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Cover Page Footnote

We would like to thank the biostatistician Özlem Arık, who conducted the statistical analysis of the article.

ORIGINAL ARTICLE

The Effects of Boric Acid on The Water Solubility of Glass Ionomer Cements

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ABSTRACT

Changing the water solubility property of glass ionomer cement (GIC), which is frequently used in pediatric dentistry, is the starting point of this study. **Objective:** To evaluate the effects of boric acid on the water solubility (WS) of GIC. **Methods:** The samples were prepared as n=12 in each of four groups: GIC-Conventional glass ionomer cement; BGIC with 1:3 boric acid added to conventional GIC powder; RMGIC-resin-modified glass ionomer cement; BRMGIC with 1:3 boric acid added to RMGIC powder. Weight changes were compared 1, 3 and 24 h after keeping in distilled water. One sample in each group was measured by SEM-EDX analysis. The data were analyzed using a one-way analysis of variance, Dunnett's T3 in multiple comparison tests, and generalized linear models. **Results:** In all groups, water solubility increased. There was a significant difference between the mean values of the WS-1h, WS-3h, and WS-24h variables in each group and between the GIC, BGIC, RMGIC, and BRMGIC groups in the mean values of the WS-1h, WS-3h, and WS-24h variables. The SEM-EDX analysis revealed 14.19–18.47%; 0.80–1.00%; 8.69–14.91%; 0.09–13.10% boron minerals in GIC, BGIC, RMGIC, and BRMGIC, respectively. **Conclusion:** The addition of boric acid led to an increase in water solubility. The effects of boric acid on the GIC samples emphasized its potential role in altering the cement's physicochemical properties. Therefore, it is important to consider carefully when using boric acid as a supplement in GIC formulations for dental applications.

Key words: boric acid, dental material, glass ionomer cement, resin-modified glass ionomer cement, water solubility

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INTRODUCTION

Glass ionomer cement (GIC), which can be attached to tooth structures without preliminary application, is frequently used in dentistry because of its several advantages, such as fluoride release, low thermal expansion coefficient, and acceptable aesthetic properties. The only disadvantage of glass ionomer cement is its solubility in water in the first 24 hours because of its sensitivity to moisture. In addition to low values of durability and fracture toughness, the high values of water absorption and GIC solubility limit this material's clinical use.¹ Water solubility causes several clinical complications, such as secondary caries, microleakage, and defective restoration margins.

GICs are water-based and formed by the acid-base reaction resulting from the mixing of calcium fluoro aluminosilicate glass and polyacrylic acid.^{2,3} Early GICs contained polyacrylic acid liquid and calcium

fluoro aluminosilicate glass powder in an average concentration of 45%, which was solely dissolved in water.^{2,4,5} These conventional GICs are sensitive to moisture and dryness during the setting. These problems have been minimized by the development of new materials. Resin-modified glass ionomer cement (RMGIC) was developed to eliminate the restrictions of conventional GICs. The structure of RMGICs contains fluor aluminosilicate glass beads, modified polyacrylic acid, hydroxyethyl methacrylate (HEMA), and water.³ Water solubility (WS), which affects restorative materials' physical, chemical, and mechanical properties, is an important problem, especially in glass ionomer-based materials. In particular, the extreme sensitivity of conventional GICs to moisture is also evident in RMGICs. In light curing GICs due to photochemical reaction, it is known that the amount of water absorption and water solubility is

less than in conventional GICs because of the formation of a resin network and a layer where resins infiltrate the dentin.^{6,7}

The GIC's physical, chemical, and mechanical properties can be changed according to a powder: liquid ratio. Several applications have been developed to improve the mechanical properties of GICs, such as modifications to amalgam, resin, metal, fiber, polyacrylic acid, phosphoric acid, and the addition of boric acid to the cement powder.^{2,5,8,9} Boron, glass production, glass fiber insulation, porcelain enamel, ceramic glass, and metal alloys are also used in many industrial applications.¹⁰ Recent studies using bioactive glasses in tissue engineering and bone tissue regeneration have provided evidence that boron is useful in bone formation. When bioactive glasses were modified to contain boron, bone formation was found to increase.^{11,12}

Although previous studies in the literature evaluated the effects of boron incorporation on the physical properties of glass ionomers, no study has evaluated the effects of the addition of boron to glass ionomers on water solubility. Thus, this study aims to evaluate the effects of adding boric acid on the water solubility of GICs. The null hypothesis was that the incorporation of boric acid into GICs would affect the water solubility of these materials.

METHODS

Sample preparation

The present study used conventional GIC (Meron, Voco, Cuxhaven, Germany) and RMGIC (Kavitan LC, Pentron, Spofa Dental, Markova, Czech Republic). The boron product used in the GIC experiments contained more than 99.9% boric acid (H_3BO_3 , ETİ Maden, Emet Boron General Administration, Kütahya, Turkey). Boric acid powders were mechanically milled to standardize them using a tungsten grinder (Swing Mill HK 40, Hajek & Koucky Comp, Turnov, Czech Rep.) to a particle size of 30 microns.

GIC was mixed with liquid by adding boric acid to the cement powder at a ratio of 1:3. The mixed cement was placed into steel molds 10 mm in diameter and 2 mm thick. Conventional GIC was self-polymerized in molds between two pieces of glass. RMGIC was polymerized between two pieces of glass in the molds using a light source (Light Emitting Diode-LED, Demi Plus, Kerr Dental, Orange, California, USA) from the upper surface for 20 seconds. The following four groups were prepared: 1- conventional GIC; 2- boric acid added to conventional GIC (BGIC); 3- RMGIC; 4- boric acid added to RMGIC (BRMGIC).

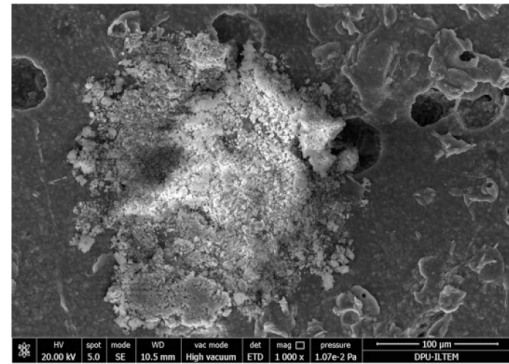


Figure 1. Boric acid aggregation in the SEM image of a 100 μ m area of a sample (magnification 1000x, 100 μ m).

Assessment of surface structure and mineral analysis

All specimens from the four test groups were selected, and the surfaces were inspected using a scanning electron microscope (SEM, NOVA NanoSEM 650, FEI Company, Oregon, USA). The samples were dried in a high vacuum and then prepared for analysis by coating their surfaces with gold. Each sample was measured using a probe at 20 kV power and 120x–50.000x magnification. The SEM images and surface mineral analyses were recorded. To observe the sizes and the homogeneous distribution of boric acid and its effects on the crystal structure, SEM images of each group were examined. Thirteen samples were prepared for each group. Three samples, observed to be not homogeneously dispersed in SEM examination, were excluded from the study. In order to equate the sample numbers in accordance with the power analysis, 12 samples for each homogeneously distributed group were included in the study (Figure 1). The samples' surface homogeneity and surface structure were evaluated by energy-dispersive X-ray spectroscopy (EDX). Clean areas free from contamination, dust, or debris on the sample surface were selected. Homogeneous areas in terms of composition and structure without boric acid aggregations were selected. A wide selection of areas representing the general sample was also made in the selected areas.

Water solubility

After polymerization, the samples were weighed using precision scales. The disk-shaped specimens (diameter= 10 mm and thickness= 2 mm) were prepared, and water solubility was evaluated according to the methodology described in ISO 4049:2019-05.¹³ The samples were kept in dark bottles containing 40 cc distilled water at 37°C in an incubator. They were then removed. After 1 h, 3 h, and 24 h, both sides of the disk were lightly dried using paper and weighed again. Changes in the weight of each sample were compared at 1 h (M1), 3 h (M2), and 24 h (M3) with the initial mass (M0). Water solubility was calculated using the following formula¹⁴:

Water solubility (WS) (ng/mm³) = M1 (ng) – M0 (ng) / V (mm³)

Water solubility (WS) (ng/mm³) = M2 (ng) – M0(ng) / V (mm³)

Water solubility (WS) (ng/mm³) = M3 (ng) – M0(ng) / V (mm³)

The initial dry weights of samples were determined at M0 and after maintenance in distilled water at M1, M2, and M3 in nanograms (ng). The volumes of the samples were calculated in millimetres (mm³) according to the diameters and thicknesses, and the water solubility values of the samples were calculated as ng/mm³.

Statistical analysis

The statistical analysis results were obtained using the IBM SPSS (Statistical Package for Social Sciences) Statistics 20. The results were evaluated using a one-way analysis of variance (ANOVA), Dunnett's T3, and generalized linear models (GLM). Interpretations were made of the obtained p-values. The sample size in each group was calculated depending on the statistical analysis method suitable for the purpose of the research and the data type to be used. In order to reveal the 19-unit difference with 20 standard deviations at a 0.05 significance level (Type 1 error) and 0.95 confidence level, using a paired-sample t-test, with a power of 80% (1-β), 12 sample sizes should be taken in each group.

RESULTS

Surface structure and mineral analysis

In this study, an SEM-EDX analysis was performed to determine the aggregation of boric acid, the participation of boric acid in the crystallization structure on the surface, and the surface homogeneity of all samples. Morphological analysis of test specimens' particle sizes was conducted by SEM-EDX, and the size of the boron crystal particles was measured at 30 microns. SEM images of one specimen among four randomly selected test groups are shown in Figure 2.

In the GIC group, B, C, O, F, Na, Al, Si, Sr, Ca, and I minerals were detected, as shown in Figure 3. The results showed that the mineral structures formed by boron ranged from 14.19–18.47%.

In the BGIC group, B, C, O, F, Al, Si, Ca, and I minerals were detected, as shown in Figure 4. The results showed that the mineral structures formed by boron ranged from 0.80–1.00%.

In the RMGIC group, B, C, O, F, Na, Al, Si, Sr, Ca, and I minerals were detected, as shown in Figure 5. The results showed that the mineral structures formed by boron ranged from 8.69–14.91%, which were mainly on the surface.

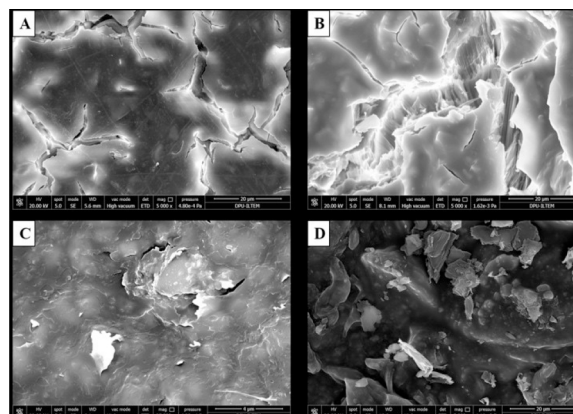


Figure 2. Morphological analysis of test specimens by SEM imaging was presented with high magnifications. It is seen that the surface of glass ionomer cement has a smooth and homogeneous structure in all samples. Boric acid aggregations are not seen. This means that the cement is well mixed and applied. All groups have microcracks. A) Conventional glass ionomer cement (GIC) (5000x), B) Boric acid added conventional GIC (5000x), C) Resin modified glass ionomer cement (RMGIC) (25000x), D) Boric acid added RMGIC (5000x).

The results of the analysis of the minerals on the surface of BRMGIC are shown in Figure 6. B mineral was detected in a range from 0.09–13.10%. In addition, C, O, F, Na, Al, Si, P, Cl, and I minerals were detected.

Water solubility of the samples

Since the data of the group variables provided the assumption of normal distribution and homogeneity of variance, results were obtained using parametric hypothesis tests.

The General Linear Model (GLM) analysis showed that there was a statistically significant difference between the mean values of the WS-1h, WS-3h, and WS-24h variables calculated for each group (* p<0.05, ** p<0.01) (Table 1). Comparisons of water solubility after 1 h, 3 h, and 24 h (WS-1h, WS-3h, and WS-24h), as well as the minimum, maximum, mean, and standard deviation values of the four groups (GIC, BGIC, RMGIC, and BRMGIC), are shown in Table 1. When the mean values were examined, the group with the lowest water absorption was found to be the BGIC-1h group, and the BRMGIC-3h group had the highest water absorption. In Table 1, the negative value was expressed as water solubility because of the loss in volume and mass, which was found in the highest BGIC-24 h group.

The one-way ANOVA analysis showed that there was a statistically significant difference at a confidence level of 0.95 between the GIC, BGIC, RMGIC, and BRMGIC groups in terms of the mean values of the WS-1h, WS-3h, and WS-24h variables (p<0.01) (Table 2). Table 2 shows the minimum, maximum, mean,

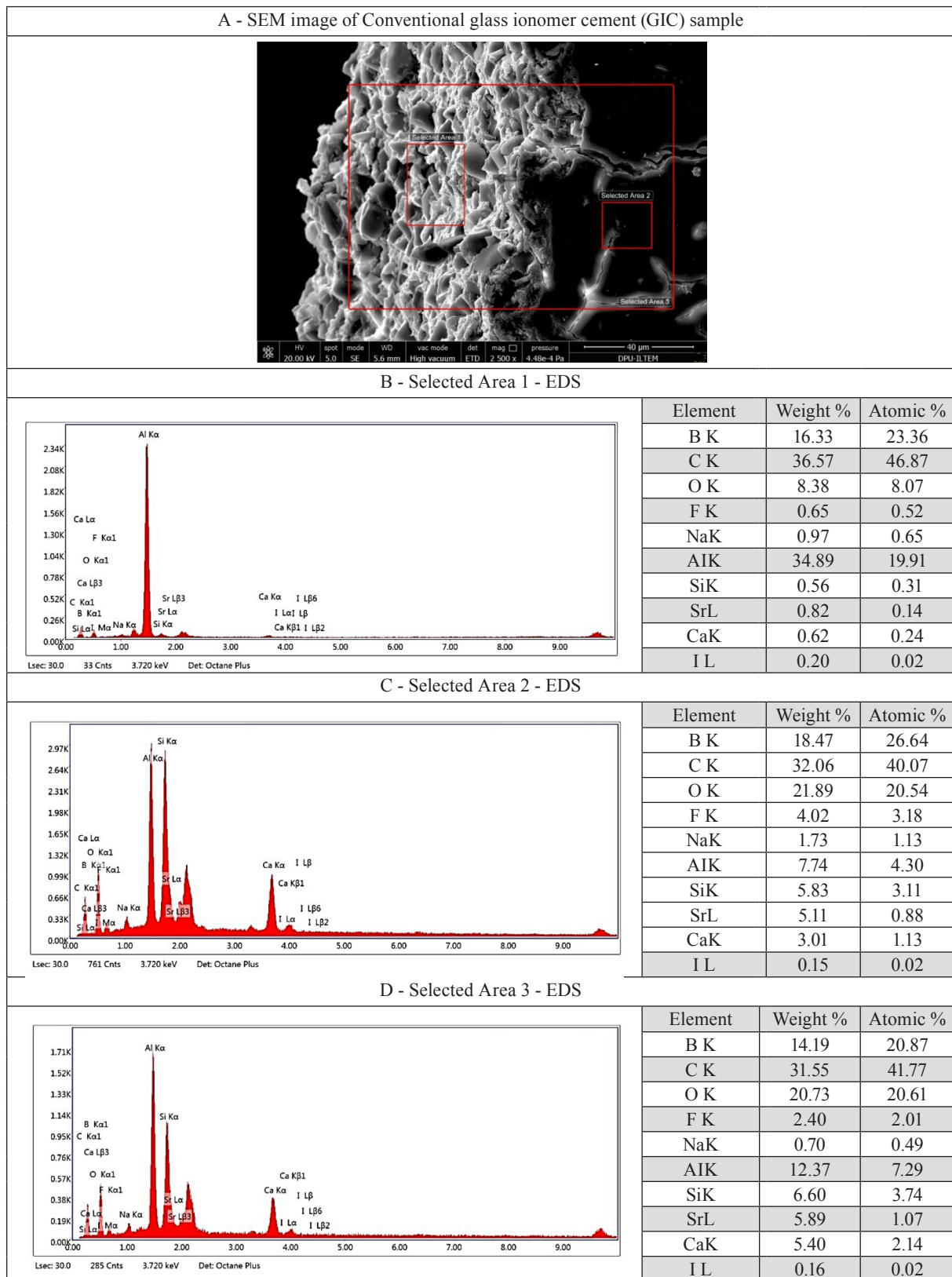


Figure 3. SEM-EDX elemental analysis: A) SEM image of Conventional glass ionomer cement (GIC) sample with selected areas for mean quantitative elemental analysis; B, C, D) EDX elemental spectrum demonstrating the presence for B, C, O, F, Na, Al, Si, Sr, Ca, I elements in selected areas.

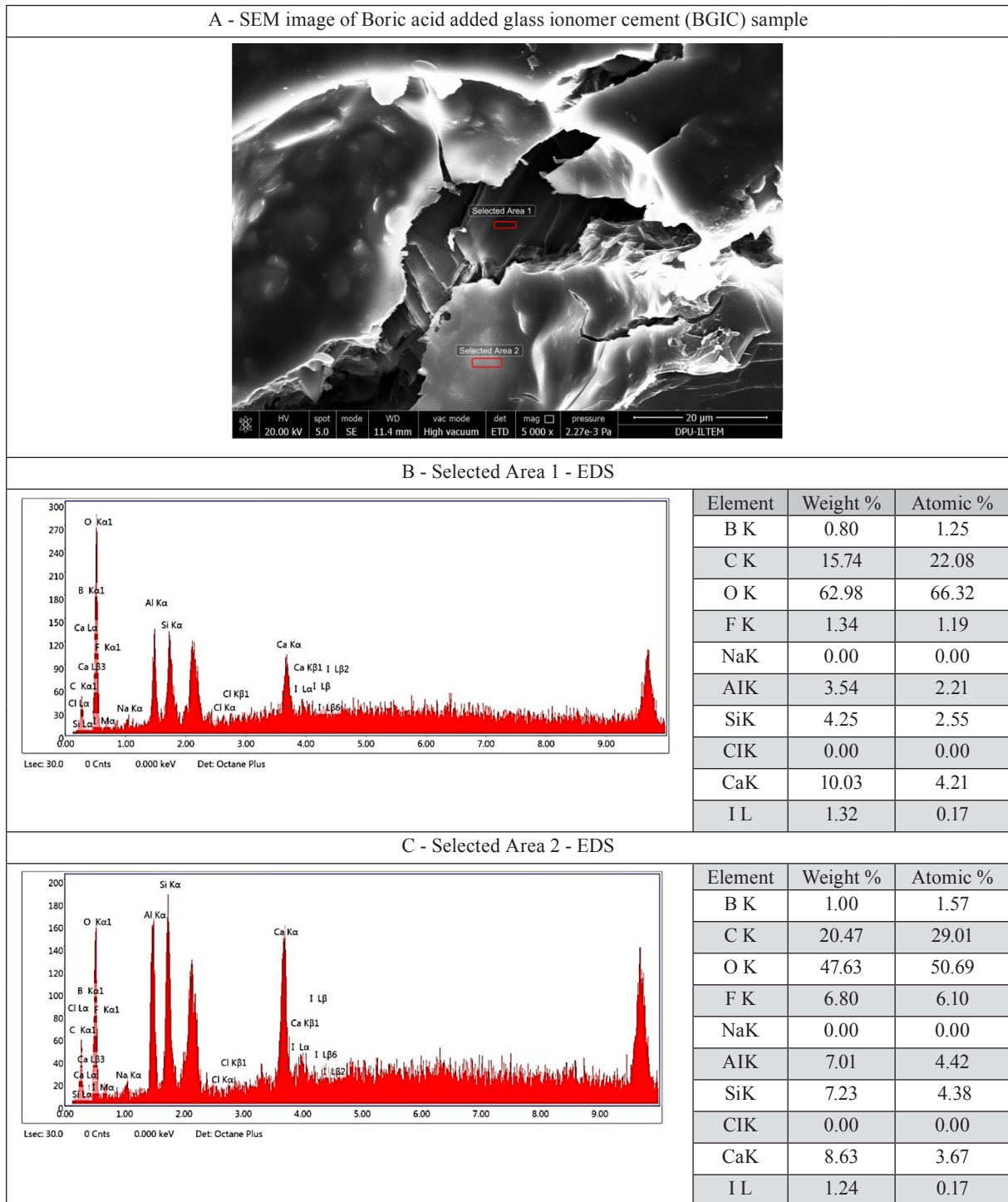


Figure 4. SEM-EDX elemental analysis: A) SEM image of Boric acid added glass ionomer cement (BGIC) sample with selected areas for mean quantitative elemental analysis; B, C) EDX elemental spectrum demonstrating the presence for B, C, O, F, Al, Si, Ca, I elements in selected areas.

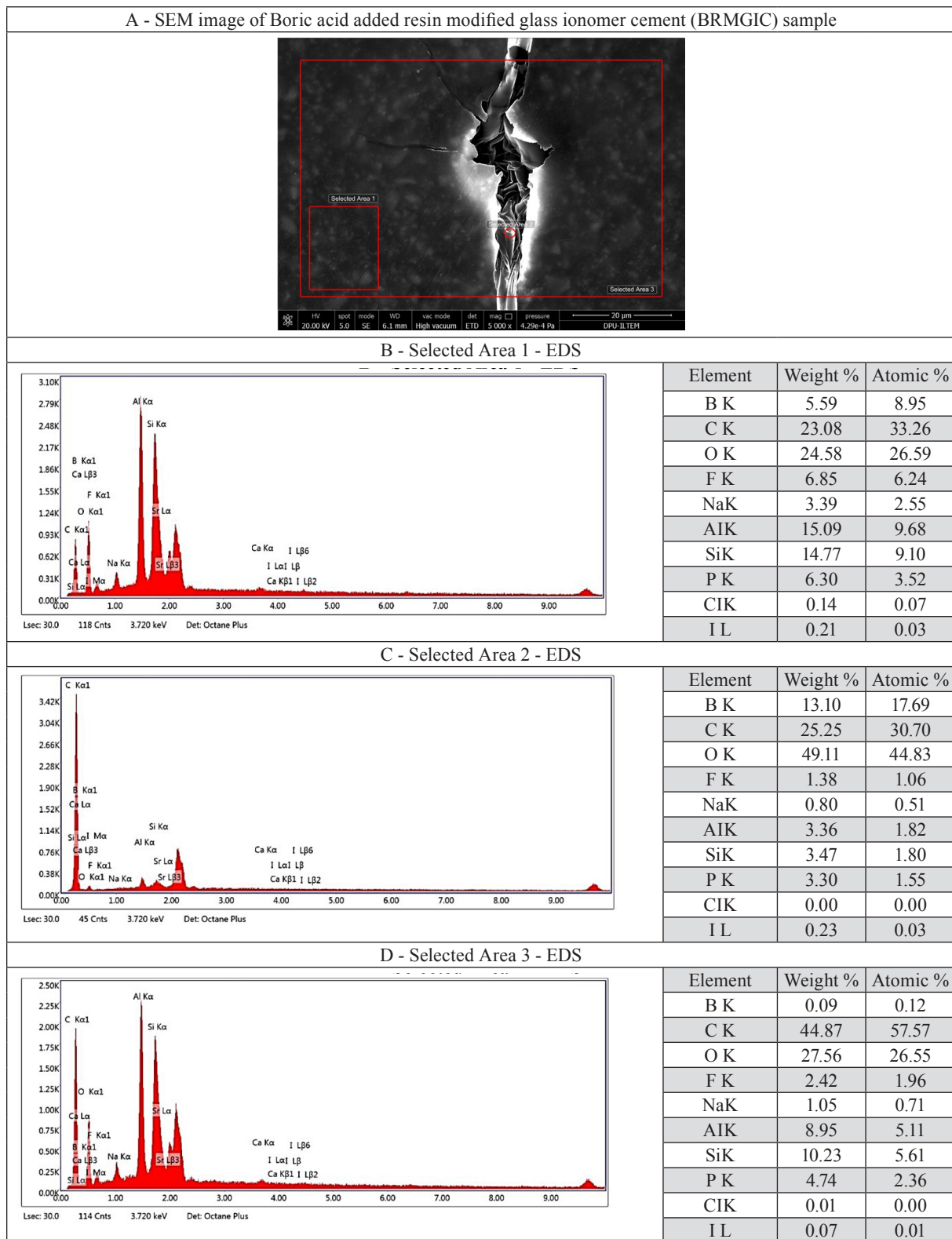


Figure 5. SEM-EDX elemental analysis: A) SEM image of Resin modified glass ionomer cement (RMGIC) sample with selected areas for mean quantitative elemental analysis; B, C, D) EDX elemental spectrum demonstrating the presence for B, C, O, F, Na, Al, Si, Sr, Ca, I elements in selected areas.

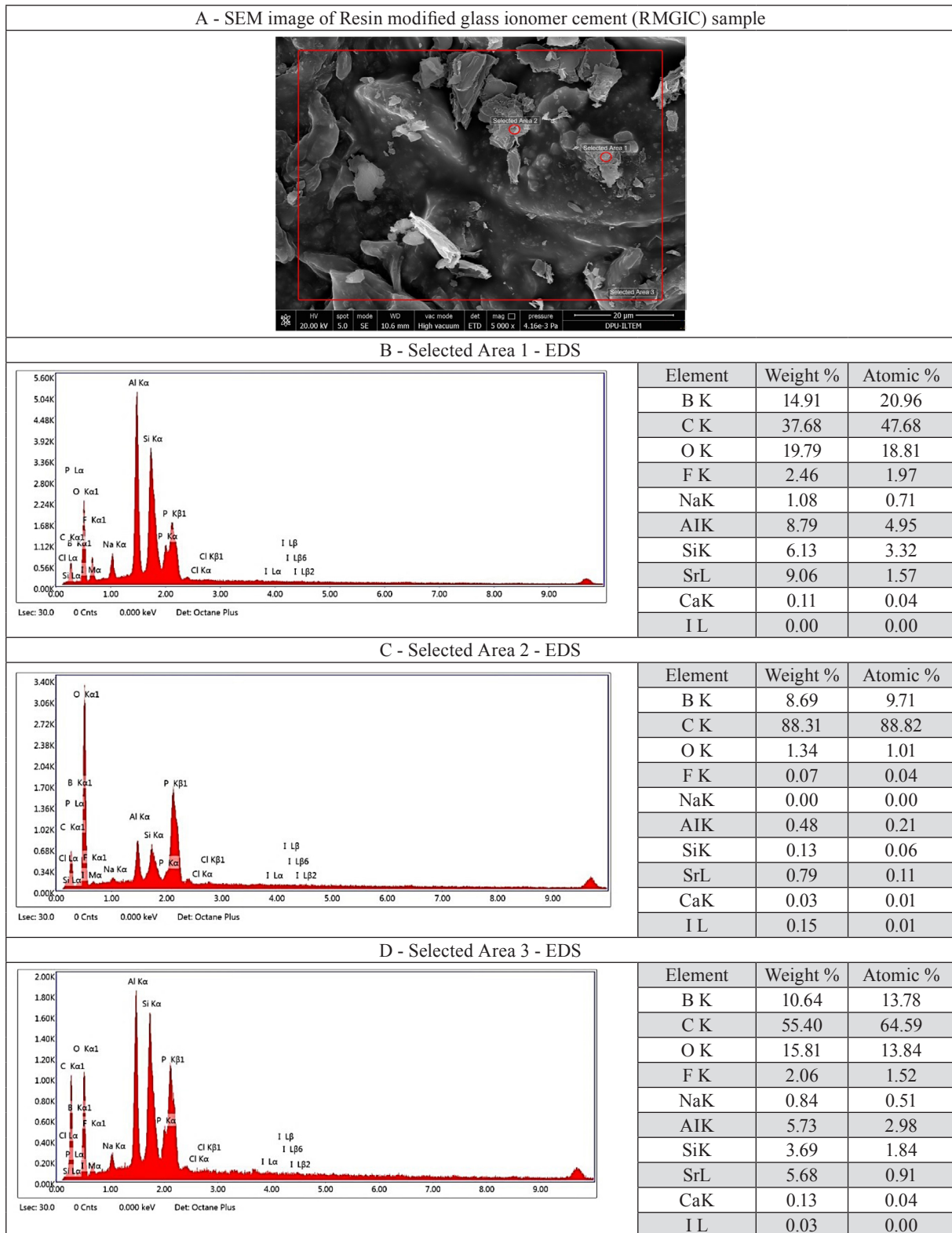


Figure 6. SEM-EDX elemental analysis: A) SEM image of Boric acid added resin-modified glass ionomer cement (BRMGIC) sample with selected areas for mean quantitative elemental analysis; B, C, D) EDX elemental spectrum demonstrating the presence of B, C, O, F, Na, Al, Si, P, Cl, I elements in selected areas.

Table 1. Comparison of water solubility (ng/mm³) of conventional glass ionomer cement (GIC), resin-modified glass ionomer cement (RMGIC) and boric acid added GIC and boric acid added RMGIC samples according to the variables.

Groups	Variables	Min	Max	Mean	SD	F ^a	p
GIC	WS-1h	4.5	6.4	5.7	0.53	1620.042	0.000**
	WS-3h	5.8	9	6.8	0.89		
	WS-24h	8.5	11.9	9.9	1.02		
BGIC	WS-1h	1.8	4.3	3.2	0.73	5.407	0.040*
	WS-3h	1.8	5.9	4.1	1.24		
	WS-24h	-7.6	-0.9	-5	1.92		
RMGIC	WS-1h	6.6	14.6	9.1	2.65	221.997	0.000**
	WS-3h	9.1	17.4	12.4	2.99		
	WS-24h	12.6	22.4	15.7	3.29		
BRMGIC	WS-1h	12.9	26.7	20.7	4.12	294.274	0.000**
	WS-3h	18.9	39.1	30	5.80		
	WS-24h	15.6	36.5	27.5	5.93		

GIC: Conventional glass ionomer cement; BGIC: Boric acid added glass ionomer cement; RMGIC: Resin-modified glass ionomer cement; BRMGIC: Boric acid added resin-modified glass ionomer cement; WS-1h: Water solubility-1h; WS-3h: Water solubility-3h; WS-24h: Water solubility-24h; SD: Standard deviation. * p < 0.05; ** p < 0.01; ^a General Linear Model (GLM).

Table 2. Difference between groups in terms of average variable values.

Variables	Groups	Min	Max	Mean	SD	F ^a	p
WS-1h	GIC	4.5	6.4	5.7	0.53	116.543	0.000*
	BGIC	1.8	4.3	3.2	0.73		
	RMGIC	6.6	14.6	9.1	2.65		
	BRMGIC	12.9	26.7	20.7	4.12		
WS-3h	GIC	5.8	9.0	6.8	0.89	144.710	0.000*
	BGIC	1.8	5.9	4.1	1.24		
	RMGIC	9.1	17.4	12.4	2.99		
	BRMGIC	18.9	39.1	30	5.80		
WS-24h	GIC	8.5	11.9	9.8	1.02	173.087	0.000*
	BGIC	-7.6	-0.9	-5.0	1.92		
	RMGIC	12.6	22.4	15.7	3.29		
	BRMGIC	15.6	36.5	27.5	5.93		

GIC: Conventional glass ionomer cement; BGIC: Boric acid added glass ionomer cement; RMGIC: Resin-modified glass ionomer cement; BRMGIC: Boric acid added resin-modified glass ionomer cement; WS-1h: Water solubility-1h; WS-3h: Water solubility-3h; WS-24h: Water solubility-24h; SD: Standard deviation. *Statistically significant: p < 0.01; ^aOne-way analysis of variance.

and standard deviation values of the GIC, BGIC, RMGIC, and BRMGIC groups according to the WS-1h, WS-3h, and WS-24h variables. When the samples were evaluated after 1 h, the lowest water absorption was found in the BGIC group, and the highest water absorption was found in the BRMGIC group. After 3 h, the lowest water absorption was found in BGIC, and the highest water absorption was found in BRMGIC. After 24 h, the lowest water absorption was observed in the GIC group, and the highest water absorption was observed in the BRMGIC group. The negative value of BGIC indicated water solubility, mass, and volumetric loss in the formula.

Because there was a statistically significant difference between the groups in terms of mean values of the WS-1h, WS-3h, and WS-24h variables, the groups that

caused the difference were analyzed using Dunnett's T3 multiple comparison test. Paired comparisons between the groups showed a statistically significant difference between all groups (p<0.01) (Table 3). The comparison of all groups showed that the difference between GIC and BGIC after 24 h was the highest, and the difference between BGIC and BRMGIC after 24 hours was the lowest.

DISCUSSION

In this study, which started with the idea of taking advantage of the stable structure of boron to eliminate the disadvantages of GICs that cause clinical complications, the null hypothesis that the addition of boric acid in GICs would affect the water solubility of

Table 3. Multiple comparisons examining different groups.

Variables	Group (I)	Group (J)	Mean Difference (I-J)	p	95% Confidence interval	
WS-1h	GIC	BGIC	2.5	0.000*	1.8	3.3
		RMGIC	-3.4	0.006*	-5.8	-1.0
		BRMGIC	-15	0.000*	-18.8	-11.3
	BGIC	RMGIC	-5.9	0.000*	-8.3	-3.4
		BRMGIC	-7.5	0.000*	-21.3	-13.8
		RMGIC	-11.7	0.000*	-15.8	-7.5
WS-3h	GIC	BGIC	2.7	0.000*	1.4	4.0
		RMGIC	-5.6	0.000*	-8.0	-2.9
		BRMGIC	-23.2	0.000*	-28.5	-18.0
	BGIC	RMGIC	-8.3	0.000*	-11.0	-5.5
		BRMGIC	-25.9	0.000*	-31.0	-20.6
		RMGIC	-17.6	0.000*	-23.0	-12.0
WS-24h	GIC	BGIC	14.9	0.000*	13.0	16.8
		RMGIC	-5.9	0.000*	-9.0	-2.8
		BRMGIC	-17.7	0.000*	-23.0	-12.0
	BGIC	RMGIC	-20.8	0.000*	-24.0	-17.5
		BRMGIC	-32.5	0.000*	-38.0	-27.0
		RMGIC	-11.8	0.000*	-17.0	-6.0

GIC: Conventional glass ionomer cement; BGIC: Boric acid added glass ionomer cement; RMGIC: Resin modified glass ionomer cement; BRMGIC: Boric acid added resin modified glass ionomer cement; WS-1h: Water solubility-1h; WS-3h: Water solubility-3h; WS-24h: Water solubility-24h. *Statistically significant: $p < 0.01$; ^aDunnnett's T3 test.

GIC, BGIC, RMGIC, and BRMGIC dental materials was accepted.

In a previous study on the effects of the addition of cetrimide or silver nanoparticles on the antibacterial and physical properties of GIC, 1% and 2% by weight of cetrimide or silver nanoparticles were added to GIC materials.¹⁵ One study concluded that the inclusion of up to 0.15% by weight of boron nitrite nanotubes improved the chemical and mechanical properties of dental adhesives and enhanced mineral accumulation by 66% and 33% of HEMA-BisGMA, respectively.¹⁶ In their experimental groups, they added boron nitrite nanotubes at 0.05, 0.075, 0.1, and 0.15% by weight. In the present study, experimental groups were created by adding massive boric acid at a ratio of 1:3. The Food and Nutrition Board of the US Medical Institute established the tolerable upper intake level of boron at 20 mg/day.¹⁷ The World Health Organization first reported that 13 mg/day would be a safe uptake level but then increased it to a body weight of 70 mg/kg or about 28 mg/day in a 70 kg person.^{18,19} The European Union reported that there should be a higher level of total boron intake based on body weight equal to 10 mg/day for adults.²⁰ In the present study, the addition of boric acid to GIC did not exceed the daily toxic dose.

In the present study, such as similar studies in the literature,^{6,14,21,22} water absorption was calculated in accordance with ISO 4049, and weight loss and increase was evaluated. Another study evaluated the loss in

disk diameter and thickness using this method in their study.²³ It was reported that the effects of desiccation on a calcium silicate-based material, conventional glass ionomer material, and resin-modified glass ionomer material were significant.²² A study about the water absorption of samples containing inorganic boron nitrite according to a contact angle showed that the contact angles of water and α -bromonaphthalene increased in samples containing boron nitrite, and consequently, the contact angle decreased after boron nitrite was added to the polymer matrix.¹⁶ Despite the apparent disadvantage of not using a desiccator in assessing water absorption, drying the samples on blotting paper and evaluating the mass and volumetric measurements in three different periods contributed to the originality of the study.

The results showed that the effects of the addition of boron on water solubility varied over time. The evaluation of the mean values showed that the group with the lowest water absorption was the BGIC-1h group, and the BRMGIC-3h group had the highest water absorption. This result may be related to the presence of HEMA in the RMGIC.^{7,22} Depending on the time, the highest water absorption was determined in the BRMGIC group. These results could be explained by the fact that the water absorption of boric acid accelerated the reaction by reducing the water content available for flowability and ion transfer and by reducing the degree of crosslinking in the cured cement (especially in polyalkenoate types).²⁴ The results also

showed that GIC had greater water solubility than RMGIC, as well as the solubility of boron salts in water.^{7,22} The comparison of all groups showed that the difference between GIC and BGIC after 24 hours was the highest, and the results of BGIC and BRMGIC were similar. This finding could be attributed to the fact that boric acid acts as a weak polyalkonate cross-linker²⁵ that is weaker and slower than metal ions.²³ In addition, in all groups, the solubility in water of the resin networks, the hydrophilic structures of glass ionomers sensitive to dehydration and water absorption, and the hydrophilic hydrogel structure of resin-modified glass ionomer cement affected water solubility by causing changes in mass and volume.²⁶

The increase in solubility with boric acid addition can be attributed to several factors. Firstly, boric acid acts as a weak acid in the GIC matrix, resulting in an increase in the number of protons available for ion exchange. This higher concentration of protons facilitates the dissolution of the GIC material, leading to a rise in solubility. Furthermore, the introduction of boric acid may promote the formation of additional soluble compounds within the GIC structure. It is crucial to consider the influence of boric acid on the setting reaction of GICs, as changes in the reaction kinetics may impact the overall solubility of the material. Because boric acid may act as a weak polyalkenoate cross-linker, but this effect is weaker and slower than for metal ions, it is likely that boric acid interferes with, rather than aids, the acid-base glass-ionomer re-action.^{24,25}

The advantages of SEM-EDX over other methods (i.e., mass spectrometry, neutron activation analysis, inductively coupled plasma atomic emission spectroscopy, inductively coupled plasma spectrometry, laser ablation inductively coupled plasma mass spectrometry, inductively coupled plasma mass spectrometry, high-resolution inductively coupled plasma mass spectrometry) are that it shows the morphology and elemental composition of the desired area up to a depth of 200 μm on the sample. It also allows mapping in the relevant area.²⁷ Previous studies have investigated different element percentages in these mappings.^{27,28} These elements are found in human teeth, including oxygen, carbon, calcium, phosphorus, magnesium, sodium, sulfur, zinc, aluminum, and chlorine, as well as the elements found in restorations, such as potassium, fluorine, mercury, barium, lead, silver, copper, nickel, and titanium.^{27,29} In the present study, B, C, O, F, Na, Al, Si, Sr, Ca, I, P, and Cl elements were evaluated.

When boric acid was not added to the GIC group, the mineral structures formed by boric acid were found more than in the boric acid-added group. This suggests that even without intentional boron addition, the GIC

material contained naturally occurring boron-based minerals as part of its structure. The element boron can take place in some glass ionomer compositions in the form of boron compounds such as boric acid or borax. The additional boric acid significantly altered the mineral composition, reducing the proportion of boron-based minerals compared to the GIC group without added boron. Boron compounds change the chemical and physical properties of the glass ionomer material, and these changes may have an effect on the solubility, generally having a solubility-reducing effect.³⁰

Glass ionomers may be susceptible to dissolution by interacting with water. However, with the addition of the element boron, it can have a modulating effect on the structural strength and solubility of the material. Boron compounds can reduce solubility by adding to the structure of the material, which can increase the durability of the material. However, in our research, it was determined that the mass of the sample increased compared to the initial mass. That is, it absorbs water, with the addition of boron in all groups except the 24 h group, in which boron was added. Boron-containing glass ionomers may be better protected from acid exposure and more resistant to dissolution. Due to its low acidity (pKa 9.2), boric acid is likely to dissolve in ionomer solutions while remaining completely protonated and inert at the acidic pH values of GIC.³⁰

The limitations of this study included that observation of water absorption at least in BGIC and at most in the BRMGIC group, requires XRD to examine the molecular connections of HEMA and boron as content. The intraoral aging procedure, which is done by keeping it in artificial saliva, is not performed. The fact that the artificial aging procedure, which is done by keeping samples in artificial saliva, has not been performed is also a limitation. Although some of the boron molecule derivatives are cytotoxic, cytotoxicity studies of boric acid in pulp mesenchymal cells will give information about the incorporation of boric acid into the restorative material. Further *in vitro* and *in vivo* studies are needed to evaluate the effects of the addition of boric acid, such as XRD analysis, characterization of the material by FTIR, and cytotoxicity tests on odontoblast cells.

Within the limitations of this *in vitro* study, the addition of boric acid to glass ionomer cement was found to affect the water solubility of the materials. On the other hand, the resistance of RMGIC samples to the water solubility obtained by adding boric acid, when compared with boric acid added to conventional GICs, is a subject that needs to be investigated in more detailed studies. The development of biocompatible materials that maintain or improve their mechanical properties remains a problem in dentistry. Further studies are needed to develop water-insoluble boric acid

derivatives to maintain the strength of the mechanical properties of dental materials.

CONCLUSION

In this study, we investigated the effects of boric acid on the water solubility of GIC, a widely utilized material in pediatric dentistry. Our results revealed that the addition of boric acid led to an increase in water solubility across all groups, including GIC, BGIC, RMGIC, and BRMGIC. The significant differences observed in the WS measurements highlighted the influence of boric acid on the cement's solubility characteristics.

Moreover, SEM-EDX analysis provided valuable insights into the elemental composition of the samples. Notably, we observed varying percentages of boron minerals in GIC, BGIC, RMGIC, and BRMGIC. This information further supported the effects of boric acid on the GIC samples and emphasized its potential role in altering the cement's physicochemical properties. Water solubility starts from the surface of a substance, so surface element analysis is important in water solubility studies.

Overall, our findings indicate that the increased water solubility of GICs, caused by the presence of boric acid, may compromise the mechanical strength of the material and elevate the risk of secondary caries development over time. These clinical implications underscore the importance of careful consideration when utilizing boric acid as a supplement in GIC formulations for dental applications.

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CONFLICT OF INTEREST

The authors deny any conflicts of interest related to this study. The authors do not have any financial interest in the companies whose materials are included in this article.

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