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The evaluation of internal adaptation of glass ionomer restorations applied after the use of different cavity conditioners in primary teeth: an in-vitro study

Sümeyye Gürler[1], Akif Demirel[1*] and Arda Buyuksungur[2]

Abstract

Background This study aimed to comparatively evaluate the effects of different cavity conditioners on internal adaptation (IA) of glass ionomer-based restorative materials applied to primary teeth.

Methods 80 extracted primary second molar teeth were randomly assigned to four different cavity conditioner groups [10% polyacrylic acid, 20% polyacrylic acid, 17% ethylene diamine tetraacetic acid (EDTA), 35% phosphoric acid]. Class V cavities were prepared on the buccal surfaces and relevant cavity conditioners were applied, and the samples in each cavity conditioner group were randomly assigned to glass hybrid (GHR) or conventional glass ionomer restoratives (CGIR). Subsequently, restorative materials were applied and all samples were thermocycled (5–55 °C, 5000 cycles) and IA were calculated volumetrically by using a Micro Computed Tomography (Micro-CT) system. IA values was recorded as % and data were analyzed with Mann-Whitney U and Kruskal-Wallis H tests. Statistical significance level was set as 5%.

Results 35% phosphoric acid showed the lowest mean internal voids (between the cavity-restoration interface) for both restorative materials (for GHR = 0.180% and for CGIR = 0.936%). However, the highest mean internal voids for GHR and CGIR were observed after the use of 17% EDTA (2.438%) and 10% polyacrylic acid (8.483%), respectively. For both restorative materials, 20% polyacrylic acid showed the second lowest mean internal voids (for GHR = 0.321% and for CGIR = 3.580%), however, no significant difference was found between 35% phosphoric acid and 20% polyacrylic acid ($p = 0.941$ for GHR and $p = 0.061$ for CGIR). In the samples applied the cavity conditioners other than 17% EDTA, glass hybrid restoratives showed significantly higher IA quality than conventional glass ionomer ($p = 0.0001$ for 10% polyacrylic acid, $p = 0.001$ for 20% polyacrylic acid and $p = 0.002$ for 35% phosphoric acid).

Conclusions Within the limitations of this study, 35% phosphoric acid and 20% polyacrylic acid were determined to be the most successful cavity conditioners in terms of IA, and glass hybrid restorative system showed superior IA quality than conventional glass ionomer. Further studies are needed to confirm the present results.

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Keywords Cavity conditioners, Glass hybrid systems, Internal adaptation, Micro computed tomography, Primary teeth

Background

Cavitated caries lesions are still a major oral health problem affecting primary teeth. Primary teeth have vital importance for the development of young children and therefore every effort should be made to keep primary teeth functionally in the mouth for as long as possible [1–3]. The restorative dental treatment needs of pediatric dental patients arise primarily due to dental caries. In addition to dental caries, this need arises from dento-alveolar traumatic injuries, developmental dental anomalies and, less frequently, erosive tooth wear [4]. Restorative materials must meet certain success criteria for an acceptable and sustainable restorative treatment [1, 5]. The anatomical and functional characteristics of the primary teeth and the differences between primary and im/mature permanent teeth should be taken into consideration in the clinician's selection of the appropriate restorative material [4]. In this context, resin-based restorative materials (compomer or composite), prefabricated or custom-made crowns, or glass ionomer-based materials are generally preferred in pediatric dentistry [1, 4, 6].

Glass ionomers are one of the adhesive restorative materials that have been increasingly used in pediatric dentistry in recent years [1, 4, 7]. Glass ionomer technology has shown tremendous development since they were first introduced to the market [8–10]. High-viscosity glass ionomers have been introduced to the market offering improved mechanical, physical and biomimetic properties to eliminate the clinical disadvantages of conventional glass ionomer restorations [1, 4, 11]. In recent years, restorative materials based on glass ionomer technology, also referred to as glass hybrid, have been produced by modifying the material with glass particles of different sizes, such as small particles with high reactivity. This reinforcement both increased the level of reactivity and significantly improved the mechanical properties. In addition, since glass hybrid materials are applied with a light-cured surface coating material containing nano-filled resin, the success of the material is at a level to compete with resin-containing systems [1, 4, 6, 12, 13]. On the other hand, there are many different previous studies in the dentistry literature testing the properties of glass ionomer-based restorative materials, and the adhesion of glass ionomer to dental tissues is an important indicator of success [14]. For acceptable adhesion of glass ionomer systems, a closely contact between the material and tooth surfaces is required [7, 8]. However, the smear layer formed especially on the dentin surface after operative dental procedures negatively affects the adhesion between glass ionomers and dental hard tissue surfaces. Moreover, the smear layer hydrolyses under the restorative material over time, creating a risk factor for microleakage and secondary caries formation. Therefore, removal of the smear layer is strongly recommended for effective and acceptable adhesion [7, 8, 15]. In this context, there are materials defined as cavity conditioners that provide an appropriate adhesion by removing the smear layer on cavity surfaces before glass ionomer placement [7, 8]. These solutions are generally in acid form, and various dilutions of polyacrylic acid, citric acid, acrylic acid, ethylene diamine tetraacetic acid (EDTA) or phosphoric acid were generally used [7, 8, 16].

Different tests are used to measure the success of restorative materials in in-vitro studies [6]. One of them, internal adaptation (IA), is a parameter for testing the adhesion of restorations. Investigations of IA allow assessments of the micromorphology of the tooth surface-restorative material interface and provide a better understanding of the current limitations and failures in adhesive dentistry [17]. The quality of adaptation at the interface of restorative materials and tooth tissue is a factor that closely and significantly affects the success of dental restoratives. Possible failure of IA of restorative materials is a problem that may occur due to lack of adhesion, and the lack of adaptation cause the development of sealing and related problems at the interface [6, 18–20].

When the dental literature is examined, it is seen that a clear consensus and clinical protocol for the use of cavity conditioning agents prior to the application of glass ionomer-based restorative materials has not yet been defined. Moreover, previous studies on cavity conditioners prior to the placement of glass ionomer restorative materials mostly included permanent teeth, and most of these studies evaluated parameters such as microleakage or bond-strength [16]. However, to our knowledge, no study has been found to examine IA of the glass ionomers to the cavity walls after the use of different cavity conditioners by using three-dimensional methods. Based on this preliminary introduction, the present study, performed under in-vitro design, aimed to comparatively evaluate the effects of different cavity conditioners on IA of glass ionomer-containing restorative materials applied to primary teeth. The null hypothesis (H0) was that there would be no statistically significant difference between the effects of different the cavity conditioners on IA levels of the glass ionomer-based restorative materials.

Methods

The present study, in which IA of different types of glass ionomer restorations applied after the use of different cavity conditioners were examined by Micro Computed Tomography (Micro-CT), was planned to include 4 different cavity conditioning material groups and 2 different restorative material groups. Research design, ethics committee approval, guidelines followed and the study procedures were given in detail below.

Ethical approval and informed consent forms

Ethical approval For the approval of the research protocol of this study was obtained from Ankara University Faculty of Dentistry Clinical Research Ethics Committee on 18.12.2023 with the decision number 15/13. Since extracted primary molar teeth were included in the study procedures, verbal and written informed consent forms were approved by all pediatric patients whose teeth were used and their parents. Also, the research protocol was conducted in accordance with the ethical principles for medical research (involving human participants, including research using identifiable human material or data) of World Medical Association (WMA) Declaration of Helsinki [21]. In addition, this study was followed by the guidelines of the CRIS Guidelines (Checklist for Reporting In-vitro Studies) developed to improve the quality of in-vitro research [22].

Study design and sample size analysis

This study had a randomised, controlled and blinded (for only Micro-CT analysis) research design under in-vitro conditions. Since there were no similar previous studies in the literature including the same materials used in this study, the sample size analysis was calculated based on the effect size. For the comparative evaluation of the effects of four different cavity conditioning materials planned to be used before the application of two different restorative materials on IA of restorations, Type I error (α)=0.05, effect size (effect size-f)=0.4, and power (1-β)=0.80 were taken. As a result, it was planned to include a minimum of 76 samples in the research protocol, a minimum of 19 for each cavity conditioner groups. However, considering the possible loss, it was planned to include 80 primary molar teeth in the methodology.

Sample selection criteria and storage media

In this in-vitro study, upper and lower primary second molar teeth extracted for orthodontic reasons or due to physiologic exfoliation included. Initially, the samples were examined with a stereomicroscope (Leica Microsystems GmbH, Leica MZ21, Wetzlar, Germany) and the teeth with the fractures, cracks, caries or previously restored were excluded. Also, teeth with more than half root resorption level were excluded. Following the examination of the coronal and radical structures of the teeth, all the surfaces were washed under tap water to remove blood, tissue remnants and debris. Subsequently, the teeth were kept in 0.5% chloramine-T solution until the study experiments. The collection of the extracted primary molar teeth took approximately 20 days, during which time the teeth were kept in Chloramine-T and then further study procedures were carried out.

Definition of the study groups

In the research protocol, it was planned to evaluate IA of two different restorative materials after the use of four different cavity conditioners (1 control, 3 experimental groups). A total of 80 teeth included in the study protocol were randomly assigned to four different cavity conditioner groups (primary randomisation). Randomisation procedures was performed with the software available on the website of www.randomizer.org. Cavity conditioner groups were specified below.

Group 1 10% Polyacrylic Acid (n=20) (Experimental Group).

Group 2 20% Polyacrylic Acid (n=20) (Control Group).

Group 3 17% EDTA (n=20) (Experimental Group).

Group 4 35% Phosphoric Acid (n=20) (Experimental Group).

Cavity preparation

The teeth immersed in chloramine-T solution were gently irrigated and dried for 5 s with air-water spray. Afterwards, standard Class V cavities of 3×3 mm^2 in size and 1.5 mm in depth were prepared on the buccal surfaces of the teeth without bevelling (Fig. 1a and b). The cavities were prepared with a high-speed dental turbine and diamond fissure burs not previously used (141H010, Meisinger, Germany) under water cooling. A new diamond fissure bur for each preparation was used to provide the standardization in cavity preparation procedure. The dimensions of the cavities were verified with a periodontal probe to ensure standardization. Also, the cavities were at least 1 mm coronal to the cemento-enamel junction. Following cavity preparation, the teeth were subjected to the cavity conditioning materials to which each sample was assigned as described below.

Application of cavity conditioners

Cavity conditioners included were applied to the prepared cavities with the procedures below, in accordance with the study group to which each sample was assigned.

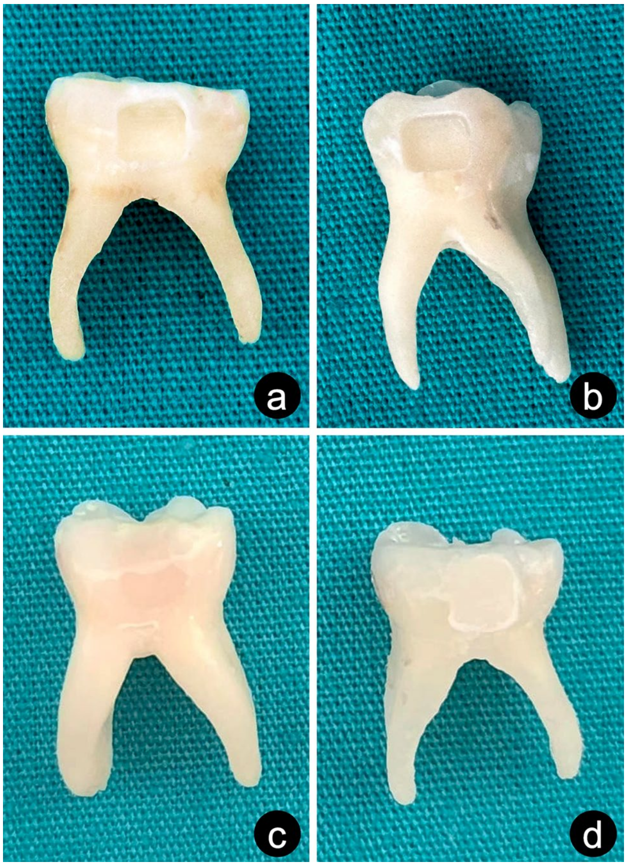

Fig. 1 Representative images of the cavities prepared in the teeth (**a** and **b**). Samples with completed restoration procedures (**c**: glass hybrid restorative, **d**: conventional glass ionomer restorative)

Group 1 (10% polyacrylic acid) (*n*=20) In 20 cavities of this experiment, 10% polyacrylic acid (GC Dentin Conditioner, GC America) was applied with a micro brush for 10 s. The cavities were gently washed and dried after cavity conditioner application.

Group 2 (20% polyacrylic acid, Control Group) (*n*=20) 20% polyacrylic acid (GC Cavity Conditioner, GC America) was applied to 20 cavities of the control group with a micro brush for 10 s. The cavities were gently washed and dried after cavity conditioner application.

Group 3 (17% EDTA) (*n*=20) In 20 cavities of this experiment, 17% EDTA (Cerkamed 17% EDTA Endo-Prep Gel, Poland) was applied with a micro-brush for 60 s. The cavities were gently washed and dried after cavity conditioner application.

Group 4 (35% phosphoric acid) (*n*=20) In 20 cavities of this experiment, 35% phosphoric acid (3 M Scotchbond Universal 35% Phosphoric Acid, USA) was applied with a micro brush for 10 s. The cavities were gently washed and dried after cavity conditioner application.

Following the application of the relevant cavity conditioners for each group, the restorative materials were applied.

Application of restorative materials

After the cavity conditioners were applied to the specimens belonging to each study group, half (*n*=10) of the tooth cavities in each group were randomly assigned to the restorative material subgroups so that half (*n*=10) of the tooth cavities in each group were restored with glass hybrid restorative system and the other half (*n*=10) with conventional glass ionomer restorative material (secondary randomization). Randomization procedures was performed with the software available on the website of www.randomizer.org. Subsequently, according to the groups to which the specimens were assigned, the cavities were restored with glass hybrid restorative system or conventional glass ionomer restorative material. All the restorative procedures were performed by the same author (S.G.) to ensure standardisation and control potential operator variability. Details regarding the application of the restorative materials were presented below.

Glass hybrid restorative system (n = 10)

Bulk Fill Glass Hybrid Equia Forte® HT system (GC Corp, USA) was prepared by mixing in a capsule mixer for 10 s and then applied to the prepared cavities. After finishing and polishing procedures (Sof-Lex® Finishing and Polishing Discs, 3 M ESPE, St. Paul, MN, USA), the surface coating material "Equia Forte® Coat" (GC America Inc., Alsip, IL, USA) containing nano-filled resin was applied to the surface of the restorative material and polymerized for 20 s (Fig. 1c).

Conventional glass ionomer restorative (n = 10)

Voco Ionofil (Voco Ionofil Molar, Voco, Cuxhaven, Germany) was applied to the prepared cavities by mixing powder and liquid according to the manufacturer's instructions. 7 min after the application, the restoration was finished and polished (Sof-Lex® Finishing and Polishing Disks, 3 M ESPE, St. Paul, MN, USA). Subsequently, Final Varnish LC (Voco, Cuxhaven, Germany) was applied and light polymerized for 10 s (Fig. 1d).

Artificial aging

Following the restorative procedures, all the specimens were thermocycled in a thermal cycler (SD Mechatronik GMBH, Feldkirchen-Westerham, Germany) for 5000 cycles [23, 24], equal to approximately 500 days [25]. between 5 and 55 °C with a 30 s dwell time in order to reflect intraoral temperature changes and to subject the specimens to artificial aging procedures for a certain period of time. Subsequently, IA analysis was performed using a Micro-CT system.

Micro-CT scanning and analysis

The samples were scanned with a Micro-CT system (Bruker Skyscan 1275, Kontich, Belgium) for IA analyses. Scanning procedures were performed with 80 kV/125 mA X-ray power [6], 15 micron/pixel image resolution, 1 mm Aluminium (Al) filter parameters [26]. Scans were performed using 0.2 degree steps through 360 degrees. Post-scan reconstruction was performed using NRecon software (version 1.7.4.2, Bruker Skyscan 1275, Belgium) with smoothing 3, ring artifact correction 7 and 38% beam hardening correction [27]. After reconstruction, the region of interest (ROI) were selected [26, 27] (CTAn software version 1.23.0.2, Bruker Skyscan, Belgium), then the volume of interest (VOI) was determined to include the entire cavity and analyses were performed only in these regions [28]. CTvox software (version 1.23.0.2, Bruker Skyscan, Belgium) was used for three-dimensional analysis of the images.

IA analysis and blinded evaluation

The segmentation of enamel, dentin, restorations and gaps of the specimens used in this study was completed by global thresholding using CTAn software. Thresholding is used to extract only black/white pixels from greyscale images, and black/white images were analysed for the calculations used for the detection of gap volumes and restorations. With this method, the total gap volume (for total cavity volume) (mm^3) was calculated, then the region of interest was organised to include only the restoration and the gap volume (mm^3) was calculated. Subsequently, the internal gaps (mm^3) inside the restoration were calculated and subtracted from the total gap volume to obtain IA gaps (mm^3) between the cavity-restoration interface. Following all these procedures, the percentage of voids (%) indicating IA failure was calculated by proportioning IA gaps (mm^3) to the total cavity volume and recorded for statistical analyses (Fig. 2). Micro-CT evaluation was performed by an at least 10 years experienced and blinded operator (A.B.).

The flow diagram summarising the entire methodological process of the present study was shown in Fig. 3 below, and all the steps from the sample selection to the statistical analyses were included in the relevant diagram (Fig. 3).

Statistical analysis

The data were analysed with SPSS 22 software (IBM Corporation, Armonk, NY, USA). Obtained data was analysed for normality with Shapiro-Wilk test. Due to the non-normal distribution of the data, Mann-Whitney U test was used for two-group comparisons and Kruskal-Wallis H test was used for four-group comparisons. The statistical significance level was taken as 0.05.

Results

In the first part of this study, statistical comparisons were performed between the cavity conditioners in terms of the gaps seen at the cavity-restoration interface in glass hybrid restorations. The mean gaps between the cavity surface and restorative material interface were shown in Table 1. Accordingly, the highest IA quality was observed in 35% phosphoric acid group, while 17% EDTA showed the worst IA quality. There was a statistically significant difference between the cavity conditioners regarding the gaps in the cavity-restoration interface in the specimens applied glass hybrid system ($p=0.004$) (Table 1; Figs. 4, 5, 6 and 7).

In the post-hoc tests, no statistically significant differences were found between 10% polyacrylic acid and 20% polyacrylic acid; between 10% polyacrylic acid and 17% EDTA; between 10% polyacrylic acid and 35% phosphoric acid and between 20% polyacrylic acid and 35% phosphoric acid ($p=1.000$, $p=0.365$, $p=0.511$ and 0.941, respectively). However, statistically significant differences were found between 20% polyacrylic acid and 17% EDTA and between 35% phosphoric acid and 17% EDTA ($p=0{,}029$ and $p=0{,}002$, respectively) (Table 1; Figs. 4, 5, 6 and 7).

In the second part of this study, statistical comparisons were performed between the cavity conditioners in terms of the gaps seen at the cavity-restoration interface in conventional glass ionomer restorations. The mean gaps between the cavity surface and the restorative material interface were shown in Table 2. There was a statistically significant difference between the cavity conditioners regarding the gaps in the cavity-restoration interface in conventional glass ionomer system ($p=0.0001$) (Table 2; Figs. 4, 5, 6 and 8).

In the post-hoc tests, no statistically significant differences were found between 20% polyacrylic acid (control group) and 17% EDTA; between 20% polyacrylic acid and 35% phosphoric acid ($p=1.000$ and $p=0.061$, respectively). On the other hand, statistically significant differences were found between 10% polyacrylic acid and 20% polyacrylic acid; between 10% polyacrylic acid and 17% EDTA ($p=0.042$ and $p=0.027$, respectively). Also, a statistically significant difference was found between 10% polyacrylic acid and 35% phosphoric acid; between 17% EDTA and 35% orthophosphoric acid ($p=0.0001$ and $p=0.019$, respectively) (Table 2; Figs. 4, 5, 6 and 8).

For each cavity conditioner, statistical comparisons were also performed between the restorative materials in terms of IA quality. After 10% polyacrylic acid application, the gaps between the conventional glass ionomer restorative and the cavity surfaces was found to be statistically significantly higher than the gaps between the glass hybrid restorative material and the cavity surfaces ($p=0.0001$) (Table 3).

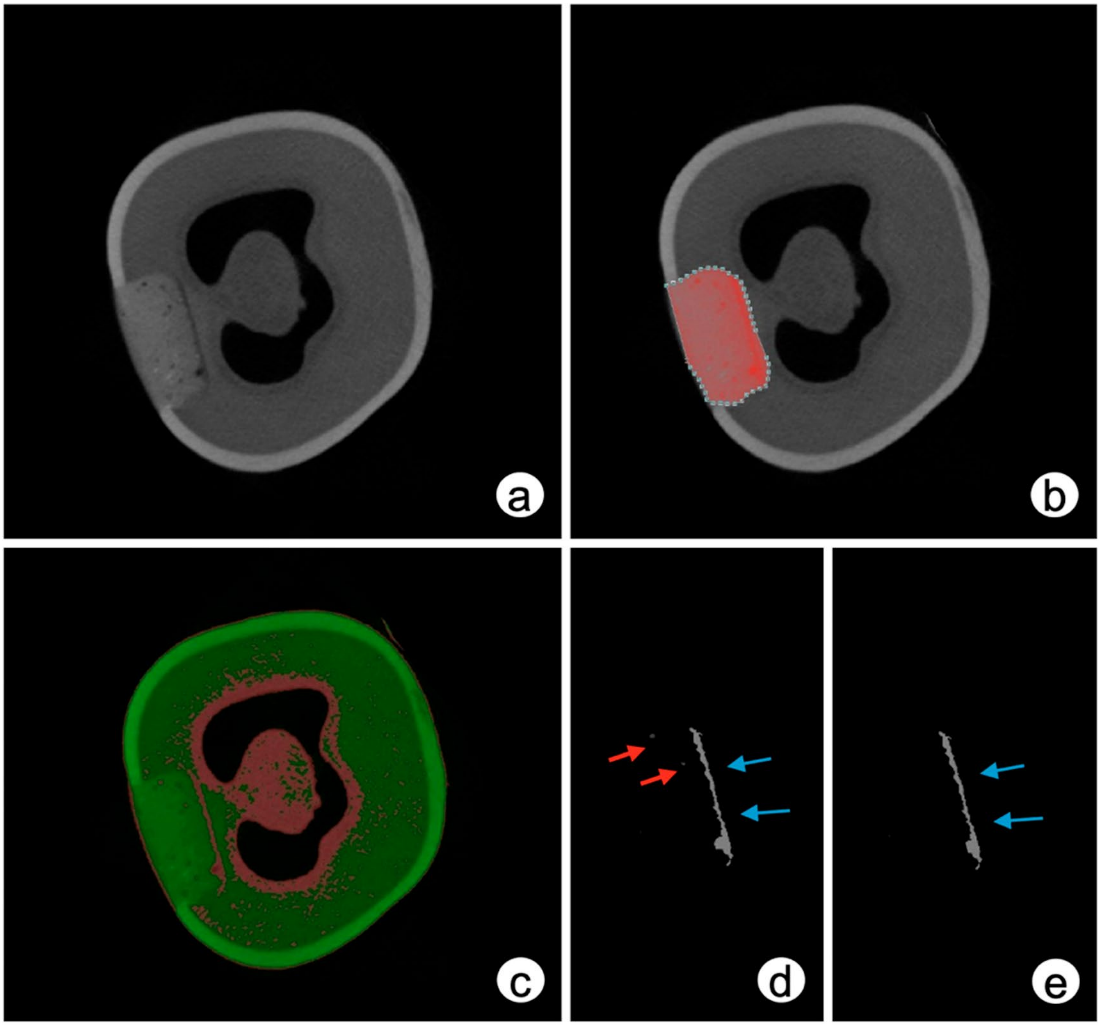

Fig. 2 Representative images of the calculation of the internal gaps in the Micro-CT system. [**a**: Micro-CT image of the tooth structures and the restorative material, **b**: segmentation of the total cavity volume, **c**: segmentation of all the gaps from the total cavity volume, **d**: calculation of internal gaps inside the restoration (red arrows) and internal gaps at the cavity-restoration interface (blue arrows), **e**: calculation of internal adaptation gaps (blue arrows) by subtracting the internal gaps inside the restoration from the total gaps]

After 20% polyacrylic acid (control) application, the gaps between the conventional glass ionomer restorative and the cavity surfaces was found to be statistically significantly higher than the gaps between the glass hybrid restorative material and the cavity surfaces ($p=0.001$) (Table 4).

After 17% EDTA application, there was no statistically significant difference between conventional glass ionomer restorative and the glass hybrid restorative system regarding the IA quality ($p=0.131$) (Table 5).

After 35% phosphoric acid application, the gaps between the conventional glass ionomer restorative and the cavity surfaces was found to be statistically significantly higher than the gaps between the glass hybrid restorative material and the cavity surfaces ($p=0.002$) (Table 6).

Discussion

Dental caries is a disease that causes localised demineralisation and destruction of dental hard tissues, and it is extremely important to rehabilitate the cavity with restorative materials to prevent further complications in cavitated caries lesions [1, 29]. Conventional glass ionomer restoratives, which were introduced to the market especially in the early periods, have disadvantages such as their durability, long hardening time, sensitivity to moisture in the early period and long-term clinical success not being as high as resin-containing restoratives. On the other hand, considering their positive features -such as ease to handle, fluoride release, adhesion to moist enamel and dentin surfaces, and not requiring advanced and precise application techniques in patients who are difficult to cooperate- the importance of new generation glass

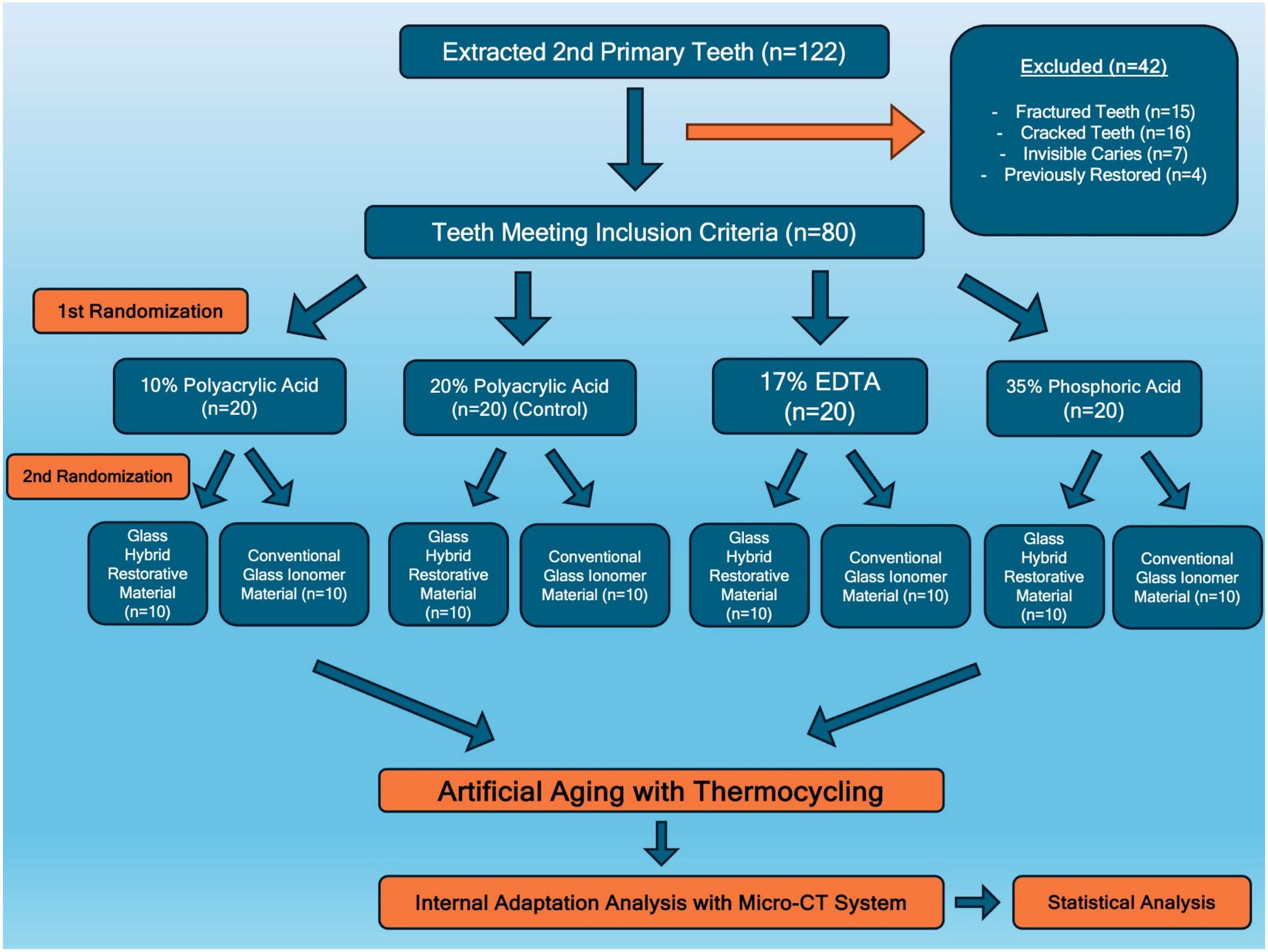

Fig. 3 Flow diagram of the study methodology

Table 1 Statistical comparisons between the cavity conditioners in terms of IA quality for glass hybrid system

Tested Parameter	Tested Groups	Glass Hybrid Restorative Material						Kruskal-Wallis H test			
		n	Mean	Median	Min	Max	SD	Mean Rank	χ2	p	Post-Hoc Tests
Internal gaps between the cavity surfaces and the restorative material (%)	**Group 1: 10% Polyacrylic Acid**	10	1.191	0.467	0.000	4.011	1.514	20.70	13.13	**0.004***	Group 1–Group 2: $p=1.000$ Group 1–Group 3: $p=0.365$ Group 1–Group 4: $p=0.511$ Group 2–Group 3: $p=0.029$* Group 2–Group 4: $p=0.941$ Group 3–Group 4: $p=0.002$*
	Group 2: 20% Polyacrylic Acid (control)	10	0.321	0.266	0.072	0.645	0.200	19.10			
	Group 3: 17% EDTA	10	2.438	1.406	0.135	7.761	2.558	30.50			
	Group 4: 35% Phosphoric Acid	10	0.180	0.046	0.020	0.978	0.303	11.70			
	Total	40	1.033	0.346	0.000	7.761	1.702	-			

Min: Minimum, Max: Maximum, SD: Standart Deviation, χ2: Chi-Square, p: Probability Value

* indicates statistical significance

hybrid systems in pediatric dentistry is indisputable [1, 30–32].

Although the use of glass ionomer systems has increased over time, the higher bond strength of resin-containing materials to dental hard tissues has led to initiatives and research to increase the adhesion and adaptation properties of glass ionomers to the cavity [1, 32–35]. In this context, it has been suggested by various studies and researchers that cavity conditioning procedures should be applied to increase the adhesion and adaptation by removing the smear layer [7, 8, 36–38]. When previous studies are examined, the most commonly used cavity conditioners include polyacrylic acid, phosphoric acid, EDTA, pyruvic acid, citric acid, maleic

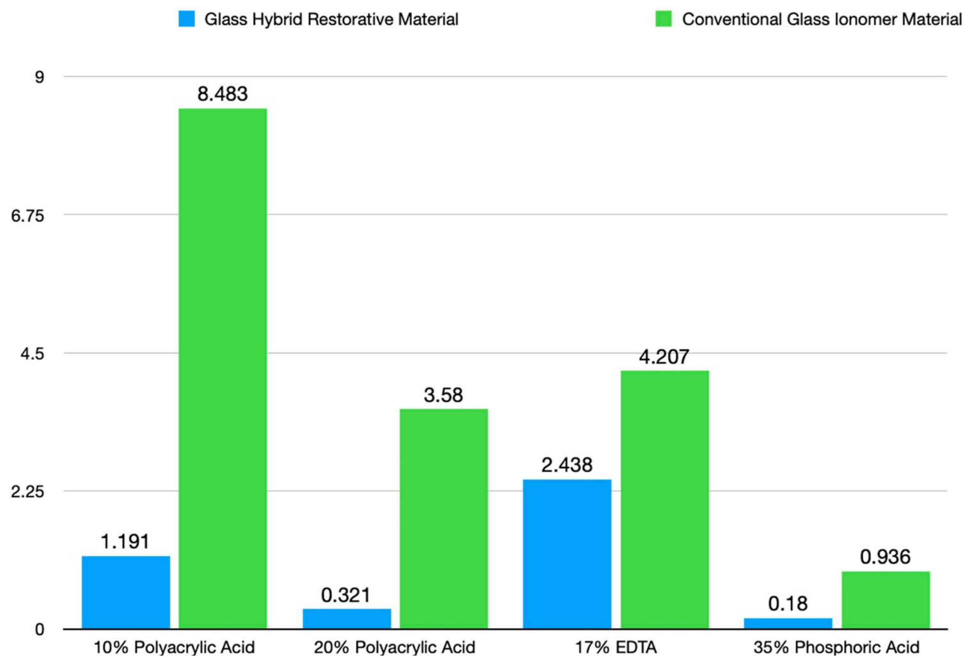

Fig. 4 Internal gap distributions (mean - %) between the cavity surface and the restorative materials

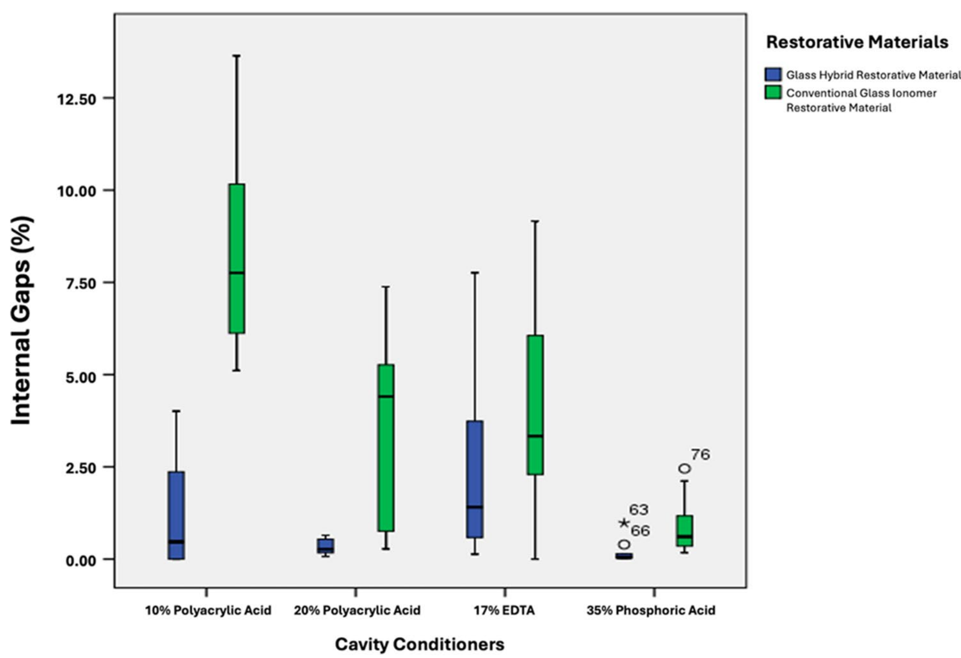

Fig. 5 Box-plot showing the gap (%) distributions between the cavity surface and restorative materials for each cavity conditioner and restorative material

acid and other organic acids or, to a lesser extent, other experimental acids [7, 8, 36–39]. Polyacrylic acids contained in glass ionomer materials are known as cavity conditioner that are both recommended by glass ionomer manufacturers and previous scientific studies. Polyacrylic acid is known as an agent capable of removing the smear layer, increasing the wettability of dentin and maximising the bond strength by improving ion exchange with the glass ionomer restorative material [8, 40]. Therefore, 10% and 20% dilutions were preferred to be used in this study. On the other hand, since 20% polyacrylic acid is reported to be more successful than 10% polyacrylic acid [41] and 20% polyacrylic acid is recommended by the manufacturers of glass ionomer systems, 20% polyacrylic acid group was planned as a control. Also, since it was desired to compare the effectiveness of 10% and 20% polyacrylic

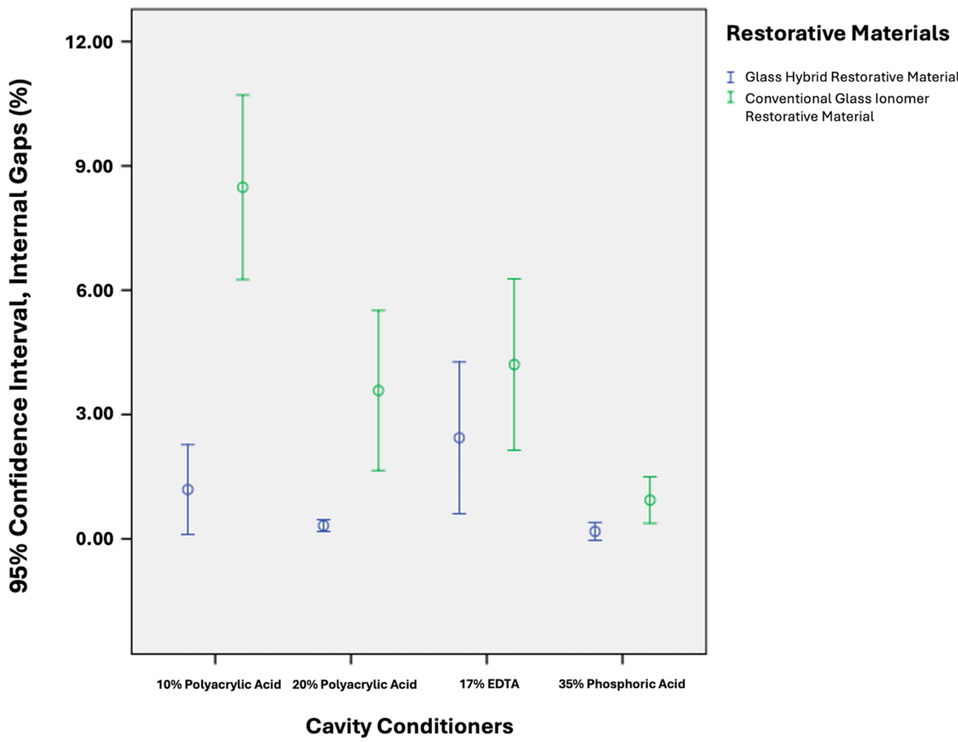

Fig. 6 95% confidence interval plot of the mean internal gaps (between the cavity surface and restorative materials) for each cavity conditioner and restorative material

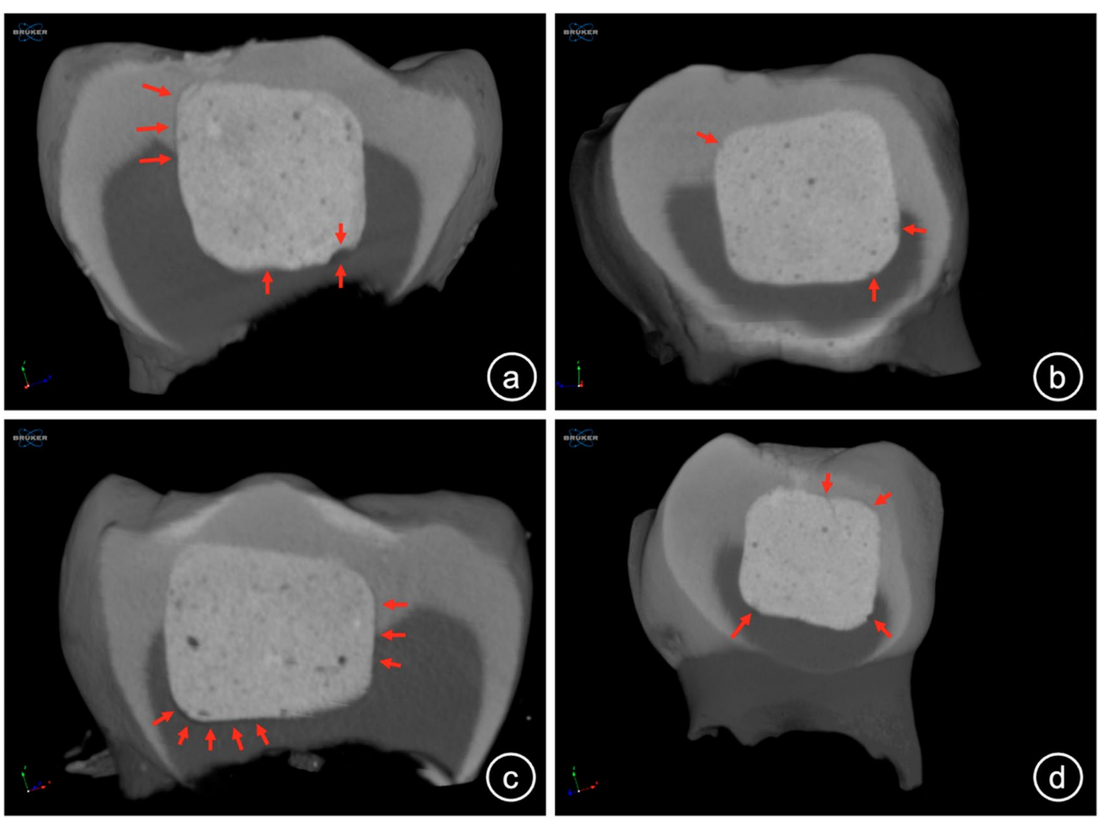

Fig. 7 Representative images showing the gaps (red arrows) formed at the cavity-restorative material interface in the specimens applied glass hybrid system after different cavity conditioners. [**a**: 10% polyacrylic acid, **b**: 20% polyacrylic acid (control group), **c**: 17% EDTA, **d**: 35% phosphoric acid]

Table 2 Statistical comparisons between the cavity conditioners in terms of IA quality for conventional glass ionomer restorative

Tested Parameter	Tested Groups	Conventional Glass Ionomer Restorative Material						Kruskal-Wallis H test			
		n	Mean	Median	Min	Max	SD	Mean Rank	χ2	p	Post-Hoc Tests
Internal gaps between the cavity surfaces and the restorative material (%)	**Group 1: 10% Polyacrylic Acid**	10	8.483	7.756	5.110	13.640	3.116	32.90	21.18	**0.0001***	Group 1–Group 2: $p=0.042$* Group 1–Group 3: $p=0.027$* Group 1–Group 4: $p=0.0001$* Group 2–Group 3: $p=1.000$ Group 2–Group 4: $p=0.061$ Group 3–Group 4: $p=0.019$*
	Group 2: 20% Polyacrylic Acid (control)	10	3.580	4.408	0.276	7.382	2.700	18.80			
	Group 3: 17% EDTA	10	4.207	3.334	0.000	9.158	2.889	21.30			
	Group 4: 35% Phosphoric Acid	10	0.936	0.604	0.175	2.451	0.785	9.00			
	Total	40	4.301	3.892	0.000	13.640	3.676	-			

Min: Minimum, **Max**: Maximum, **SD**: Standart Deviation, **χ2**: Chi-Square, **p**: Probability Value

*indicates statistical significance

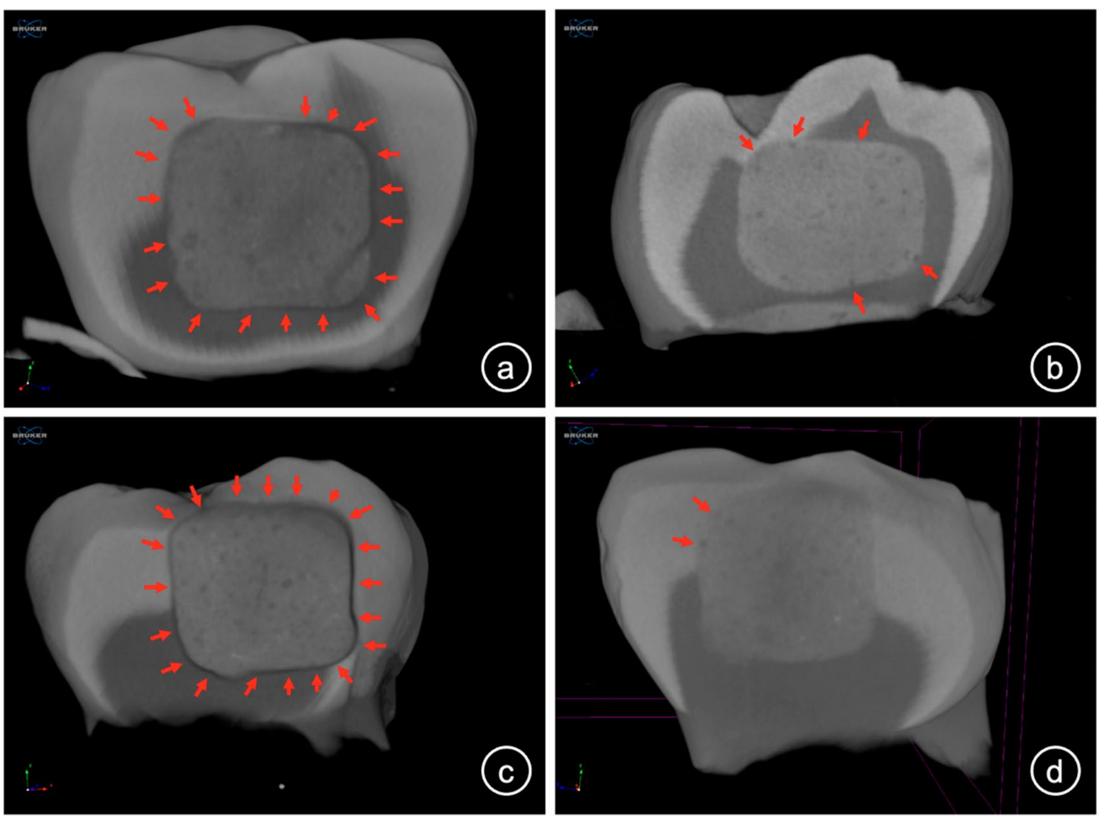

Fig. 8 Representative images showing the gaps (red arrows) formed at the cavity-restorative material interface in the specimens applied conventional glass ionomer restorative after different cavity conditioners. [**a**: 10% polyacrylic acid, **b**: 20% polyacrylic acid (control group), **c**: 17% EDTA, **d**: 35% phosphoric acid]

acid in the same application time, 10% polyacrylic acid was applied for 10 s.

Based on the researches for an alternative material to polyacrylic acid to be used as a cavity conditioner, mostly 17% dilutions of EDTA were preferred in previous studies. EDTA effectively removes the mineralised/inorganic part of the smear layer from cavity surfaces [6, 42]. Also, there were previous studies in dental literature on the use of phosphoric acid as a cavity conditioner [8, 43, 44]. Suresh et al. [44] emphasised that after the use of phosphoric acid as a cavity conditioner, the penetration of high-viscosity glass ionomer restorative materials into the dentin surface was more acceptable than other agents. Therefore, in this study, 17% and 35% dilutions of EDTA and phosphoric acid, respectively, were included in the study protocol.

Previous studies used different methods to perform IA analyses. Although there were studies using Scanning

Table 3 Statistical comparisons between the restorative materials in terms of internal gaps (at the cavity-restoration interface) after the use of 10% polyacrylic acid

Tested Parameter	Restorative Materials	Group 1: %10 Polyacrylic Acid						Mann-Whitney U test		
		n	Mean	Median	Min	Max	SD	Mean Rank	z	p
Internal gaps between the cavity surfaces and the restorative material (%)	**Glass Hybrid Restorative System**	10	1.191	0.467	0.000	4.011	1.514	5.50	-3.7	**0.0001***
	Conventional Glass Ionomer Restorative	10	8.483	7.756	5.110	13.640	3.116	15.50		
	Total	20	4.837	4.561	0.000	13.640	4.436	-		

Min: Minimum, **Max**: Maximum, **SD**: Standart Deviation, **p**: Probability Value

*indicates statistical significance

Table 4 Statistical comparisons between the restorative materials in terms of internal gaps (at the cavity-restoration interface) after the use of 20% polyacrylic acid

Tested Parameter	Restorative Materials	Group 2: %20 Polyacrylic Acid						Mann-Whitney U test		
		n	Mean	Median	Min	Max	SD	Mean Rank	z	p
Internal gaps between the cavity surfaces and the restorative material (%)	**Glass Hybrid Restorative System**	10	0.321	0.266	0.072	0.645	0.200	6.20	-3.25	**0.001***
	Conventional Glass Ionomer Restorative	10	3.580	4.408	0.276	7.382	2.700	14.80		
	Total	20	1.951	0.565	0.072	7.382	2.503	-		

Min: Minimum, **Max**: Maximum, **SD**: Standart Deviation, **p**: Probability Value

*indicates statistical significance

Table 5 Statistical comparisons between the restorative materials in terms of internal gaps (at the cavity-restoration interface) after the use of 17% EDTA

Tested Parameter	Restorative Materials	Group 3: 17% EDTA						Mann-Whitney U test		
		n	Mean	Median	Min	Max	SD	Mean Rank	z	p
Internal gaps between the cavity surfaces and the restorative material (%)	**Glass Hybrid Restorative System**	10	2.438	1.406	0.135	7.761	2.558	8.50	-1.51	0.131
	Conventional Glass Ionomer Restorative	10	4.207	3.334	0.000	9.158	2.889	12.50		
	Total	20	3.322	2.467	0.000	9.158	2.807	-		

Min: Minimum, **Max**: Maximum, **SD**: Standart Deviation, **p**: Probability Value

Table 6 Statistical comparisons between the restorative materials in terms of internal gaps (at the cavity-restoration interface) after the use of 35% phosphoric acid

Tested Parameter	Restorative Materials	Group 4: 35% Phosphoric Acid						Mann-Whitney U test		
		n	Mean	Median	Min	Max	SD	Mean Rank	z	p
Internal gaps between the cavity surfaces and the restorative material (%)	**Glass Hybrid Restorative System**	10	0.180	0.046	0.020	0.978	0.303	6.40	-3.099	**0.002***
	Conventional Glass Ionomer Restorative	10	0.936	0.604	0.175	2.451	0.785	14.60		
	Total	20	0.558	0.308	0.020	2.451	0.697	-		

Min: Minimum, **Max**: Maximum, **SD**: Standart Deviation, **p**: Probability Value

*indicates statistical significance

Electron Microscopy (SEM) to examine the restorative material-cavity interface, SEM is very sensitive to the technique used and has significant limitations in terms of quantitative evaluation due to its two-dimensional nature [45–47]. Therefore, in recent years, Micro-CT technique, a non-invasive method, has been preferred to evaluate IA quality [6, 48–50]. By reconstructing three-dimensional images obtained from Micro-CT system, the adaptation capacity of restorations and the internal gaps at the restoration-tooth interface can be detailed examined to the desired extent and degree, regardless of the shape or dimensions of a specimen [50]. In this study, it was preferred to perform IA analyses with a three-dimensional Micro-CT device and to analyse the results because of its advantages such as allowing non-invasive examination without taking any cross-section on the teeth and providing re-evaluation in the desired area. On the other hand, it was preferred chloramine-T solution for the storage of extracted primary teeth until the initiation of the study procedures. Chloramine-T solution is a surface active disinfectant agent and a source of free radicals that hydrolyse in water to create amino groups (NH_2) and hypochlorous acid (HClO) [51, 52]. Its 0.5-1% diluted solution is frequently used in dentistry [53, 54]. Also, it is recommended to immerse extracted teeth in 0.5% chloramine-T solution before the laboratory procedures in in-vitro studies, especially those investigating parameters such as adhesion or internal/marginal adaptation as in the current study [52]. In this context, in many internal adaptation studies in dentistry literature [6, 50, 55–57], chloramine-T solution was used to store the teeth until the study procedures.

In this study, which investigated the effects of different types of cavity conditioners used before the placement different glass ionomer systems into the prepared cavities on IA at the cavity-restoration interface, two types of statistical comparisons were performed. The first of these is the statistical comparison between the cavity conditioner materials for each restorative material. The second one is the comparison between the restorative materials for each cavity conditioner. According to obtained data, for both restorative materials, the null hypothesis was rejected. In the specimens restored with glass hybrid system, cavity conditioners with the highest IA quality were 35% phosphoric acid and 20% polyacrylic acid, and no statistically significant difference was observed between these two materials. On the other hand, the internal gaps determined with the use of 17% EDTA were significantly higher than the gaps after the use of 20% polyacrylic acid (control) and 35% phosphoric acid. When the dental literature is examined, it was seen that most of the studies evaluating the effectiveness of cavity conditioners did not include glass hybrid systems, so it could be said that comparative discussion of the glass hybrid results of this study with the results of previous studies would not give accurate results. Nevertheless, Mazaheri et al. [7] applied high viscosity glass ionomer restoration after the use of 20% acrylic acid, 35% phosphoric acid, 12% citric acid and 17% EDTA and comparatively evaluated the microleakage at the cavity-restoration interface. Researchers reported that the best sealing results were obtained with the use of 20% acrylic acid and 17% EDTA. The successful results in the use of 20% acrylic acid are consistent with the results of this study, while the unsuccessful results of phosphoric acid in that study did not coincide with the findings of the present study. This may be due to differences in study methodology. However, in an in-vitro study by Saad et al. [58], the microtensile bond strengths of RMCIS in healthy and artificial carious dentin were evaluated after the use of three different cavity conditioners including 20% polyacrylic acid, 20–30% HEMA and 17% EDTA. The researchers emphasised that the use of 17% EDTA solution was less successful than the other two cavity conditioners. In addition, in the current study, although there were no statistically significant differences between them, 10% polyacrylic acid showed more successful IA results than 17% EDTA in the samples restored with glass hybrid restorative, and the gaps indicating IA failure at the cavity-restorative material interface were found to be less in the use of 10% polyacrylic acid compared to 17% EDTA. Unnikrishnan et al. [38] preferred 10% polyacrylic acid and 17% EDTA as cavity conditioners applied before the placement of high viscosity glass ionomer to primary anterior teeth. The researchers stated that 10% polyacrylic acid provided a better surface conditioning in modifying or removing the smear layer compared to 17% EDTA and, in this context, 10% polyacrylic acid offered a better adhesion quality. This finding was also consistent with the findings of the present study.

In this study, 20% polyacrylic acid and 35% phosphoric acid were found to be the best cavity conditioners for the specimens restored with glass hybrid system, although there was no statistically significant difference between them. Although there was not enough evidence-based data in the literature, there were studies on the use of phosphoric acid as a cavity conditioner before the application of glass ionomers. Phosphoric acid is an agent with the ability to bind calcium ions, which helps to remove calcium from the tooth surface and thus helps to clean the surface and eliminate the smear layer [59]. Depending on the application time, phosphoric acid can cause the removal of minerals such as calcium and phosphorus while removing the smear layer [8]. Khaoruf et al. [60] applied phosphoric acid (gel and liquid) and polyacrylic acid on coronal dentin surfaces for 15 s. They pointed out that phosphoric acid performed more successful surface preparation. As a matter of fact, in this study, in line with this information, although there was no significant statistical difference between them, the fact that phosphoric acid was superior to 20% dilution of polyacrylic acid in terms of IA success was attributed to a more acceptable surface preparation. In a study on the use of phosphoric acid as a surface conditioner, Suresh et al. [44] investigated the effects of 10% polyacrylic acid and 37% phosphoric acid on permanent teeth before the application of high viscosity glass ionomer. According to the results, the use of 37% phosphoric acid was found to be effective in providing a higher penetration depth of high viscosity glass ionomers into dentin. In addition, in a study conducted by Imbery et al. [61] on the occlusal surfaces of caries-free third molars, the authors used 35% phosphoric acid for 10 s, Cavity Conditioner (20% polyacrylic acid+3% aluminum chloride) for 10 s, EDTA for 60 s and Ketac Primer (10% polyacrylic acid) for 15 s before 3 different RMCIS applications and evaluated the bond strengths. The researchers observed that the highest success was observed in the samples with 35% phosphoric acid. These findings reported by Suresh et al. [44] and Imbery et al. [61] were consistent with our study.

In the samples restored with glass hybrid system, no statistically significant difference was found between two different dilutions of polyacrylic acid. However, 20% polyacrylic acid provided more successful IA results than 10% polyacrylic acid. In a study conducted by Pereira et al. [39] 10% and 20% polyacrylic acid were applied to the cavities for 20 s and 10 s, respectively and the restorations were completed with RMCIS (Fuji II LC) and its improved version (Fuji II LC-I) and the bond strengths were measured afterwards. The researchers stated that the bond strength values in the samples where 20% polyacrylic acid was at more acceptable level. Es-Souni et al. [62] emphasized that conditioning the dental surface with polyacrylic acid before the application of glass ionomer restorations caused the formation of a thin polymeric film layer on the surface, and this film layer could act as a primer and increase adhesion.

In the specimens restored with conventional glass ionomer, the highest IA quality was observed in the use of 35% phosphoric acid, while 10% polyacrylic acid showed the poorest IA success. 10% polyacrylic acid showed less successful IA quality with a statistically significant difference compared to other cavity conditioners. This differed from the results in specimens restored with glass hybrid system. The fact that 10% polyacrylic acid showed poorer IA than the other agents may also be attributed to the differences in chemical composition between conventional glass ionomers and glass hybrid restoratives. Khan et al. [63] used 37% phosphoric acid, 2% chlorhexidine digluconate and 10% polyacrylic acid as cavity conditioners before the placement of conventional glass ionomer in premolar teeth and evaluated the microleakage and bond strength. Accordingly, it was reported that phosphoric acid showed the least microleakage and the highest bond strength. In this study, it was found that 35% phosphoric acid and 20% polyacrylic acid were the cavity conditioners that offered the best IA quality in the samples restored with conventional glass ionomer, however, no statistically significant difference was found between them. This finding was similar to the samples restored with glass hybrid restorative system in this study. However, Khaoruf et al. [60] applied phosphoric acid and polyacrylic acid to coronal dentin surfaces for 15 s. The authors argued that the application of polyacrylic acid for 15 s did not significantly demineralize dentin. Based on this finding reported by Khaoruf et al. [60], although statistically significant differences were not observed, the increased success of phosphoric acid compared to polyacrylic acid (20%) can be attributed to its successful surface preparation on the dentin surface. However, we think that this issue should be supported by further studies in order to confirm this issue on the basis of IA quality.

In another part of this study, for each cavity conditioner, two restorative materials were statistically compared between them. According to these results, in the use of 10% polyacrylic acid, 20% polyacrylic acid and 35% phosphoric acid, glass hybrid system showed superior IA quality than conventional glass ionomer. In contrast, in the use of 17% EDTA, there were no statistically significant differences in the quality of IA between glass hybrid and conventional glass ionomer. This finding was attributed to the fact that the application of 17% EDTA as a cavity conditioner produced a similar bonding effect on the surfaces where both restorative materials would be applied. However, in order to confirm these results, it is thought that further IA studies should be performed by using advanced evaluation methods.

This study had some limitations. The first one is that each tooth included in the study protocol presented different chemical and dental properties due to the fact that they were extracted from different pediatric patients. Extracted teeth may show significant differences in the parameters such as mineralization, dental age, diameter, density and orientation of dentinal tubules, and collagen structures, which may affect adhesion and adhesion-related IA analysis. Due to the possibility of these differences, the allocation of extracted teeth to the study groups in this study was based on the randomization. However, one of the most important limitations of this study was that the cavities were first exposed to cavity conditioners and then restorative procedures were performed. At this point, the dilemma of whether the success or failure of IA depends on the cavity conditioning material or the different glass ionomer materials applied may also be a limitation for this study. To eliminate this limitation, both cavity conditioners and restorative materials were statistically analyzed among themselves. Another limitation for this study was that no negative control group was included in the methodology. This was because the use of cavity conditioners prior to the application of glass ionomer restorations was strongly recommended by manufacturers and previous scientific research. On the other hand, as mentioned, in-vitro studies on cavity conditioners have generally focused on the bond strength or microleakage. In this context, there were some gaps in comparatively discussion of the results with the results of previous studies in the dental literature. In this respect, it is extremely important and necessary to confirm the findings of this study with further and comprehensive studies on IA of glass ionomer restorations after the use of cavity conditioners in primary teeth.

Conclusions

Within the limitations of this study, in terms of IA quality, 35% phosphoric acid and 20% polyacrylic acid as cavity conditioners, and glass hybrid system as restorative material showed superior results than the others. Since there was no preliminary study in dental literature testing IA of glass ionomer-based restoratives after the use of included cavity conditioners, the results of this study need to be confirmed with further and comprehensive in-vitro tests and further randomized clinical trials.

Abbreviations

IA	Internal Adaptation
EDTA	Ethylene Diamine Tetraacetic Acid
H0	Null Hypothesis
Micro-CT	Micro Computed Tomography
WMA	World Medical Association
Min	Minimum
Max	Maximum
SD	Standart Deviation
χ2	Chi-Square
p	Probability Value

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None.

Author contributions

S.G., A.D. and A.B. conceived and designed the experiments; S.G. and A.D. performed the in-vitro experiments; S.G., A.D. and A.B. analyzed the data; S.G., A.D. and A.B. prepared figures and/or tables; S.G., A.D. and A.B. authored or reviewed drafts of the article; S.G., A.D. and A.B. approved the final draft.

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Data availability

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

Ethical approval for the research protocol of this study was obtained from Ankara University Faculty of Dentistry Clinical Research Ethics Committee on 18.12.2023 with the decision number 15/13. Since extracted primary molar teeth were included in the study procedures, verbal and written informed consent forms were approved by all pediatric patients whose teeth were used and their parents.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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