Original Article

Chemical Stability of Bioglass in Simulated Oral Environment

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Abstract

Statement of Problem: Bioglasses are a series of biocompatible dental materials, which are considered as light conducting inserts in resin composite restorations. Consequently, their chemical stability is more essential when they are used in conjunction with resin composite.

Objectives: The aim of this study was to evaluate and compare the chemical stability of Bioglass with dental porcelain and resin composite by determining the amount of released K^+, Na^+, Ca^{2+} ions and silicone elements from these materials as a result of exposure to tested solutions with different pH levels including: Sodium Bicarbonate [SB, (pH=9.2)], Sodium Buffer Lactate [SBL, (pH=2.4)], Acetic Acid [AA, (pH=2.4)], and Distilled Water [DW, (pH=6.2)].

Materials and Methods: In this experimental study, forty 2.0×4.0 cylindrical rods for each tested material group (Dental porcelain, Resin composite and Bioglass) were prepared. They were divided into four subgroups of 10 rods each, which immersed in one of the four testing solutions in a designated container. The containers were stored at 50°C and 100% humidity for one week. The released ions were measured by using a spectrophotometer ($\mu g/cm^2/ml$). The data were statistically analyzed by nonparametric Kruskal-Wallis H test.

Results: It was observed that the tested materials released ions at different levels of concentration. The significant amounts of Sodium, Calcium, and Silicon ions release were measured in Bioglass subgroups in all the tested solutions ($p < 0.001$). Potassium ion release from dental porcelain was the largest in all solutions except for AA in which Bioglass had the greatest potassium ion release ($p < 0.001$).

Conclusions: A greater structural instability was observed for Biogalss group than dental porcelain and resin composite in testing solutions with different pH levels.

Introduction

Ceramics are categorized into crystalline, non-crystalline (vitreous) and compound forms based on their chemical structures. Glass is an example of non-crystalline ceramics [1,2]. Degradation of dental ceramics is generally due to mechanical forces or chemical attacks within the oral environment. Dental ceramics chemical durability has also been shown to be great except when in contact with acidic fluoride, ammonium bifluoride and hydrofluoric acid which have professional use [3].

Bioglasses are a type of non-crystalline ceramics which are series of bioactive/biocompatible glasses, composed of SiO_2, Na_2O, CaO and P_2O_5 in different proportions from low ratio of silica in one product to high sodium/calcium or calcium/phosphorus ratios in other products [1,2].

With the advent of bioactive glass in 1969 by Hench *et al*., one of the first completely synthetic materials that seamlessly bonds to the bone and is able to integrate with host tissues, as a new rehabilitating procedure was introduced to the field of medicine [4]. Bioglasses were used to reconstruct tissue deficiencies such as mid-ear bony defects [5]. Later, its application was extended to dentistry in procedures such as ridge augmentation and reconstruction of the alveolar bone defects [4,6-9].

Bioglasses are a series of promising materials used in oral cavity which are used as restorative material as well. Therefore, the concept of using Bioglasses in a restorative material to conduct light in light cured resin composite restorations as a glass insert addressed as "Light Conducting Bioglass Insert" (LCBI) was firstly introduced in 1996 [10]. It was observed that hardness of these restorations, especially in the deepest areas, was significantly improved by LCBI. These findings also confirmed the reduction of micro-leakage, discussed by better polymerization, along the gingival margins of the posterior resin composite restorations [11]. Because some parts of the LCBI might be exposed to the oral environment, the chemical and physical stability of LCBI must to be also at an acceptable level.

High resistance to chemical attack is one of the critical and desirable properties of restorative materials. Dental ceramics have to provide an acceptable tolerance against different solutions with different pH levels in the oral cavity. Generally, there are two accepted mechanisms for glass degradation in aqueous solutions: selective alkaline ion release and glass lattice solubility [3].

The rate of degradation of dental material when used as a restoration is an important issue. As to bioglass as a LCBI, it must be acceptable and at least in the same rate of other restorative materials such as resin composite and dental porcelain. Degradation is generally due to mechanical forces or chemical attacks within the oral environment [3].

The most commonly employed test set-up for this purpose is wear analysis and ion release analysis. Because of the lack of an internationally acceptable method, different methods have been used for assessing the chemical stability of dental materials which can be categorized in two distinct classes: clinical and laboratory test methods. The clinical testing is complex and time consuming (up to six years). Laboratory methods can simply simulate the oral condition and give some reasonable results to compare different dental materials. *In-vitro* chemical tests were of utmost importance in evaluation and comparison of the chemical behavior of such newly introduced material to determine its compatibility with the oral cavity environment and other restorative materials. These methods include visual examination, weight changes observation, dye penetration assessment, physical and mechanical measurements, instrumental methods, and chemical analysis of the reactant [12-14]. Atomic absorption spectrophotometer or an atomic emission spectrometer (flame photometer) is a simple and an appropriate method.

The aim of this study was to evaluate the chemical stability of newly introduced LCBI in comparison with resin composite and dental porcelain in four different solutions with different pH levels: Sodium Bicarbonate [(SB), (pH = 9.2)], Sodium Buffer Lactate [(SBL), (pH = 2.4)], Acetic Acid [(AA), (pH = 2.4)], and Distilled Water [(DW), (pH = 6.2)] using Atomic absorption spectrophotometer. The null hypothesis was that the three materials show similar chemical stability in the simulated oral environment.

Materials and Methods

Specimen preparation
One hundred twenty 2.0 × 4.0 mm rods were prepared

using three tested material groups (n = 40) as follows: a- Dental Porcelain group (DP): Forty specimens were fabricated of Vita porcelain (217 VMK 68N B3+4, Germany) by packing the porcelain powder in prefabricated copper cylinders with an inner diameter of 3.0 mm and height of 12.0 mm in order to make 2.0 × 4.0 mm rods. The cylinders were placed in a dental porcelain furnace (VITA- Vacumat 200, Vita Zahnfabrik H. Rauter GmbH & Co. KG 79704 Bad Sackingen, Germany) and fired in compliance with the manufacturers' recommendations at 920°C in10 minutes. The details of the procedure have already been described [10]. b- Resin Composite group (RC): Forty specimens were fabricated of resin composite (Filtek ™ Z250, USA) by bulk placing the material in transparent plastic cylinders with internal diameter of 3.0 mm and height of 9.0 mm in order to make 2.0 × 4.0 mm rods. The curing step was then performed using a visible light curing unit (Coltolux50), for 80 seconds in a scan mode from one side/end to the other from both sides. c- Bioglass Insert group (BI): Forty specimens were fabricated by cutting off the bioglasss block (Pare-e-Tavoos, Mashhad, Iran) into cylinders of 3.0 mm diameter and 10.0 mm length in order to make 2.0 × 4.0 mm rods using diamond disks (D&Z, Darmstadt, Germany).

Preparation of the rod specimens of the same dimensions: The cylindrical specimens of all groups were cut, ground and shaped into rods with a diameter of 2.0 mm. To fabricate the specimens precisely, we held them in a fixed position handpiece. While the specimens were put in rotating mood, an adjustable high-speed air motor was run to grind the specimens to the desired dimension [10]. Subsequently, the samples were cut short to a length of 4.0 mm using diamond bur (# 450213-BD1, Kerr Corporation 1717 West Collins, Orange, CA, USA) (Figure 1).

Ion release test

Forty prepared rods of one of the three groups were randomly divided into four subgroups of 10 rods each and transferred into a 20 ml laboratory plastic container. Fifteen milliliters of each testing solutions AA, SBL, DW and SB were added to each subgroup of testing materials, each consisting of 10 samples. The containers were subsequently sealed tightly to prevent evaporation. In order to maintain 100% humidity at 50°C, we put the containers into an incubator, especially designed for this study, for a period of seven days (Figure 2). The containers were automatically shaken with a platform shaker (F37041-0000 Spindrive Orbital Shaker Platform, Bel-Art – SP Scienceware. USA) for 10 minutes to accelerate the diffusion process every 12 hours, homogenize the
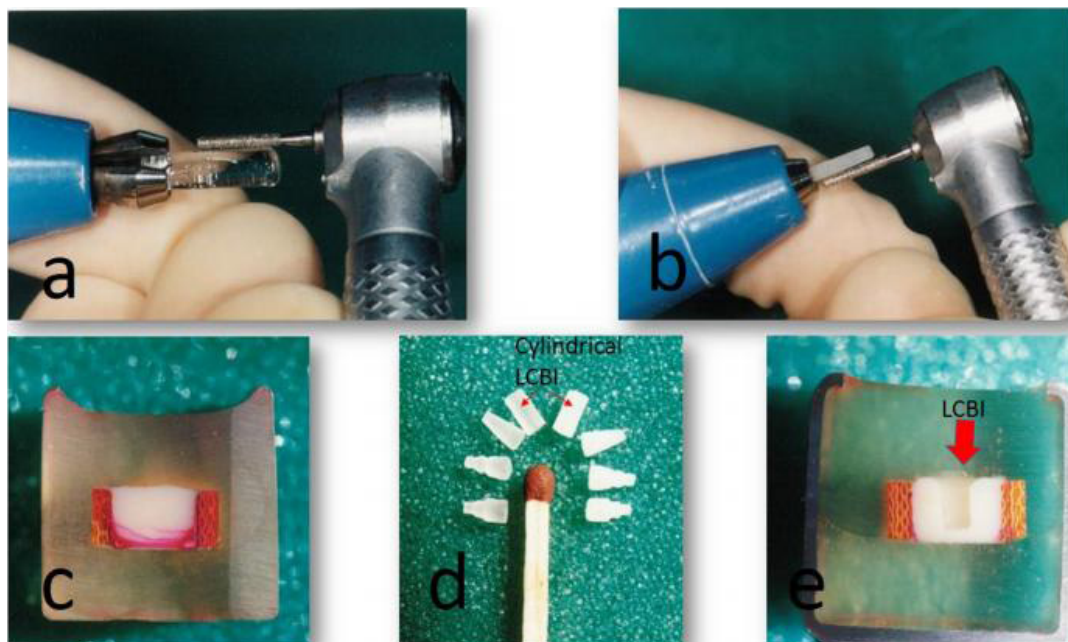

Figure 1: All cylindrical Bioglass rods were cut and shaped into a diameter of exactly 2.0 mm by using a combination of a low-speed hand-piece to hold the specimen and a high-speed air motor to grind the samples while they were run in the opposite directions as Moazzami *et al*. described (a and b of reference "10"). Subsequently, they were cut into a length of 4.0 mm using a diamond disk (Figure 1d). The same procedure was done for preparing the porcelain and composite rods. Figures 1c and 1e are related to the study with reference "10", showing the use of LCBI for increasing the bottom hardness of composite. Courtesy of Moazzami *et al*.

Figure 2: Humidity and temperature simulator for oral cavity which were especially designed for this study by Moazzami *et al*.

solution and help renew the material-solution contact.

After seven days, the specimens were removed from the containers to allow the solutions to be analyzed by the atomic absorption spectrophotometer (AA-680 atomic absorption/flame emission spectrophotometer, Shimadzu/Japan). Prior to testing, the solutions were prepared by diluting in accordance with the original element concentration, as shown in Table1. The sodium concentration in SB and SBL solutions could not be accurate because of the previous presence of this element in the solution. Silicon concentration was below the measurable amount in the resin composite and dental porcelain subgroup solutions; thus, its value was considered zero (Table 1).

The data distribution was not normal and the sample size was not large enough; therefore, they were statistically analyzed by non-parametric Kruskal-Wallis H test.

Results

Kruskal-Wallis H tests showed that ions released from all the testing materials in different solutions were significantly different (Table 1 and Figures 3-6) and ions released in all solutions (except Potassium ion in DW ($p = 0.095$) from different testing materials were significantly different as well ($p = 0.001$).

Maximum potassium ion release form Bioglass, resin composite and dental porcelain was in SBL,

Table 1: The average of different ion release in different solutions by various materials after one week at 50°C ($\mu g/cm2/ml$).

| Materials	Solutions	K$^+$	Na$^+$	Ca^{2+}	Si^{4+}
Bioglass	AA	133.12	4584.40	5996.18	2664.81
	SBL	149.46	-----------	5268.63	1879.38
	DW	22.04	369.08	260.10	1678.42
	SB	134.27	-----------	43.88	216.53
p-value		<0.001	<0.001	<0.001	<0.001
Resin Composite	AA	43.90	82.72	187.89	0.00
	SBL	90.06	-----------	92.72	0.00
	DW	19.24	176.69	107.36	0.00
	SB	123.87	-----------	41.14	0.00
p-value		<0.001	<0.001	<0.001	-----------
Dental Porcelain	AA	112.66	109.30	196.15	0.00
	SBL	268.38	-----------	117.24	0.00
	DW	24.17	135.92	99.41	0.00
	SB	145.80	-----------	76.45	0.00
p-value		<0.001	0.003	<0.001	-----------
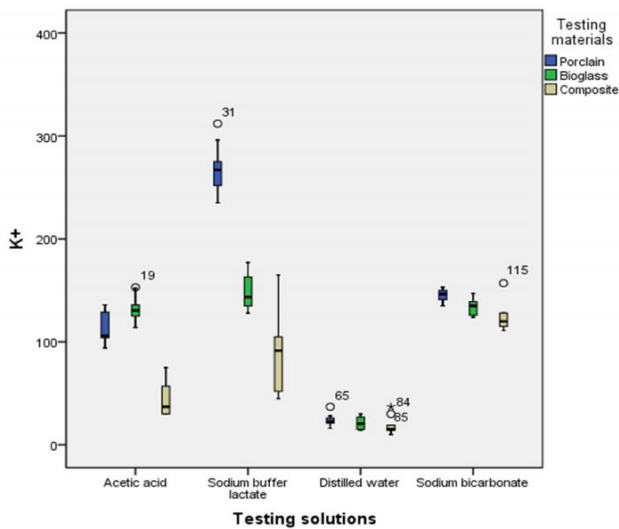
Figure 3: Potassium ion release of porcelain, Composite and Bioglass in different testing solutions (µg/cm²/ml). The numbers (the small circles and star) shows the observation (sample) which is far from the others (suspected as an outlier).
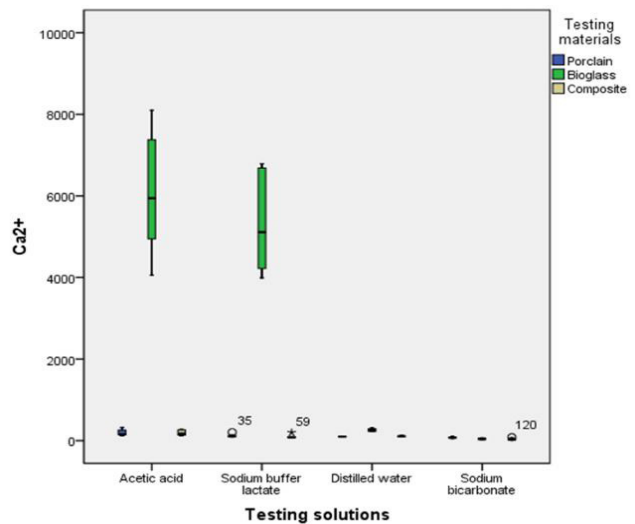

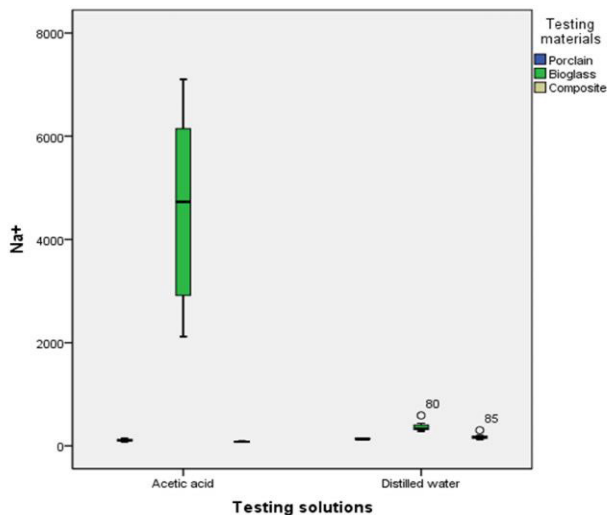**Figure 5**: Calcium ion release of porcelain, composite and Bioglass in different testing solutions (µg/cm²/ml). The numbers (the small circles and star) shows the observation (sample) which is far from the others (suspected as an outlier).

Figure 4: Sodium ion release of porcelain, composite and Bioglass in different testing solutions (µg/cm²/ml). SB and SBL were not tested because of their sodium content. The numbers (and the circles) shows the observation (sample) which is far from the others (suspected as an outlier).

Figure 6: Silicon ion release of Bioglass in different testing solutions (µg/cm²/ml). Silicon ion release of porcelain and composite were not at measurable levels. The numbers (and the small circles) shows the observation (sample) which is far from the others (suspected as an outlier).

SB and SBL with 149, 123 and 268; their minimum release was in DW with 22, 19 and 24 (µg/cm²/ml), respectively (Table 1and Figure 3).

Maximum sodium ion release from Bioglass, resin composite and dental porcelain was found in AA, DW and DW subgroups in the order of 4584, 176,135 (µg/cm²/ml) where the minimum release was measured in DW, AA and AA subgroups in the same order of 369, 82 and 109 (µg/cm²/ml), respectively (Table 1 and Figure 4). The least values were found in resin composite and dental porcelain in AA subgroups,
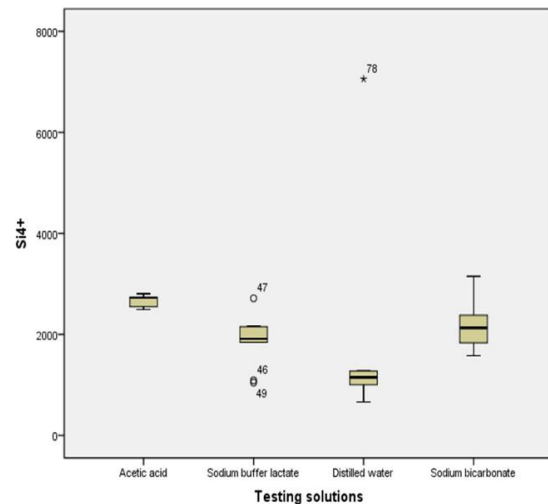
which were significantly different from the one in Bioglass in the same subgroup ($p < 0.001$). Due to sodium component in the formulation of SBL and SB solutions, sodium ion release in these two subgroups was not tested (Table 1 and Figure 4).

Maximum calcium ion release from Bioglass, resin composite and porcelain was found in AA subgroups in the order of 5996, 187 and 196 (µg/cm²/ml), where the minimum release was measured in the SB subgroup with the same order of 43, 41 and 76 (µg/cm²/ml), respectively (Table 1 and Figure

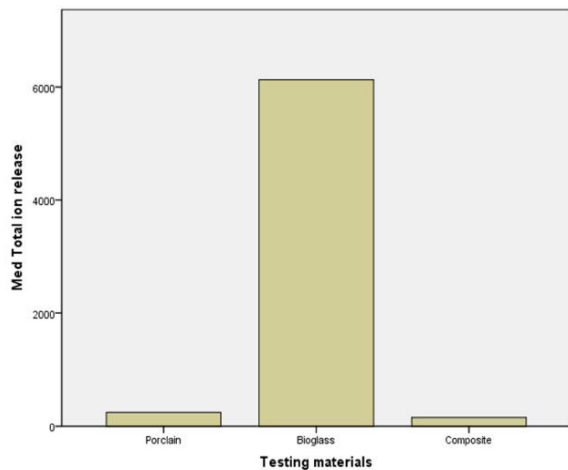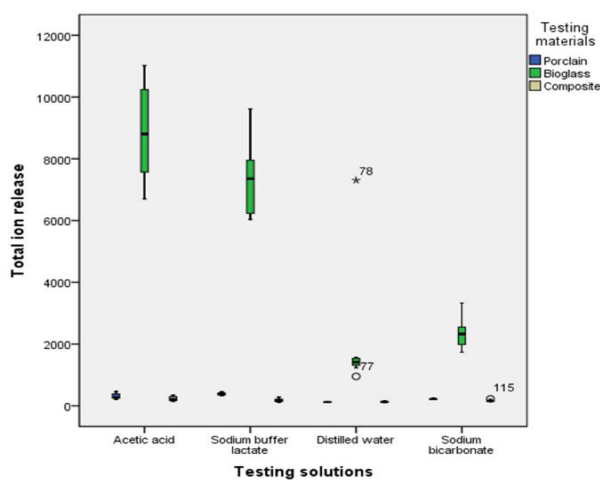**Figure 7:** Total ion release from different materials regardless of solutions ($\mu g/cm2/ml$).

Figure 8: Total ion release from Porcelain, Composite and Bioglass in different testing solutions ($\mu g/cm2/ml$). The numbers (and the small circles) shows the observation (sample) which is far from the others (suspected as an outlier).

5). Maximum calcium release from Bioglass was significantly higher in AA and SBL than DW and SB subgroups ($p < 0.001$), (Table 1 and Figure 5).

Maximum silicon ion release was measured for Bioglass in all subgroups in order of AA; 2664, SBL; 1879, SB; 216 and DW; 1678 ($\mu g/cm^2/ml$), respectively (Tables1 and Figure 6). As to silicon ion release, Bioglass showed the maximum release in all solutions. Silicon ion release was hardly measurable for resin composite and dental porcelain; therefore, it was considered zero (Table 1 and Figure 6).

In Bioglass in comparison with resin composite and dental porcelain groups, regardless of the subgroup solutions used, the total ion release was significantly different ($p < 0.001$) (Table 1 and Figure 7). Furthermore, the total ion release in different solutions by different materials is shown Figure 8.

Discussion

Deterioration of dental materials is a complex process depending not only on the materials' compositions and structures, but also on many other factors related to the oral environment, such as surface exposure to different oral conditions (e.g. acidity of the saliva, its composition, etc.).

In the present research study, a variety of solutions with different pH levels were used to investigate the chemical behaviour of the testing materials in simulated oral cavity conditions, replicating the regular occurrence of pH level fluctuations resulting from different foods and beverages. The acidity of the environment (low pH) leads to a shift in the electrochemical equilibrium potential towards further ion release [15].

In the present study, the selected testing dental materials belonged to different classes of dental material chemical structures. Considering the limitation of this study, a series of procedures were carried out to investigate the Bioglass chemical durability and stability in comparison with dental porcelain and resin composite.

As anticipated, Bioglass showed the "lowest chemical stability" because of the "highest ion release". This can be explained by its chemical property of the non-crystalline three-dimensional structure [1]. However, for porcelain which exhibited the "highest chemical stability" because of the "lowest ion release", it could be explained by its chemical property of the structural integrity and crystalline three-dimensional atomic arrangement.

The main components of ceramics are silicon, aluminum, and potassium [15,16]. Bioglass, resin composite and dental porcelain all contain ceramic particles. The solubility of these components is high in acidic solutions [16,17]. The highest sodium, calcium and silicon ion were also released from Bioglass in all the tested solutions ($p < 0.001$) that may contribute to more instability of this type of dental material.

The potassium releases from bioglass, in comparison with resin composite and porcelain, is not the same as other ion releases. Porcelain ranked first for potassium release in SBL and SB solutions. Bioglass, ranked second with not a very significant difference in all solutions except for AA, which in Bioglass ranked first. Lower Bioglass potassium release among other alkaline elements (Ca, Na) could

be explained well by its lower containing percentage of K_2O rather than Na_2O and CaO [3].

It was anticipated that silicon ion release from Bioglass would be higher in pH levels above 9, but in this study, it was observed that the highest silicon release was obtained in AA (pH = 2.4) and next in SB (pH = 9.2); this is probably due to different contents and molecular arrangements [3]. The same study also revealed that the calcium ion release, as it had been anticipated, decreased as pH increased [3]. These findings were confirmed by the results of our study.

However, our results of potassium ion release were in contrast with their findings [3,16]. Considering all the ions released from Bioglass (except for potassium) in all solutions, the chemical durability of Bioglass in different solutions may be concluded as follows: AA < SL< SB < DW. It means that stronger acidic environments impose greater deterioration of Bioglass material. The potassium release rate from all materials was observed as "SB > SBL> AA > DW", except in the porcelain group which was "SBL> SB > AA > DW"; these results are in contrast with Anusavise's findings [3].

Further studies are required to enhance Bioglass chemical stability and bonding capacity along with its light conductivity behaviour. It is also of importance to investigate the physico-mechanical properties of Bioglass in relationship with other dental materials, especially resin composite, in favor of improving its unique dental application.

Conclusions

Based on the limitation of this study, greater structural instability and less durability in simulated oral cavity conditions were observed for Bioglass compared to resin composite and dental porcelain in testing solutions with different pH levels. In the control solution (DW), durability of the testing materials, including Bioglass, was not compromised. Efforts are needed to improve the chemical resistance of Bioglass in more acidic environments to make it a stable material for in-mouth usage.

Acknowledgements

Conflict of Interest: None declared.

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