Effects of frequently consumed beverages by children on the surface roughness of glass ionomer-based materials

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Objective: The aim of this study was to evaluate and compare the surface roughness changes of various glass ionomer-based restorative materials when exposed to beverages commonly consumed by children.
Materials and Methods: A total of 144 discs (7 x 1.2 mm) were prepared from four different GI-based materials: conventional glass ionomer cement (GIC–Fuji IX), resin-modified glass ionomer cement (RMGIC–Fuji II LC), zirconia-reinforced glass ionomer (Zr-GI–Zirconomer Improve), and giomer (Beautifil X injectable). Each material group (n=36) was divided into four subgroups (n=9) and immersed in distilled water, grape juice, cola, or chocolate milk for 7 days. The surface roughness values were measured using a non-contact profilometer before and after immersion. The data were analyzed using the Wilcoxon signed-rank and Kruskal-Wallis tests ($p<0.05$).
Results: The surface roughness of the materials ranked from highest to lowest was Zr-GI, GIC, RMGIC, and giomer. No significant differences in surface roughness were observed for any material after 7 days of immersion in the tested solutions.
Conclusion: Exposure to commonly consumed beverages (water, grape juice, cola, and chocolate milk) for one week did not significantly affect the surface roughness of the tested GI-based restorative materials comprising conventional GIC, RMGIC, Zr-GI, and giomer.

Keywords: giomer, glass ionomer cement (GIC), resin-modified glass ionomer cement, (RMGIC), surface roughness, zirconia-reinforced glass ionomer

Introduction

Dental caries is a non-communicable disease (NCD) that markedly impacts children's quality of life [1]. The prevalence of dental caries in the primary dentition of 3-year-old Thai children is 52.9% and reaches 75.6% after the age of 5. However, 73.8% of Thai children with dental caries do not receive treatment. Children residing in rural areas have a higher need for dental treatment but often face limited opportunities to access the required care [2].

Alternative/Atraumatic Restorative Treatment (ART) is a conservative dental approach designed to address dental caries in a minimally invasive manner. Utilizing hand instruments, such as spoon excavators, and Glass ionomer cement (GIC), ART focuses on caries removal and restoration without the need for drilling tooth structure or polishing after filling. This method prioritizes simplicity, accessibility, and patient comfort, making it particularly relevant in resource-limited settings and aligning with contemporary trends in conservative dentistry.

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The World Health Organization (WHO) promotes ART as dental care for underdeveloped countries that lack electricity or access to sophisticated dental equipment [3]. The American Academy of Pediatric Dentistry (AAPD) has incorporated GIC as a substantiated material for dental restoration procedures on the primary dentition. Additionally, GIC releases fluoride, contributing to its ability to prevent further tooth decay [4].

GIC is a dental material made from glass powder and polyacrylic acid. It chemically bonds with enamel and dentin and releases fluoride to help prevent caries formation [5]. GIC can be used as a filling material, sealant, liner, or luting cement and is available in various forms [6]. Resin-modified GIC (RMGIC) improves upon traditional GIC with added resin, enhancing its durability and mechanical properties [7]. Zirconia-reinforced GI (Zr-GI) further enhances wear resistance and fracture toughness [8, 9]. Giomer combines GIC and resin, improving strength and aesthetic appeal for restorations and preventive applications [10-12].

The surface roughness of dental materials or restorations can impact various aspects of oral health. Increased surface roughness may contribute to the accumulation of plaque and bacteria, potentially leading to oral health issues, such as tooth decay and gum disease. Monitoring and controlling surface roughness are essential considerations in the design and maintenance of dental restorations to ensure optimal oral health outcomes [13-15].

Daily consumption of beverages can potentially affect the surface roughness of GI restorative materials, especially if the beverage is acidic, has high staining potential, or has high sugar content [13, 15-17]. Coffee, tea, cola, and red wine can contribute to surface discoloration and potentially alter the surface roughness of GI restorative materials over time [18]. Fruit juices, flavored milks, and carbonated drinks are popular beverages frequently consumed by children [19]. Chocolate milk, cola, and grape juice are good examples of children's beverages that have acidic properties, high staining potential, or high sugar content.

Although some studies have investigated the surface roughness of restorative materials, such as resin composites, GICs, compomers, and base materials [13, 15, 16, 20], there are no studies comparing the outcomes of beverages on the surface roughness of conventional GIC, RMGIC, Zr-GI, and injectable giomer. Therefore, the aim of this study was to compare the effects of beverages frequently consumed by children on the surface roughness of conventional GIC, RMGIC, Zr-GI, and giomer.

Materials and Methods

A total of 144 discs (1.2 mm thick and 7 mm diameter), were prepared using 4 different GI-based materials: 36 conventional GICs – Fuji IX shade A2 (GC, Tokyo, Japan), 36 RMGICs - Fuji II LC shade A2 (GC, Tokyo, Japan), 36 Zr-GIs – Zirconomer Improve (Shofu Inc., Kyoto, Japan), and 36 Giomers – Beautifil X injectable shade A2 (Shofu Inc., Kyoto, Japan). The details of each material are described in Table 1. During the preparation, the materials were placed in a metal mold and covered with celluloid sheets on both sides. According to Beghari, *et al* [21], a plastic matrix strip produces the smoothest surface of GIC-based materials. The sheets were gently pressed with a glass plate to remove excess material. The self-cured materials were left according to the manufacturer's instructions to completely set. The light-cured materials were cured using an LED light curing unit (Bluephase N, Ivoclar Vivadent, Zurich, Switzerland) at an intensity of 1,200 mW/cm^2 according to the manufacturer's instructions. The discs were kept in 4 airtight containers, categorized by material, for 24 hours for maturation. The containers were then filled with distilled water and kept at room temperature (25°C) before measurement.

Table 1 Glass ionomer-based restorative materials used in the study.

Product name	Type	Manufacturer	Composition	Shade/Lot number
Beautifil X injectable (BX)	Giomer	Shofu Inc., Kyoto, Japan	Bis-GMA, TEGDMA, Bis-MPEPP, S-PRG filler based on fluoroboroaluminosilicate glass, Polymerization initiator, Pigments and others	A2/062311
Zirconomer (Zr-GI)	Zirconia reinforced glass ionomer	Shofu Inc., Kyoto, Japan	POWDER: Fluoroaluminosilicate glass, Zirconium oxide, pigments and others LIQUID: Polyacrylic acid solution and Tartaric acid	-/2301071
FujiII LC (F2)	Resin modified glass ionomer	GC, Tokyo, Japan	Fluoroaluminosilicate glass, Copolymers of polyacrylic acid and maleic acid, HEMA, water, camphoroquinone, and photoinitiator	A2/2301131
Fuji IX (F9)	Conventional glass ionomer	GC, Tokyo, Japan	Fluoroaluminosilicate glass, polyacrylic acid distilled water, polybasic carboxylic acid	A2/01220781

The discs were dried using blotting paper before the initial measurement. A noncontact type profilometer (Olympus OLS5100-SAF, Tokyo, Japan) was used to measure the surface roughness, and the average Ra from 3 random areas was recorded before immersion in the different solutions. The samples in each group (n=36) were divided into 4 subgroups (n=9) to immerse in distilled water, grape juice, cola, and chocolate milk. The details of each beverage are described in Table 2. The pH of the solutions was measured using a pH meter (Thermo Scientific™ Orion Star™ A211 Benchtop pH Meter, Massachusetts, USA) before immersion. The discs were kept in airtight containers with 5 ml of each solution and placed in an incubator (Sheldon Lab Manufacturing Incubator Model 1545, Oregon, USA) at 37°C for 7 days. The immersion protocol was adopted from Bal et al [22], then extended to 7 days and modified to changing the solutions daily. The discs were rinsed with distilled water and dried using blotting paper before measuring the roughness values.

The data were statistically analyzed using SPSS version 29.0 (IBM, Newyork, USA). with a significance level of *p<0.05*. The normality assumption was assessed using the Shapiro-Wilk test. The Wilcoxon Signed Ranks Test was employed to compare the means of two dependent groups when the data did not follow a normal distribution. The Kruskal-Wallis test was utilized to assess the differences between the means of three or more independent groups in cases where the normality assumption was violated. Post-hoc corrected Bonferroni testing was subsequently employed to identify the specific group or groups responsible for observed differences.

Table 2   Beverages used in this study

Product name	Type	Manufacturer	Composition
Tipco	Grape juice	Tipco F&B Co., Ltd., Phra Nakhon Si Ayutthaya, Thailand	Red grape juice from red grape juice concentrate
Coca-Cola	Cola	ThaiNamthip Co., Ltd., Bangkok, Thailand	Sugar, Carbonated water, Caramel color, Phosphoric acid, Natural flavors
Foremost	Chocolate milk	FrieslandCampina Thailand Pcl., Samutprakarn, Thailand	Recombined partly skimmed milk, Sugar, Anhydrous milk fat, Cocoa powder, Vitamin & mineral premix, Food additives, Natural identical flavor

Results

The pH value of each solution was measured: distilled water had a pH of 5.97, grape juice had a pH of 3.50, cola had a pH of 2.67, and chocolate milk had a pH of 6.99. These pH measurements indicate the acidity or alkalinity of each solution, with distilled water being slightly acidic, grape juice and cola being more acidic, and chocolate milk being neutral.

Analysis of the samples indicated that there were no significant differences in roughness values between before and after 7 days immersion in all solutions ($p > 0.05$) (Table 3).

Comparing different materials, Zr-GI exhibited significantly higher roughness levels compared with RMGIC and giomer, both before and after immersion in all solutions ($p < 0.05$). Conversely, conventional GIC demonstrated similar roughness levels to the other materials: RMGIC, giomer, and Zr-GI ($p > 0.05$). Among the solutions, there was no significant difference in the roughness of RMGIC and giomer ($p > 0.05$) (Table 4).

The assessment of the roughness change rates resulting from solution immersion revealed no significant differences for the giomer ($p > 0.05$). Moreover, comparisons among distilled water-chocolate milk, chocolate milk-cola, and grape juice-cola indicated no significant difference in the surface roughness of all materials ($p > 0.05$). However, RMGIC displayed a significant increase in surface roughness after immersion in cola compared with distilled water. In contrast, conventional GIC demonstrated a notable rise in surface roughness following immersion in grape juice compared with distilled water. Furthermore, Zr-GI exhibited significant increases in surface roughness after immersion in grape juice compared with distilled water and chocolate milk (Table 5).

Table 3 Mean, standard deviation (SD), median, and interquartile range (IQR) of surface roughness before and after immersion

Medias		Distilled water			Grape juice			Cola			Chocolate milk		
Materials		Means ± SD	Median (IQR)		Means ± SD	Median (IQR)		Means ± SD	Median (IQR)		Means ± SD	Median (IQR)	
RMGIC	Before	0.29±0.04	0.28 (0)	Z = -1.069	0.26±0.02	0.26 (0)	Z = -1.604	0.23±0.01	0.22 (0)	Z = -1.604	0.31±0.05	0.32 (0)	Z = 0.000
	After	0.24±0.06	0.23 (0)	p = 0.285	0.72±0.34	0.88 (0)	p = 0.109	1.01±0.62	0.68 (0)	p = 0.109	0.31±0.14	0.30 (0)	p = 1.000
GIC	Before	0.39±0.08	0.38 (0)	Z = -0.535	0.45±0.03	0.44 (0)	Z = -1.604	0.42±0.03	0.43 (0)	Z = -1.604	0.36±0.06	0.34 (0)	Z = -1.604
	After	0.38±0.11	0.35 (0)	p = 0.593	4.95±0.46	4.84 (0)	p = 0.109	1.53±0.55	1.45 (0)	p = 0.109	0.86±0.36	0.70 (0)	p = 0.109
Zr-GI	Before	1.29±0.05	1.29 (0)	Z = -1.604	1.50±0.05	1.52 (0)	Z = -1.604	1.83±0.16	1.89 (0)	Z = -1.604	1.59±0.16	1.50 (0)	Z = -1.604
	After	1.95±1.09	1.32 (0)	p = 0.109	4.96±1.03	4.88 (0)	p = 0.109	3.86±0.31	3.92 (0)	p = 0.109	2.14±0.40	2.03 (0)	p = 0.109
Giomer	Before	0.13±0.01	0.14 (0)	Z = 0.000	0.12±0.02	0.12 (0)	Z = -1.604	0.15±0.06	0.14 (0)	Z = -1.604	0.13±0.02	0.14 (0)	Z = -1.604
	After	0.16±0.10	0.10 (0)	p = 1.000	0.23±0.07	0.26 (0)	p = 0.109	0.40±0.26	0.28 (0)	p = 0.109	0.30±0.08	0.25 (0)	p = 0.109

*$p<0.05$ indicates a significant difference.

GIC = Conventional glass ionomer cement, RMGIC = Resin-modified glass ionomer cement, Zr-GI = Zirconia-reinforced glass ionomer

Table 4 Comparison of the surface roughness of the materials before and after immersion

	p-value											
	RMGIC-GIC		RMGIC-Zr-GI		RMGIC-Giomer		GIC-Zr-GI		GIC-Giomer		Zr-GI-Giomer	
	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
Distilled water	0.427	0.334	0.047*	0.031*	0.257	0.532	0.257	0.233	0.054	0.112	0.002*	0.005*
Grape juice	0.308	0.141	0.042*	0.036*	0.308	0.308	0.308	0.910	0.052	0.113	0.002*	0.009*
Cola	0.281	0.428	0.036*	0.042*	0.364	0.428	0.307	0.213	0.057	0.113	0.003*	0.005*
Chocolate milk	0.734	0.140	0.042*	0.013*	0.173	0.910	0.173	0.307	0.059	0.112	0.002*	0.009*

*$p<0.05$ indicates a significant difference.

GIC = Conventional glass ionomer cement, RMGIC = Resin-modified glass ionomer cement, Zr-GI = Zirconia-reinforced glass ionomer

Table 5 Comparison of the surface roughness of the medias before and after immersion

	D-G		D-C		D-M		G-C		G-M		C-M	
p-value	Before	After	Before	After	Before	After	Before	After	Before	After	Before	After
RMGIC	0.495	0.054	0.306	0.031*	0.569	0.821	0.733	0.821	0.211	0.089	0.111	0.054
GIC	0.273	0.002*	0.689	0.054	0.424	0.258	0.493	0.258	0.059	0.054	0.230	0.428
Zr-GIC	0.493	0.009*	0.864	0.070	0.278	0.734	0.392	0.428	0.689	0.024*	0.209	0.141
Giomer	0.505	0.423	0.952	0.137	0.716	0.252	0.467	0.492	0.762	0.731	0.671	0.731

*p<0.05 indicates a significant difference.

GIC = Conventional glass ionomer cement, RMGIC = Resin-modified glass ionomer cement, Zr-GI = Zirconia-reinforced glass ionomer

D = Distilled water, G = Grape juice, C = Cola, M = Chocolate milk

Discussion

The aim of the present study was to investigate the effects of commonly consumed beverages by children on the surface roughness of various GI-based materials. The immersion of the materials in different solutions simulated the potential exposure to these beverages in the oral environment.

Fruit juices, flavored milks, and carbonated drinks are popular among children, unlike coffee and red wine, which were used in previous studies [18, 23] and do not reflect children's beverage choices. Chocolate milk, cola, and grape juice are better examples of beverages preferred by children and can be used for comparison in studies [13, 16, 18, 20, 24, 25].

The surface roughness measurements were conducted using a non-contact type profilometer. Non-contact profilometers offer several advantages over traditional contact profilometers, including the ability to measure soft or delicate surfaces without causing any damage or deformation [26]. This ensured that the surface of the samples was preserved and could be repeatedly measured. Additionally, non-contact methods are not influenced by stylus force or surface contamination, which can affect the accuracy of contact profilometry measurements [27].

The results revealed a general increase in surface roughness for most materials after immersion in the tested solutions, however, this was not significant. RMGIC and Zr-GI demonstrated significant differences across all media. Zr-GI had a higher surface roughness compared with RMGIC, but was not different from conventional GIC [9]. This discrepancy may be attributed to the larger size of the zirconia filler in Zr-GI, leading to an easier dissolution of the zirconia matrix, particularly in media characterized by a corrosive pH [16]. Comparing RMGIC and giomer, no significant difference emerged, as both matrices are resin-based.

In contrast, significant differences were observed between Zr-GI and giomer. This discrepancy can be attributed to giomer's use of a homogeneous nano filler comprising uniformly sized S-PRG particles [13, 20].

Our results suggest that the acidic nature of beverages, e.g., grape juice and cola may contribute to surface roughening over time. Notably, giomer exhibited no significant roughness changes across all solutions, indicating its resistance to acidic challenges. This resistance may be due to giomer's properties being more similar to resin composite than conventional GI, a finding consistent with Hamouda, *et al* [28]. The resistance of the giomer material (Beautifil X injectable) to surface roughness changes across all solutions in this study is noteworthy. The unique composition of giomers, which incorporates pre-reacted glass ionomer filler particles, may contribute to their improved acid resistance compared with conventional GICs [11].

The observed increase in surface roughness for most materials after immersion in acidic beverages like grape juice and cola aligns with findings from previous studies. Aliping-Mckenzie, *et al* [29]. reported significant increases in the surface roughness of conventional GICs and RMGIC after immersion in acidic beverages like fruit juices and cola.

Comparing the different materials, Zr-GI (Zirconomer Improve) demonstrated significantly higher roughness levels compared with RMGIC (Fuji II LC) and giomer (Beautifil X injectable) both before and after immersion. Bagheri, *et al* [18] reported that the surface roughness changes were more significant for materials with a rougher initial surface finish [18]. This observation implies that the Zr-GI may have inherent surface characteristics that predispose it to increased roughness, regardless of the solution exposure. Conversely, the conventional GIC (Fuji IX) exhibited

similar roughness levels to the other materials, suggesting that its behavior may be comparable to RMGIC and giomer in terms of surface roughness. Regarding the material comparisons, the significantly higher roughness exhibited by the Zr-GI (Zirconomer Improve) aligns with previous reports on the relatively rough surface characteristics of Zr-GI [8]. The addition of zirconia particles, while enhancing mechanical properties, may compromise the surface smoothness of these materials.

Interestingly, the RMGIC exhibited a significant increase in surface roughness after immersion in cola compared with distilled water. This finding highlights the potential vulnerability of RMGICs to the acidic environment created by cola consumption [20, 29]. The highly acidic nature of cola (pH 2.67), which is comparable to that found in previous studies [13, 23], can potentially degrade the resin matrix component of RMGICs, leading to surface erosion and roughening through the hydrolysis of ester bonds and leaching of unreacted monomers and filler particles.

Similarly, the conventional GIC demonstrated a notable rise in surface roughness following immersion in grape juice compared with distilled water. The relatively low pH of grape juice (3.50), which is comparable to that in a previous study [23], may have facilitated the dissolution and erosion of the glass ionomer matrix, disrupting the ionic cross-linking and causing the leaching of ions and the breakdown of the matrix structure [29, 30]. This is similar to Ozdemir-Ozenen, *et al* [13]. and Honorio, *et al* [31] where conventional GIC only had a significant increase in surface roughness after being immersed in fruit juice. However, the difference was not significant in cola compared with distilled water as in the present study [13, 25].

Furthermore, Zr-GI exhibited significant increases in surface roughness after immersion in grape juice compared with distilled water and chocolate milk. The acidic environment of grape juice may have selectively attacked the GI phase surrounding the zirconia particles, leaving behind protruding zirconia particles and resulting in a rougher surface topography.

The unexpected finding that chocolate milk induced greater surface roughness compared with distilled water, despite its near-neutral pH, can be attributed to the complex composition of chocolate milk and its potential interactions with the restorative materials. Components like sugars, proteins, and minerals may have contributed to surface roughening through erosive or abrasive processes, facilitating bacterial growth and acid production, forming surface precipitates, or interacting with the materials to cause surface alterations [18, 32]. This is despite the fact that distilled water has a lower pH and does not conform to any study's expected outcomes [13].

These results, consistent with previous findings, suggest that surface degradation is a multifactorial process. Damage to the surface is not solely due to low pH exposure and the overall chemical composition of acidic beverages, but is also influenced by the type and composition of the restorative materials [13, 29, 30].

In addition to the surface roughness changes, it is essential to consider the clinical implications of these findings. Increased surface roughness can potentially lead to plaque accumulation, discoloration, and reduced longevity of the restorative materials, ultimately affecting the overall success of the dental treatment [14, 33, 34]. Therefore, careful consideration should be given to the selection of materials based on their anticipated exposure to beverages, particularly in pediatric patients who may consume these beverages frequently.

Birant, *et al* [25] mimicked the beverage consumption of children and found no significant differences in surface roughness before and after immersion of all tested GICs. [25]. The present study evaluated the surface roughness of various GI-based materials after being immersed in solutions for 7 days. The immersion protocol was adopted from Bal, *et al* [22], then extended to 7 days to create extreme conditions of repeatedly consumed beverages by children. The results might not represent the actual beverage consumption in the oral cavity, but enhanced the changes in the surface roughness of each GI-based material after exposure to distilled water, grape juice, cola, and chocolate milk. To investigate how beverages consumed by children affect surface roughness, the study design should include intermittent immersion in each beverage and a washout phase using distilled water or artificial saliva. Additionally, incorporating a brushing phase may provide further insight into the effects on surface roughness.

Future studies could explore the potential mechanisms underlying the observed surface roughness changes, such as chemical interactions between the materials and the beverages, as well as the long-term effects of repeated exposure to these solutions. Additionally, investigating the relationship between surface roughness and other properties, such as wear resistance and staining susceptibility, could provide further insights into the overall performance of these materials in the oral environment.

Conclusion

Exposure to commonly consumed beverages (water, grape juice, cola, and chocolate milk) for one week did not significantly affect the surface roughness of the tested GI-based restorative materials, comprising conventional GIC, RMGIC, Zr-GI, and giomer.

Acknowledgments

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