

BIOACTIVE GLASS AS AN ABRASIVE IN AIR ABRASION TECHNIQUE: APPLICATION IN DENTISTRY

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ABSTRACT

Introduction: Bioactive glass is a material that finds more and more applications every year. It has the potential to be widely used in air abrasion because of its' special qualities.

Objectives: This study aimed to present the application and therapeutic possibilities of using bioactive glass as an abrasive.

Material and methods: Databases of PubMed/Medline, EBSCOhost, and Scopus were searched with the following combination of keywords: "(air abrasion or air-abrasion or sandblasting) and (bioactive glass or sylc)". Only original articles from the years 2010-2021 were included into the study.

Results: After removing duplicates, 41 articles were obtained. As a result of the screening, 30 articles were used in this work. Bioactive glass air abrasion can be widely used in dentistry. It promotes re-mineralization of hard tissue, enabling a conservative approach to treatment of both carious and non-carious lesions. This material is also useful in implantology, by supporting bone regeneration, or in orthodontics by removing orthodontic adhesive without enamel damage. In the era of minimally invasive dentistry, frugal tooth preparation and minimal intervention, and not high efficiency of work, have become the canon of management. Bioactive glass is a material, that perfectly fits into this standard.

Conclusions: Bioactive glass has unique advantages, such as being antibacterial or having the ability to remineralize tissues. As a result, it can now be broadly utilized for treatment in many cases.

Key words: air abrasion, bioactive glass, tooth preparation.

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INTRODUCTION

Air abrasion is a method increasingly used in dentistry. It was developed by Black in the 1940s. Black *et al.* [1] showed many advantages of this technology, such as quick enamel excision, minimal operator fatigue, and minimal painfulness of the procedure. The invention of the air turbine, which was much more convenient to use, in the 1950s made air abrasion no longer useful. With the development of adhesive dentistry, this method is experiencing a renaissance. Abrasion properties, such as leaving a rough and uneven surface, which was a disadvantage in times of widespread amalgam, nowadays, is a great development of the surface for the adhesion of composite material. Many factors, including the propellant gas pressure or the size and type of abrasive

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particles, influence the effectiveness of abrasion. A review of literature by Szerszen *et al.* [2] quotes seven abrasives practiced in this technique. The most often used abrasive is aluminum oxide. It is a hard, angular material, with a high abrasion ability to the surface of hard tooth tissues [3]. In contrast, bioactive glass is much less hard, and is often used as a polishing abrasive. The choice of abrasive is a key to achieve the desired result. Due to its' properties, bioactive glass deserves special attention.

OBJECTIVES

The aim of the study was to show the possible applications and benefits of using bioactive glass as an abrasive in air abrasion technique.

MATERIAL AND METHODS

For the information on the topic presented, PubMed/Medline, EBSCOhost, and Scopus databases were searched using the following combination of keywords: "(air abrasion or air-abrasion or sandblasting) and (bioactive glass or sylc)". Results were limited to the period between 2010 and 2021. Based on title and abstract, only original papers in English or Polish, with full-text access were included into this study. Articles that did not concern the use of bioactive glass in air abrasion technique were excluded from this research after full-text evaluation.

RESULTS

In the database of PubMed/Medline, there were 32 articles found, in Scopus 28, and in EBSCOhost 21. After removing duplicates, 41 articles were obtained, of which 37 articles met the inclusion criteria and 7 were excluded. The work uses data from 30 scientific articles, which are summarized in Table 1.

CHARACTERISTICS OF BIOACTIVE GLASS

Bioactive glasses are widely used in dentistry. They are chemically composed mainly of silicon, calcium, sodium, oxygen, and phosphorus. The content of many biogenic elements in their composition indicates the high bio-compatibility of these materials. Due to its' properties, bioactive glasses are used in dental and maxillofacial surgery, periodontology, pediatric dentistry, conservative dentistry, and endodontics [16, 33]. Many types of bioactive glasses are described in the literature. Most of them are experimental materials based on a commercially available composition. Bioactive glasses are commercially available under the trade names 'Sylc™' and 'proSylc™'. Both products have the same chemical composition and consist of oxides in the following percentages by weight: SiO_2, 45%; CaO, 24.4%; Na_2O, 24.6%; P_2O_5, 6%.

These materials are produced by two methods, alloy hardening and by the sol-gel technique. The traditional alloy hardening technique involves dissolving the components of bioactive glass at high temperature, most often above 1,300°C, and cooling it down quickly to maintain the atomic structure. After cooling, the glass is ground to a suitable grain. Unfortunately, alloy hardening reduces the bioactive properties of the material, and does not produce a porous structure. The sol-gel technique has been developed since the 1970s, and allows producing more porous material that takes the form of fibers, coatings, or scaffolds. Bioactive glass produced in this way has a greater ability to form apatites, but has poorer mechanical properties. Currently, bioactive glass for use in air abrasion is produced using the alloy hardening method [22, 33, 34].

The most important feature of this type of material is bioactivity. Bioactive glasses, in contrast to ordinary glasses, are less resistant to chemical reactions occurring in tissue fluids, and therefore, can be a source of ions. This is due to the specific chemical composition, especially the content of phosphates, which as a form of an orthophosphate not bounding to crystal lattice, facilitate the precipitation of ions [5, 27]. In the tissue fluid, bioactive glass exchanges H^+ ions into Ca^{2+} and Na^+, leading to alkalization of the environment and transformation of the glass surface into a gel rich in ions. In this gel, crystals of amorphous calcium phosphate precipitate and then, they are incorporated into the structures of hydroxyapatites [10, 33].

Another feature of bioactive glass is its' antibacterial nature. In a study by Drago *et al.* [35], it was found that it has excellent antimicrobial properties without inducing resistance. This property can be used even in the treatment of osteomyelitis. This is mainly due to the high pH and osmolarity, which are the result of dissolving glass particles [32, 33, 35]. Experiments conducted by Abushahba *et al.* [22, 31] showed that this material is highly effective against *Fusobacterium nucleatum*, *Porphyromonas gingivalis*, and *Streptococcus mutans*. However, not only the increase in pH is responsible for the antimicrobial properties. Due to the addition of zinc oxide or strontium oxide, even bioactive glass that generates a relatively low tissue pH (i.e., 8 compared to 8.8 in Sylc™), exhibits highly antiseptic properties. The mechanism of the antimicrobial action is not based on a simple alkalinization of the environment, but involves complex interactions between individual ions contained in the material [26, 36]. Moreover, the addition of fluoride to the composition increases its' antibacterial properties [37].

Bioactive glasses used in the air abrasion method are particles with a diameter of typically 38-90 µm. The hardness of this material is low, only 4.5-5.75 GPa compared with 16-18 GPa for alumina. In SEM images,

TABLE 1. Summary of the included studies

No.	First author, year [Ref.]	Type of study	Type of sample/ participants	Findings
1	Banerjee, 2010 [4]	RCT	Adult patients	BAG significantly reduces hypersensitivity in patients. In addition, BAG provides a better whitening effect after sandblasting, and is more pleasant to use compared with sodium bicarbonate.
2	Sauro, 2010 [5]	*In-vitro*	Human teeth	BAG air-abrasion reduces the permeability of dentinal tubules by occluding them. The effect persists despite the action of the acids.
3	Banerjee, 2011 [6]	*In-vitro*	Human teeth	BAG and alumina effectively clean and roughen fissures in both sound and carious enamel. The work with BAG is slower than with alumina and more conservative.
4	Banerjee, 2011 [7]	*In-vitro*	Human teeth	Air abrasion with alumina removes not only de-mineralized, but also healthy enamel. BAG works more slowly, but removes only de-mineralized enamel.
5	Sauro, 2012 [8]	*In-vitro*	Human teeth	Air abrasion with BAG-PAA improves the maintenance of glass-ionomer cement. BAG has re-mineralizing properties that complement those of glass ionomer.
6	Sauro, 2012 [9]	*In-vitro*	Human teeth	BAG-PAA does not interfere with the bonding ability of self-etching adhesives to dentin. The use of high concentrations PAA may reduce the bond strength due to hygroscopicity.
7	Farooq, 2013 [10]	*In-vitro*	Human teeth, glass microscope slides	Replacing sodium oxide with calcium oxide in the bioactive glass composition results in lower hardness and lower cutting efficiency. The calcium content implies a rapid formation of apatite.
8	Eshghi, 2014 [11]	*In-vitro*	Human teeth	The adhesive strength produced by BAG air abrasion on intact and de-calcified enamel is comparable to alumina air abrasion using etch-and-rinse or self-etch adhesives.
9	Eshghi, 2014 [12]	*In-vitro*	Human teeth	The adhesive strength generated by BAG air abrasion is comparable with alumina air abrasion in both de-calcified and sound enamel.
10	Milly, 2014 [13]	*In-vitro*	Enamel analog-Macor®	The use of BAG is more controllable and conservative compared with alumina. The increase in distance and pressure as well as the inclination of the tip at an angle of 45 degrees to the surface, increases the efficiency of air abrasion.
11	Carvalho, 2015 [14]	*In-vitro*	Human teeth	The use of the experimental niobophosphate BAG does not affect the adhesion strength of prosthetic cement.
12	Darvizeh, 2015 [15]	*In-vitro*	Yttria-tetragonal zirconia polycrystal blocs	The use of bioactive glass does not make the zirconium oxide as rough as alumina. The use of air abrasion on zirconium oxide coated with silica nano-particles causes a decrease in the adhesive strength.
13	Milly, 2015 [16]	*In-vitro*	Human teeth	Air abrasion removes the ultra-thin surface layer of carious lesion, creating conditions for re-mineralization. Pre-conditioning with PAA-BAG air abrasion is more efficient than etching.
14	Tan, 2015 [17]	*In-vitro*	Ivory dentine slabs	The use of an experimental customized fluoride-containing bioactive glass have a better cutting efficiency than alumina.
15	Farooq, 2016 [18]	*In-vitro*	Human teeth	Air abrasion using a mixture of BAG and alumina gives a similar effect as the alumina itself.
16	Johnson, 2016 [19]	*In-vitro*	Human teeth	The use of alumina in air abrasion leads to a decrease in acid resistance of the enamel. BAG and sodium bicarbonate are less invasive, and can be used for controlled surface stain removal.
17	Khoroushi, 2016 [20]	RCT	6-12 years old children	Air abrasion with alumina applied before fissure sealing produces a much higher survival rate compared with BAG air abrasion.
18	Bagheri, 2017 [21]	*In-vitro*	Human teeth	BAG air abrasion reduces fissure sealant micro-leakage, and does not influence micro-tensile bond strength. Regardless of the use of adhesive, pre-treatment with bioactive glass improves the etchability of enamel.
19	Hassan, 2017 [3]	*In-vitro*	Glass microscope slides	Alumina has the best cutting ability. BAG cuts 7 times slower than alumina. Hydroxyapatite is unable to cut glass.
20	Abushahba, 2018 [22]	*In-vitro*	Titanium discs	Titanium sandblasted using bioactive glasses with the addition of zinc and strontium oxides inhibits the S. mutans biofilm formation.
21	Sauro, 2018 [23]	*In-vitro*	Human teeth	BAG with PAA provides long-lasting high adhesive forces. Adhesive forces generated by air abrasion with bioactive glasses are higher than obtained by silicone carbide paper roughening.

TABLE 1. Cont.

No.	First author, year [Ref.]	Type of study	Type of sample/ participants	Findings
22	Taha, 2018 [24]	*In-vitro*	Human teeth	Experimental BAG containing fluoride induces re-mineralization more efficiently than Sylc™.
23	Taha, 2018 [25]	*In-vitro*	Human teeth	Experimental BAG with the highest sodium content showed to be the least hard, and allowed to selectively remove orthodontic adhesive, without damaging the enamel surface.
24	Abushahba, 2019 [26]	*In-vitro*	Titanium discs	The experimental bioactive glass with the addition of zinc is less soluble in tissues and induces lower pH fluctuations. There is no difference in bacterial eradication ability between Sylc™ and the experimental bioglass.
25	Alafifi, 2019 [27]	*In-vitro*	Human teeth	Enamel pre-conditioning with BAG-PAA air abrasion strongly enhances re-mineralization ability when it is accompanied by paste containing NovaMin®.
26	Dionysopoulos, 2019 [28]	*In-vitro*	Bovine teeth	Air abrasion with BAG effectively reduces enamel loss due to erosion. It can be used for the prevention of erosive lesions in a dentist's office.
27	Abushahba, 2020 [29]	*In-vitro*	Titanium discs	BAG air abrasion enhances wettability and surface-free energy of sandblasted and acid-etched titanium surfaces. The proliferation of pre-osteoblastic cells increases after Sylc™ or bioactive glass with zinc air abrasion.
28	Dionysopoulos, 2020 [30]	*In-vitro*	Bovine teeth	Air abrasion with BAG effectively reduces the unfavorable increase in roughness, and decrease in micro-hardness of the enamel caused by the acid test.
29	Abushahba, 2021 [31]	*In-vitro*	Titanium discs	Bioactive glass with zinc as well as Sylc™ effectively removes *P. gingivalis* and *F. nucleatum* biofilm from the sandblasted and acid-etched titanium surface.
30	Spagnuolo, 2021 [32]	*In-vitro*	Human teeth	BAG air abrasion does not affect the immediate bonding strength, but high alkaline pH may disrupt the bonding of some universal adhesives. The use of BAG does not affect the physiological metabolism of the stem cells and their differentiation into odontoblasts.

RCT – randomized control trial, BAG – bioactive glass, PAA – polyacrylic acid

they have a more rounded shape than aluminum oxide, although they are not without sharp edges. Their cutting efficiency is low. Preparation of a glass plate with bioactive glass is almost 8 times slower than preparation with aluminum oxide, but the biological effect makes this material the material of choice for minimally invasive treatment [3, 13, 18, 25]. To increase the speed of work, Tan *et al.* [17] prepared a bioactive glass with the following composition: SiO_2, 37%; P_2O_5, 6.1%; SrO, 53.9%; SrF_2, 3%. This abrasive cut a larger cavity than aluminum oxide at the same time. Farooq *et al.* [18] used a combination of aluminum oxide and bioactive glass. The speed of preparation was found to be comparable to that of alumina alone. In Figure 1, the most important applications of this material are summarized.

BIOACTIVE GLASS IN THE TREATMENT OF CARIES

The method of air abrasion is more and more often used in cariology. According to the assumptions of minimally invasive dentistry, the first therapeutic intervention at the stage of a white carious spot is re-mineralization. To make it as effective as possible, it is recommended to ensure good access of ions to the inside of the cavity. Re-mineralization can be carried out using traditional methods, such as the use of fluorine compounds, but as reported by Milly *et al.* [16], air abrasion using bioactive glass is also an effective method of treating pre-cavity caries [38]. In their experiment using optical coherence tomography, air abrasion with the use of bioactive glass reduced substrate dispersion by 3 times compared with etching and applying a paste with bioactive glass content [16]. The combination of two re-mineralization methods yields even better results. The use of NovaMin® (bioactive calcium-fluorosilicate glass) prior to application of polyacrylic acid and bioactive glass air abrasion resulted in re-mineralization of as much as 91.6% of the original mineral content within a month [27]. To improve the re-mineralization properties, Taha *et al.* [24] created a bioactive glass containing calcium fluoride. Its' use provided lower surface roughness and light backscattering values compared with Sylc™ bioactive glass.

In case of cavity caries, non-contact preparation of hard tissues of teeth due to the avoidance of vibrations is more pleasant for patient than the classic, invasive preparation with the use of an air turbine [39]. The most common abrasive for this purpose is alumina. Its' great hardness and sharper edges determine great clinical effectiveness. However, the biggest drawback is the lack of any biological activity [3, 6, 13]. An alternative to alumina is bioactive glass. Although its' cutting speed is poor, this material through the exchange of ions supports re-mineralization

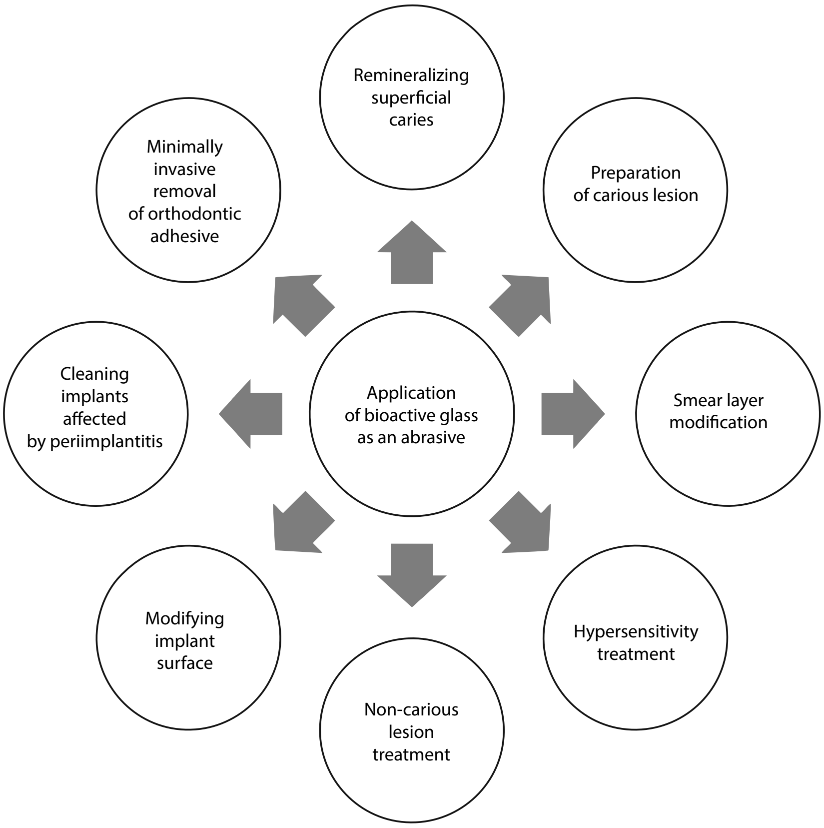

FIGURE 1. The most important dental applications of bioactive glass as an abrasive

of tissues de-mineralized by caries. Combined with antimicrobial properties, bioactive glass is a material that fits perfectly into the concept of minimally invasive carious cavities debridement [6, 17]. Due to its' low cutting speed, it is more conservative and does not lead to over-preparation, removing almost only caries tissue [6, 7].

In the air abrasion technique, particles of the material hit the surface of a soft carious lesion and get bogged down in it, losing their kinetic energy. The size of particles is directly proportional to the kinetic energy imparted by the air stream. Larger particles cut tissues less efficiently, while they sink deeper into the carious lesion [40]. Due to their re-mineralization properties, particles embedded in de-mineralized areas can efficiently deliver ions. In addition, bioactive glass does not reduce the adhesive forces generated by the bonding systems. In case of de-mineralized enamel, the adhesive force generated after preparation of the cavity with bioactive glass is higher than in processing with aluminum oxide [11, 12]. When using bioactive glass to modify dentin, no greater bond strength is achieved compared with conventional adhesive protocol. However, high pH following air abrasion may interfere with some self-etching bonds [9, 23, 32].

Another advantage of bioactive glass is the possibility of modifying the smear layer before the application of glass ionomer cement. The traditional conditioning method with 10% polyacrylic acid is less effective compared with applying air abrasion. Reports by Sauro *et al.* show that the use of bioactive glass air abrasion after 24 hours does not yield significant differences compared with conventional conditioning. However, after 6 months in artificial saliva solution, when the material was subjected to loads, the adhesive force was almost twice as high after abrasion. Bioactive glass can also be used in combination with polyacrylic acid. The use of such a technique for the preparation of cavities enhances the bonding durability of glass ionomer cement. Due to its' hydrophilicity, a high concentration of polyacrylic acid necessitates the use of bonding systems containing high vapor pressure solvents, as in the case of adhesive restoration [8, 23].

Bioactive glasses are also used in the primary prevention of caries; they can be used to clean the fissures before sealing. A study by Bagheri *et al.* [21] showed that the use of bioactive glass abrasion reduces micro-leakage compared with no modification or application of an adhesive system. Air abrasion by removing the superficial layer of aprismatic enamel, improves the penetration of acids and enables the creation of favorable etching patterns. Interestingly, the use of alumina in fissure cleaning provides a better sealant retention than the use of bioactive glass. This is due to the properties of both materials. As a harder material, aluminum oxide effectively removes hard tissues, quickly causing their roughness [3, 20].

Bioactive glass in the treatment of non-carious lesions

Non-carious lesions are becoming an increasingly important problem in a dentist's practice. Increasing life expectancy, stress, acidic diet, and greater care for teeth make attrition, abrasion, and erosion commonly encountered. Classic methods of treatment are based on the modification of the surface of the defect (e.g., with a laser) or the creation of a protective layer on its' surface (using various fluorine compounds or bioactive glass). Using air abrasion with bioactive glass ProSylc™, Dinostypulos *et al.* [28] achieved 2 times slower demineralization progress in dentine compared with control sample. In addition, the increase in roughness after acid attack, in case of the surface subjected to air abrasion was 3 times lower than in control not subjected to any protective measures. In case of enamel, bioactive glass air abrasion resulted in 2 times lower micro-hardness loss and significantly lower surface roughness decrease [30].

Due to their hardness (range, 4.5-5.75 GPa) that exceeds the hardness of enamel (3.5 GPa), bioactive glass can remove mineralized tooth tissues. This is a significant disadvantage in the treatment of non-carious defects. Compared to using only tin fluoride, abrasive blasting results in a slightly greater overall loss of hard tissue volume. However, re-mineralization properties of bioactive glass mean that cavities protected in this way show significantly greater hardness and less increase in roughness over time [24, 28]. At the expense of a slightly greater loss of dentine volume, a well mineralized acid-resistant layer can be obtained.

Bioactive glass in the treatment of dentine hypersensitivity

Dentin hypersensitivity is an increasingly common condition. The increasing number of gingival recessions and abfraction losses in the population, predisposes them to hypersensitivity reactions. In its' treatment, various methods and substances are applied to close the dentinal tubules, including bioactive glass. The conventional method is to apply an agent containing bioactive glass to the tooth area with symptoms of hypersensitivity [37]. However, an innovative method of bioactive glass application in hypersensitivity treatment is to use it as an abrasive in a sandblaster. The mechanism of action is based on the occlusion of dentinal tubules and the reduction of their permeability. Contrary to sandblasting with sodium bicarbonate, which increases hypersensitivity, bioactive glass significantly reduces hypersensitivity and is more pleasant for patient [4, 19]. As shown by SEM electron microscope studies, accelerated abrasive particles occlude the dentin surface, closing 100% of dentinal tubules. Even after etching the surface prepared in this way with citric acid at pH 3.2, 94% of channels remain closed [3, 5].

Bioactive glass in prosthodontics and implantology

Although air abrasion with aluminum oxide is mostly used in prosthodontics, bioactive glass can also find some purposes. It cannot be used in roughening prosthetic restorations as a result of poor cutting ability, but due to bioactivity, it can increase the durability of prosthetic restoration [3, 14, 15]. The major threat to permanent prosthetic restorations is secondary caries. Coating a layer of bioactive glass on the surface of the pillar may protect against secondary caries after the degradation of prosthetic cement. The bioactive glass enriched with niobium, as reported by Carvahlo *et al.* [14], does not affect the adhesive strength generated by composite cement, but due to high bioactivity, it may protect the pillars. The addition of niobium in the structure allows for better strength, bioactivity, and opacity to the radiation.

Another field, in which air abrasion with bioactive glass can be used, is implantology. Various techniques to increase the surface available for osseointegration are widely used in the manufacture of implants, including acid etching, laser processing, or air abrasion. Nowadays, the most common method of increasing the implant surface area is sandblasting with aluminum oxide. However, alumina is not a substance that promotes osseointegration. By anchoring itself to the surface of the implant, it constitutes contamination that inhibits the proliferation of osteoblasts on the implant material. Despite cleaning by various methods, it is not possible to eliminate all alumina particles from the surface subjected to abrasion [41]. The solution to this problem may be the use of bioactive glass in the process of production. Bioactive glasses are commonly known as osteoconductive materials used in the process of guided bone regeneration. The application of bioactive glass on the surface of an implant has a significant effect on wettability and surface-free energy, which enhances osteoblasts' proliferation ability [22, 29]. Air abrasion using bioactive glass causes the formation of an apatite within 6-24 hours after incubation in a TRIS-buffered solution environment that contains no Ca^{2+} and PO_4^{3-} in comparison with tissue fluid [10, 25].

However, the action of bioactive glass is not limited to improving osseointegration. According to Abushahba *et al.* [22, 26, 31], this material is perfect for the treatment of peri-implantitis. The proven activity against many pathogens and modification of the surface preventing their subsequent invasion, produce favorable conditions for the maintenance of implant. The addition of zinc ions to the bioactive glass allows for the reduction of tissue solubility, and thus does not cause such an intense increase in pH, which turns into the formation of a more tissue-friendly environment without reducing the antimicrobial effect.

BIOACTIVE GLASS IN ORTHODONTICS

Treatment with fixed orthodontic appliances, apart from numerous advantages, has a significant disadvantage: after finishing the treatment, it is easy to damage the enamel when removing the adhesive from the enamel surface. Air abrasion may be helpful in this aspect. After using an abrasive blaster, regardless of the selected abrasive, the surface is uniformly matte and easier to polish, unlike the bur, which creates numerous grooves on the surface. Due to the limited cutting ability, bioactive glass, unlike aluminum oxide, causes minimal damage to healthy enamel in the air abrasion technique [7, 13]. Lower-hardness bioactive glass that removes orthodontic adhesive with minimal enamel loss is currently developing. Taha *et al.* [25] developed fluoride-containing bioactive glass, with increased sodium content to 30 mol%.Vickers hardness of novel bioactive glass was 350 in comparison with 472 of commercially available Sylc^{TM}. The use of this experimental abrasive resulted in the fact that at the cost of doubling the working time, the roughness after removal of orthodontic adhesive was comparable with the initial roughness before bonding orthodontic brackets.

CONCLUSIONS

Bioactive glass is a widely used material in dentistry. Its' antibacterial and bioactive properties, combined with sufficient hardness, make this material successfully used in the air abrasion technique. Further research and the introduction of different hardness of glasses into the market (hard ones used for cutting tissues and soft ones used for polishing) are necessary for this material to become more popular as an abrasive. With the wide introduction of this material into dental procedures, further new applications of bioactive glass air abrasion can be discovered.

CONFLICT OF INTEREST

The authors declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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