                             | 0.106                                           |
| CPP–ACP (30 minutes) + Coca-Cola\(^*\) \( \Delta Ra \) (µm) | 0.403*                           | 0.583*                              | 0.106                                         | -                                               |

(*) statistically different value means using one-way ANOVA test (p < 0.05)

Table 4 shows a significant difference in mean surface roughness values between the group immersed in Aqua Bidest and the group immersed in Coca-Cola\(^*\), the group with CPP–ACP paste applied and immediately soaked in Coca-Cola\(^*\), and the group immersed in Coca-Cola\(^*\) 30 min after the CPP–ACP paste was applied. In addition, significant differences in surface roughness values were also observed between the group immersed in Coca-Cola\(^*\) and the group with CPP–ACP paste applied and immediately soaked in Coca-Cola\(^*\) and between the group immersed in Coca-Cola\(^*\) and the group immersed in Coca-Cola\(^*\) 30 min after the CPP–ACP paste was applied.
4. Discussion
The increase of the surface roughness of specimens immersed in Aqua Bidest is due to the diffusion of water into conventional GIC matrices. The diffusion process takes place through micro-cracks, and the aqua bidest binds to the hydrophilic ions contained in the conventional GIC. Water diffusion causes the dissolution of the matrix and degradation of the conventional GIC surface. Dissolution and degradation cause the formation of porous areas on the surface of conventional GICs to increase the efficiency of conventional GIC surfaces [8].

The increase of the surface roughness of specimens immersed in Coca-Cola® is due to the presence of citric acid and phosphoric acid in Coca-Cola®. Citric acid can disintegrate calcium ions from within the matrix [9]. The dissolution process is due to the presence of H⁺ ions from the acidic drink. The more acidic the drink, the more H⁺ ions and the greater the degree of dissolution of the material. The absence of these ions from the matrix causes the conventional GIC surface to become rough. This is because the glass particles are exposed to the surface of the cement. Citric acid forms a stable complex with Al³⁺ and Ca²⁺ (or Sr²⁺) ions. According to Zaki (2012), during immersion in the acid solution, the solution penetrates the cement, and the gel matrix increases in size [10]. The hydrogen ions (H⁺) diffuse into the cement and exchange places with the metal cations. The metal cations diffuse into the solution based on the decrease in the concentration gradient. The release of the metal cations causes the increase of oxygen not bonded in the glass tissue near the surface. The surface of the glass particles will contain many silanols, and the simultaneous cement surface exposure by the H⁺ ion will continuously disrupt the Si–O–Si glass bond. The perfect dissolution process of the glass particles causes numerous porous areas on the surface. This has led to the rise in the level of conventional GIC surfaces [10].

The reduction of the surface roughness of specimens with CPP–ACP paste applied and then immersed in Coca-Cola® is due to the release of calcium and phosphate from CPP–ACP at acidic pH [11]. CPP binds with ACP and acts as a neutral ion reservoir of CaHPO₄⁰ formed in the presence of acid. Under these conditions, the CPP binding to ACP will act as a buffer of pH and produce calcium and phosphate ions, especially CaHPO₄⁰. Increased CaHPO₄⁰ will reduce the pH value [12]. Because CaHPO₄⁰ weights the pH, the pH of the solution will not be too low, and the degradation of the material is reduced. In conventional GIC, deposits of calcium and phosphate ions from the CPP–ACP occur but are not expected to fill the porous surfaces of conventional GIC that have been dissolved [13]. This causes a decrease in surface roughness; however, it is not significant. In addition, Moezizadeh explains that the incorporation of CPP–ACP with conventional GIC can increase the release of calcium, phosphate, and fluoride ions from conventional GIC on neutral pH and acid [7].

The significant decreases in the roughness values of specimens in the group where CPP–ACP was applied and then soaked in Coca-Cola® after waiting for 30 min are due to the role of CPP–ACP as an acid buffer with calcium phosphate ions and binds H⁺ ions from the acid and also releasing and forming neutral ions to increase the pH of the solution [14]. This process is the same as that of the group where CPP–ACP paste was applied and immediately immersed in Coca-Cola®, but what distinguishes this group are deposits of calcium and phosphate ions from CPP–ACP that have adequately filled the porous areas of conventional GIC surfaces that were previously disseminated, thereby increasing their surface roughness [13].

5. Conclusion
On the basis of the results of the study, it can be concluded that GIC surface roughness increases significantly after immersion in Coca-Cola®, whereas applying CPP–ACP paste and then immediately soaking in Coca-Cola® shows a decrease in surface roughness, but it is not statistically significant. Applying CPP–ACP paste and waiting for 30 min before soaking in Coca-Cola® shows a significant decrease in surface roughness. On the basis of the results of the study, the application of CPP–ACP paste can be allowed to stand for 30 min before being soaked in Coca-Cola® or directly soaked, with no significant decrease in roughness.
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