



ORIGINAL ARTICLE

# Dynamics of different ion release from denture-base acrylic resins and their mechanical properties after the addition of bioactive materials



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**Abstract** *Background:* The denture-base acrylic resins used by partially edentulous patients can cause local demineralization of teeth. Alkali ions released from the bioactive materials that were added to acrylic resins can increase the pH of the oral environment and slow down the demineralization process.

*Aim of the study:* This study aimed to create a new denture-base acrylic resin that can release ions.

*Materials and methods:* A total of 222 samples with different fillers (calcium hydrogen phosphate, hydroxyapatite, two kinds of bioactive glasses, and a product obtained by reaction between bioactive glass formed from glass ionomer cement and polyacrylic acid) were prepared for the study. All the materials were tested for mechanical properties and their use as phosphate donors for 3 weeks. The measurements were presented as mean  $\pm$  SD error of the mean. Data were analyzed by two-way analysis of variance, with a  $p$ -value of  $< 0.05$  as statistically significant.

*Results:* Acrylic resins obtained after the addition of a small quantity of bioactive materials (2.5–5%) showed similar mechanical properties (such as flexural strength and Izod impact resistance) as non-filled material. However, the hardness of the modified materials was higher compared to pure poly (methyl methacrylate). Samples modified with materials released phosphate ions for a short period. The materials that were identified to be most promising as an ion source were samples containing 5% calcium hydrogen phosphate ( $p < 0.01$ ).

*Conclusions:* Based on the results, it can be concluded that denture-base acrylic resins resulting after the addition of different bioactive precursors have improved mechanical properties and can release ions to the oral environment for a short period.

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## 1. Introduction

In 1938, the first denture base fabricated from acrylic resin was introduced in dentistry. This material was constantly modified with the goal of improving its properties. Acrylic resin is characterized by very good optical properties, easy processing methods, medium mechanical resistance, low processing cost, and light-weight final denture. Unfortunately, it also has some disadvantages, one of which is the lack of bioactive response to the oral condition (Chand et al., 2011; Gharechahi et al., 2014). This allows the surface of denture to be easily colonized by different kinds of microorganisms, for example, *Candida albicans*, *Streptococcus oralis*, and *Actinomyces viscosus* (Krishnamurthy and Hallikerimath, 2016; Aslanimehr et al., 2017). Shortly after polymerization, acrylic resin can prevent the growth of microorganisms, but after the elution of residual monomer this property disappears. Studies have indicated the attempts made for preparing materials with biostatic properties, especially composite resins. One such direction is the synthesis of special monomers with quarterly ammonium salts having bacteriostatic properties (Antonucci et al. (2012); Imazato et al., 2012). Another possible solution is the addition of nanoparticles, such as silver, zinc oxide, calcium fluoride, silver zeolite, silver zirconium phosphate silicate, or silver zirconium phosphate, into the composite material. Some authors suggest the use of natural substances, such as rosemary, castor oil, or propolis extracts to diminish bacterial colonization (Heidrich et al., 2018). Addition of nanomaterials can effectively stop the growth of *Streptococcus mutans* and *Lactobacillus* on the surface of composites (Kasraei et al., 2014; Azarsina et al., 2013; Łukomska-Szymańska et al., 2016; Ekworap, 2013). Other authors have reported the use of some kinds of drugs and mixing them with composite or acrylic resins. As a result, the drug can be gradually released from the material and prevent bacterial growth. An alternative way is to create materials like glass ionomer cements (GICs) which can release ions to the oral cavity (Kagermeier-Callaway et al., 2000).

During the last 20 years, there is an increasing awareness of oral hygiene, and a number of patients opt for partial prosthetic restorations made from poly (methyl methacrylate) (PMMA) instead of whole dentures. In partial prosthetic restorations, some part of residual teeth is covered by denture base or clamps. In these regions, saliva flow drastically reduces, food can accumulate, and pH rapidly decreases to <5.5. In addition, microbial colonization takes place (Stamenov et al., 2016; Pereira-Cenci et al., 2007). All these conditions can lead to caries development on the remaining tooth surface. This process accelerates when the surface of denture base is not perfectly polished (Pereira-Cenci et al., 2007).

On the market, it is possible to find composite resin with filler, which is a product obtained by reaction between powder and liquid from GIC. Such a group of materials is called Gionomer, a hybrid of composite and GIC (Abdel-Karim et al., 2014).

To overcome the above-mentioned disadvantages, acrylic material needs to be modified. This study aimed to create a new acrylic resin that can release ions such as calcium, phosphate, or fluoride. Calcium or other alkali ions increase the pH of the oral environment and stop the demineralization of teeth. Furthermore, they can be a source of raw materials to

start the remineralization process. Therefore, in the first part of the investigation, an analysis was conducted on the mechanical properties of acrylic resins after the addition of different sources of substances capable of releasing ions, while in the second part the dynamics of phosphate ion release from acrylic samples was assessed.

This study hypothesized whether the addition of bioactive glasses or a phosphate compound to acrylic can cause the material to release ions into the environment.

## 2. Materials and methods

### 2.1. Sample preparation

For this study, hot curing acrylic resin Superacryl Plus (lot 6301571, Spofa Dental, Jicin, Czech Republic) was used. The powder of this resin was mixed with different quantities of materials, which can be sources of phosphate, calcium, and fluoride ions, using a ball mill. The mixing time in the case of a 2-l ball mill (Ceska Procelanka, Liberec, Czech Republic) was 2 h. As a mixing medium, 100 g of corundum spheres having a diameter of 10 mm was added to the device. For sample preparation, 100 g of PMMA powder was mixed with bioactive materials to obtain ion-releasing agents of 2.5%, 5%, or 10% concentration. Calcium hydrogen phosphate (Merck, Prague, Czech Republic) (samples P1–P3) and hydroxyapatite (HA; Merck, Prague, Czech Republic) (samples P4–P6) were used as salts which can be a donor of  $\text{PO}_4^{3-}$  as well as  $\text{Ca}^{2+}$  ions.

Powder glass from GIC Kavitan (Spofa Dental, Jicin, Czech Republic) (samples P7–P9) and glass from silicate cement Fritex (lot 674578; Spofa Dental, Jicin, Czech Republic) (samples P10–P12) were used as a substance delivering phosphate, calcium, silica, aluminum, sodium, and strontium and fluoride ions. The composition of these two glasses is shown in Table 1, and the concentration of active substances in all samples prepared for the tests is shown in Table 2 (in which column 1 indicates the ingredients added, column 2 indicates the sample numbers, and column 3 indicates the concentration of active agent).

To obtain the bioactive filler, Kavitan powder and liquid were mixed together. After setting, the material was crushed to smaller pieces, put into the ball mill, and mixed for 24 h to obtain a powder in the form of granulates measuring <10  $\mu\text{m}$ . Granulation was checked using a Cilas 1064 laser granulometer (Cilas, USA).

In the next step, the prepared filler was mixed with acrylic powder to obtain a final concentration as other materials used in this investigation (2.5%, 5%, and 10%—samples P13–P15). As a reference, samples of pure acrylic resin Superacryl Plus were prepared and tested for flexural strength, Izod impact resistance, and surface hardness.

### 2.2. Flexural strength

Powders from samples P1–P15 were mixed with Superacryl monomer (Spofa Dental) in a ratio of 2.2 g of powder and 1 g of liquid. In the dough stage (20 min after mixing the powder and liquid), the materials were placed into the metal forms and polymerized for 30 min at 60 °C and for 1 h in boiling water. Fore flexural strength metal forms dimensions: 2.5 × 10

× 65 mm were used. For each experiment, six samples of each composition were prepared. Totally 96 samples were used for the test, which was performed after 7 days of polymerization. Until testing, samples were stored in distilled water at 37 °C. Flexural strength of the samples was tested using a Shimadzu (AGS 10 kNG; Shimadzu, Japan) compressive strength instrument after entering the dimension of the sample (ISO 20795-1:2013; Raszewski and Jałbrzykowski, 2017).

### 2.3. Izod resistance

For evaluating Izod impact resistance, the metal forms (4 × 5 × 50 mm) were filled with samples P1–P15 and polymerized as described above. After removing from the forms, the samples were placed in distilled water and stored for 7 days at 37 °C. After this time, Izod impact resistance was tested using a VER Werkstoffprüfmaschinen Izod impact instrument (VER, Germany). From the dimension of the sample, its resistance was calculated using the formula:

$$R \left[ \frac{J}{mm^2} \right] = \frac{d * b}{A} \quad (1)$$

where  $R$  is the Izolde resistance,  $d$  is the thickness (mm),  $b$  is the height (mm) of the sample, and  $A$  (J) is the work read from the instrument scale (Faot et al., 2009). Totally 80 samples were tested during this analysis.

### 2.4. Vickers hardness

Samples for surface Vickers hardness analysis were prepared by hot polymerization (samples P1–P5) in cylindrical forms (40 × 4 mm). The hardness of the samples was measured after 24 h of storing in laboratory conditions (Faot et al., 2009). For hardness analysis, one sample was tested in different regions (five measurements), and therefore, 16 samples, one for each composition, were prepared.

After polymerization, the specimens were visually inspected to determine if they had a smooth surface without voids or porosity. They were manually wet-polished in a circular motion with a sequence of 600-, 800-, 1000-, and 1200-grit silicon carbide papers (Saint Gobain, Poland).

To determine Vickers hardness, a load of 612 N was applied for 120 s to specimens using a digital hardness tester (WPM, Leipzig, Germany). Each specimen was tested three times (one at the center and two at the border), and the average hardness value was calculated for each group of samples.

### 2.5. Phosphate ion release

For ion release, the acrylic dough was put into forms of 15 × 1 mm, and polymerized. For one test, two samples were

**Table 2** Samples prepared for testing by mixing acrylic resins with fillers in different concentrations.

Sample	Groups	Concentration
CaHPO <sub>4</sub> (Merck)	P1–P3	2.5%, 5%, 10%
Hydroxyapatite (Merck)	P4–P6	2.5%, 5%, 10%
Kavitan powder (Spofa Dental)	P7–P9	2.5%, 5%, 10%
Fritex powder (Spofa Dental)	P10–P12	2.5%, 5%, 10%
Product of reaction between Kavitan powder and liquid	P13–P15	2.5%, 5%, 10%
Pure resin Superacryl Plus (Spofa Dental) ref. sample	P0	

prepared (totally 30). Phosphate ions were detected with a UV–VIS spectrophotometer, in 5-cm-long quartz cuvettes, by molybdenum blue phosphorus method, under a wavelength of 740 nm. Tests were performed as described in the study of Adelowo and Oladeji (2016). The basis of ammonium molybdenite method is the formation of blue color. After contact with molybdenite slat and reducing agent like hydrazine, phosphate ions in acid pH can form blue molybdenum acid.

The quantity of eluted phosphate ions was calculated from formula (2) derived from the calibration curve:

$$C \left[ \frac{mg}{l} \right] = \frac{A + 0.0234}{0.8711} \quad (2)$$

where  $C$  is the concentration of PO<sub>4</sub><sup>3-</sup> ions and  $A$  is the absorbance.

Knowing the sample mass and concentration of PO<sub>4</sub> inside the substance, it is possible to calculate the total ions that can be released. For example, a sample of 2.5% HA possesses  $m \times 0.025 \times 0.58$  phosphate ions, where  $m$  is the mass of the sample, 0.025 is the concentration of HA, and 0.58 is the concentration of phosphate ions inside HA based on molar mass.

#### 2.5.1. Calibration curve

A solution of ammonium molybdenite (1.5 g/100 ml water; Aldrich, Prague, Czech Republic) and hydrazine (0.120 g/100 ml water; Aldrich, Prague, Czech Republic) were prepared. For calibration curve a water solution of Na<sub>3</sub>PO<sub>4</sub> (Aldrich, Prague, Czech Republic) was made by diluting a concentrated solution containing 3 g Na<sub>3</sub>PO<sub>4</sub>/1000 ml (totally 8 samples). The concentration of trisodium phosphate ranged from 0 to 3.5 mg/l. For preparing this solution, 1 ml of hydrazine and 2 ml of ammonium molybdenite solutions were mixed and 1 drop of 50% sulfuric acid was added to achieve a lower pH. Glass was placed in the water bath at 60 °C for 1 h, and blue color formation was observed. The intensity of color was proportional to the concentration of phosphate ions (Lambert's law). Absorbance was measured by a spectrophotometer, and the calibration curve was generated (Fig. 1). The trend line was determined using Microsoft Excel.

#### 2.5.2. Acrylic sample testing

Each disc for ion release was put into clean dark bottles which were then tightly closed and filled with 10 ml of distilled water.

**Table 1** Fritex and Kavitan glass composition.

Glass	Composition
Kavitan glass	SiO <sub>2</sub> 26%, Al <sub>2</sub> O <sub>3</sub> 29%, Na <sub>2</sub> O 4%, P <sub>2</sub> O <sub>5</sub> 8%, SrO 17%, F 10%
Fritex glass	SiO <sub>2</sub> 44%, Al <sub>2</sub> O <sub>3</sub> 30%, P <sub>2</sub> O <sub>5</sub> 3%, Na <sub>2</sub> O 6.0%, CaO 5.0%, F 6%

Samples were placed in a laboratory dryer for 1 week at 37 °C. After this period, the samples were removed and carefully dried with a filter paper. Eluent of water solution was mixed with solutions of ammonium molybdenite and hydrazine. One drop of sulfuric acid was added to each sample. Following mixing, the glass bottles were heated in a water bath at 60 °C for 1 h to obtain a blue color. After another 1 h, the samples were measured in a spectrophotometer.

After tests, the acrylic discs were transferred to new glass bottles and a new portion of distilled water was added. After 7 days, the second measurement of ion release was performed. This procedure was repeated 3 times for 3 weeks.

### 2.6. Statistical analysis

All experiments were performed in triplicate for each parameter, resulting in nine repetitions for each parameter. The measurements were presented as mean  $\pm$  standard error of the mean. Data were analyzed by two-way analysis of variance (GraphPad Software Inc., San Diego, CA, USA), with a  $p$ -value of  $< 0.05$  as statistically significant.

## 3. Results

The results obtained from the flexural strength test, Izod resistance test, and Vickers hardness test are documented in Table 3.

Samples with 10% Kavitan powder/liquid reaction product were too brittle and difficult to remove from the form. Addition of inorganic filler reduced the flexural strength of acrylic resin, with one exception—2.5% HA samples (P4 group). Sam-

ples containing 2.5% HA were more resistant to breaking than Superacryl Plus (reference standard). Their fracture resistance was  $112.78 \pm 4.32$  MPa ( $p < 0.05$ ). A decrease in resistance was especially visible after the addition of Kavitan powder/liquid reaction product. Samples containing 2.5% of the Kavitan Plus powder/liquid reaction product showed the lowest fracture resistance of  $82.49 \pm 6.64$  MPa ( $p < 0.05$ ).

However, fracture toughness was higher than 65 MPa, as defined by ISO 20795-1:2013, but the difference was not statistically significant.

Izod impact resistance was found to be improved with small addition (2.5%) of fillers such as calcium hydrogen phosphate ( $1.075 \pm 0.094$  J/mm<sup>2</sup>), HA ( $1.088 \pm 0.078$  J/mm<sup>2</sup>), or Kavitan glass ( $1.004 \pm 0.042$  J/mm<sup>2</sup>) than using unmodified Superacryl Plus ( $0.853 \pm 0.097$  J/mm<sup>2</sup>, reference sample), but the difference was not statistically significant.

Inorganic fillers increased surface hardness in all the tested groups (P1–P15). The hardest surfaces were found in samples containing 5% Fritex glass ( $222.2 \pm 5.3$ ) ( $p < 0.01$ ), compared to those containing Superacryl Plus ( $154.9 \pm 2.7$ ) (see Table 3 and 4).

The materials in which phosphate ions were added released them with different efficiencies. Samples with Fritex glass was found to act as a donor of phosphate ions in very high concentration (10% of total ion concentration) for a short period ( $p < 0.001$ ), compared to the reference sample Superacryl Plus which did not release ions. A contrasting observation was noted for samples containing calcium hydrogen phosphate. They released phosphate ions for 3 weeks ( $p < 0.01$ ), and the total amount of phosphate ions released was over 25%. The quantity of delivered anions decreased with time. The reference samples did not release phosphate ions.

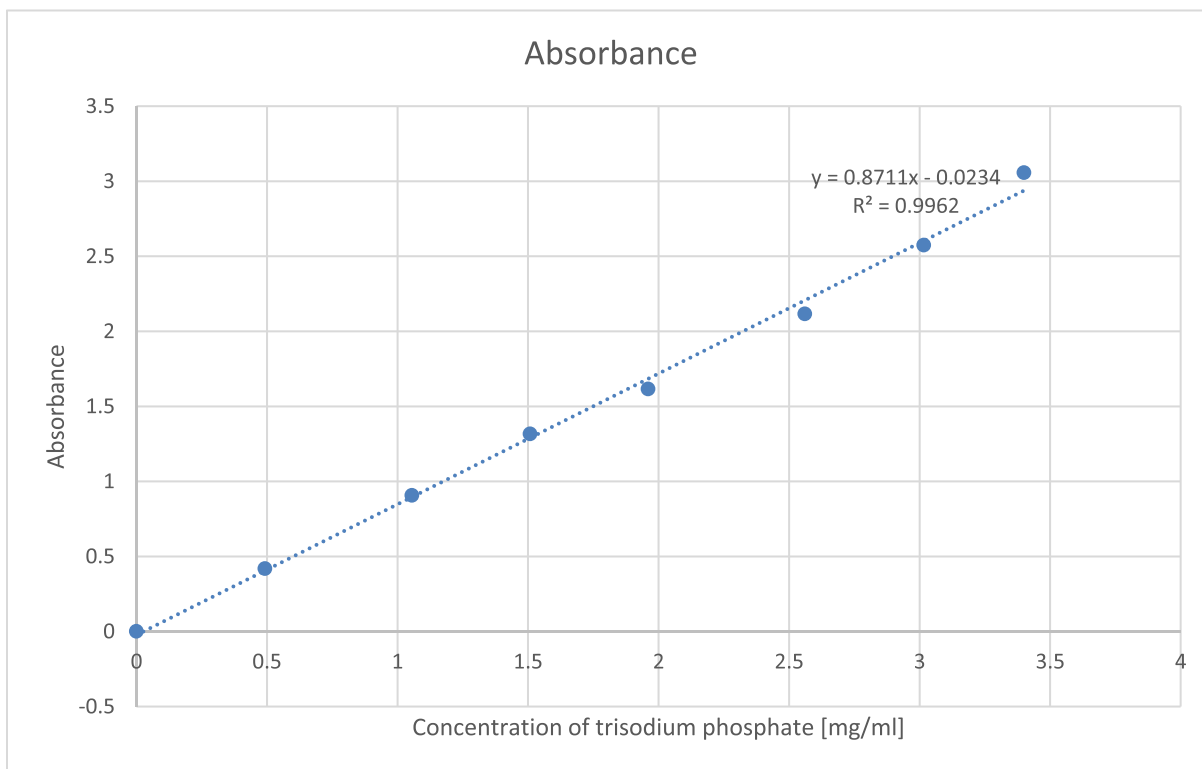


Fig. 1 Calibration curve (Y-axis: absorbance, X-axis: concentration of phosphate ions).

**Table 3** Flexural strength, Izod impact resistance, and Vickers hardness of acrylic samples after modification with bioactive fillers.

Sample	Group number	Flexural strength mean $\pm$ SD [MPa]	Izod resistance mean $\pm$ SD [J/mm <sup>2</sup> ]	Vickers hardness mean $\pm$ SD [°]
Superacryl Plus (reference)	P0	100.20 $\pm$ 2.61	0.853 $\pm$ 0.097	154.9 $\pm$ 2.7
2.5% CaHPO <sub>4</sub>	P1	99.75 $\pm$ 5.65	1.075 $\pm$ 0.094	181.7 $\pm$ 13.0
5% CaHPO <sub>4</sub>	P2	91.58 $\pm$ 7.89	0.808 $\pm$ 0.096	161.0 $\pm$ 3.7
10% CaHPO <sub>4</sub>	P3	93.99 $\pm$ 6.97	0.856 $\pm$ 0.087	161.3 $\pm$ 7.1
2.5% HA	P4	112.78 $\pm$ 4.32	1.088 $\pm$ 0.078	172.1 $\pm$ 3.3
5% HA	P5	101.48 $\pm$ 5.04	0.94 $\pm$ 0.062	169.1 $\pm$ -3.7
10% HA	P6	89.43 $\pm$ 7.21	0.807 $\pm$ 0.077	162.0 $\pm$ 2.5
2.5% Kavitan	P7	90.82 $\pm$ 7.22	1.004 $\pm$ 0.042	166.1 $\pm$ -4.1
5% Kavitan	P8	94.54 $\pm$ 6.96	0.793 $\pm$ 0.118	176.4 $\pm$ 5.9
10% Kavitan	P9	91.5 $\pm$ 11.18	0.573 $\pm$ 0.020	177.0 $\pm$ -6.0
2.5% Fritex	P10	93.05 $\pm$ 2.0	1.001 $\pm$ 0.086	170.50 $\pm$ -0.40
5% Fritex	P11	88.45 $\pm$ 6.22	0.751 $\pm$ 0.073	222.2 $\pm$ 5.3
10% Fritex	P12	71.19 $\pm$ 4.12	0.702 $\pm$ 0.104	145.7 $\pm$ 3.3
2.5% Kavitan p/l reaction	P13	82.49 $\pm$ 6.64	0.833 $\pm$ 0.038	221.7 $\pm$ 6.6
5% Kavitan p/l reaction	P14	84.99 $\pm$ 5.19	0.682 $\pm$ 0.099	170.6 $\pm$ 0.5
10% Kavitan p/l reaction*	P15			180.7 $\pm$ 4.4

\* Samples with 10% of Kavitan were too brittle and not possible to remove from metal forms.

**Table 4** Phosphate ion release from acrylic samples after modification with different bioactive substances.

Sample	1st week		2nd week		3rd week	
	[mg]PO <sub>4</sub> <sup>3-</sup>	Total [%] ions eluted	[mg]PO <sub>4</sub> <sup>3-</sup>	Total [%] ions eluted	[mg]PO <sub>4</sub> <sup>3-</sup>	Total [%] ions eluted
2.5% CaHPO <sub>4</sub>	2.08 $\pm$ 0.06	38.42 $\pm$ 2.06				
5% CaHPO <sub>4</sub>	2.49 $\pm$ 0.06	20.53 $\pm$ 0.93	0.28 $\pm$ 0.01	2.01 $\pm$ 0.09	0.22 $\pm$ 0.00	1.55 $\pm$ 0.00
10% CaHPO <sub>4</sub>	3.35 $\pm$ 0.09	13.39 $\pm$ 0.20	0.40 $\pm$ 0.01	1.35 $\pm$ 0.02	0.22 $\pm$ 0.01	0.77 $\pm$ 0.03
2.5% HA	0.89 $\pm$ 0.01	27.67 $\pm$ 0.73				
5% HA	2.26 $\pm$ 0.02	32.99 $\pm$ 1.44	0.24 $\pm$ 0.01	3.00 $\pm$ 0.21		
10% HA	4.04 $\pm$ 0.01	29.40 $\pm$ 0.27	0.27 $\pm$ 0.00	1.70 $\pm$ 0.02		
2.5% Kavitan	0.83 $\pm$ 0.01	65.18 $\pm$ 1.16				
5% Kavitan	1.44 $\pm$ 0.01	57.53 $\pm$ 2.88	0.26 $\pm$ 0.01	9.03 $\pm$ 0.73		
10% Kavitan	4.05 $\pm$ 0.01	77.43 $\pm$ 1.27	0.26 $\pm$ 0.01	4.36 $\pm$ 0.24		
10% Fritex*	0.53 $\pm$ 0.00	21.20 $\pm$ 0.05				
2.5% Kavitan p/l reaction product	0.48 $\pm$ 0.00	34.06 $\pm$ 0.32				
5% Kavitan p/l reaction product	0.58 $\pm$ 0.00	20.77 $\pm$ 0.37				
10% Kavitan p/l reaction product	0.68 $\pm$ 0.01	12.12 $\pm$ 0.06				

\* At lower concentration of Fritex glass, no phosphate ions were detected.

#### 4. Discussion

The study confirmed the assumed hypothesis that acrylic samples, after the addition of compounds containing phosphate ions, release them in a short period of time up to 3 weeks.

The available studies in the literature have discussed well the creation of ion-releasing materials for composites.

Some articles have described the modification of *composite materials* with bioactive fillers but do not provide information on acrylic resins containing different bioactive fillers instead of HA, used for denture bases in the case of partially edentulous patients (Tham et al., 2010; Pan et al., 2013; Sonarkar and

Purba 2015). Dental-filling resins (composites) are crosslinked materials (matrix composed of resins, with two or three methacrylic groups) which can protect the ions from releasing. On the contrary, acrylic materials are not highly crosslinked (linear structure of PMMA chains) and can be a potential source of ions.

Hassan et al. (2014) tried to modify acrylic resins with the addition of HA in concentrations of 2% and 5% and measured their infrared spectrum. They observed no chemical reaction between polymers and HA and indicated that the material can be released for a certain time and act as an alternative to bone cement used for patients with HA deficiency. The results

of the present study showed that HA can migrate from samples during a 2-week period. The total material eluted from resins was about 30%.

Safarabadia et al. (2014) investigated the mechanical properties of composite based on PMMA, HA, and  $Al_2O_3$ , in concentrations of 5% and 10%. They concluded that the mechanical properties of hybrid composites were significantly improved in comparison with pure PMMA. The authors used different kinds of fillers (aluminum oxide, HA, or others) mainly with an aim of obtaining materials with better mechanical properties of PMMA. These results are similar to the observations made during this study that the addition of 2.5% of HA to resins improves the flexural strength by about 12%. Moreover, Izod resistance improved after the addition of a small amount of well-dispersed filler.

Regarding the biocompatibility of HA-modified materials, Chadda et al. (2016) described the use of HA/silica composites and tested their cytotoxicity to ensure that such modification is biologically safe. The material for their study was constructed from a mixture of bis (GMA) (bisphenol A-glycidyl methacrylate) and triethylene glycol dimethacrylate. The results showed that the materials were nontoxic and supported cell adherence.

Tham and coauthors (2010) prepared a composite based on HA and acrylic resin and measured the sorption of the formed materials. They concluded that diffusion coefficient was very sensitive to the silane concentration inside the PMMA/5HA composites.

Chiari et al. (2015) tested the release of  $PO_4^{3-}$  ions from composite using inductively coupled plasma optical emission spectrometry. Dicalcium phosphate was tested as a raw material for phosphate and calcium sources. The authors observed that this phosphate salt can be easily removed from the curing material but significant reductions were observed in the mechanical properties of such material.

The tests performed in the present study with a similar phosphate salt showed that mechanical properties can be improved but with a smaller concentration of filler—2.5% and 5%. At higher filling ratio—10%, flexural strength and Izod impact resistance can be significantly reduced compared to pure acrylic resin. Calcium hydrogen phosphate was found to be a good material for releasing ions (totally 23% of whole ions from the samples).

In this investigation, it was observed that phosphate salts and bioactive glass used for GICs are capable of releasing phosphate ions. If they can potentially deliver anions, cations can also be removed. However, this should be tested further in another study.

It is important to ensure good dispersion of filler inside the resin matrix; otherwise, the standard deviation between the samples during the mechanical test will be very high. A similar conclusion was formulated by Zebarjad et al. (2011) in their study in which 2.5% of HA was added into acrylic resin and the mechanical properties of the resulting material were tested. The authors noticed that the HA–PMMA nanocomposite containing 2.5% of filler possessed better compressive strength and compression yield strength.

## 5. Conclusions and limitation

It can be concluded that:

1. Addition of 2.5% HA to denture-base acrylic resins improves their mechanical properties.
2. Addition of different bioactive precursors allowed the release of ions for a short time. Further studies should focus on finding the ions that can be released for a long time.
3. There is a need to test the release of other ions such as calcium and fluoride.

## 6. Clinical significance

Currently, a new trend of development of bioactive materials is noticed, which could spontaneously improve the treatment and rehabilitation process by exposing drugs, active substances, or bactericidal substances from their surface.

## Ethical statement

I, Zbigniew Raszewski, as the author of the article below, declare that this work, in whole or in part, has not been published in any periodical.

The conducted studies are in vitro tests, without the participation of humans or animals.

## Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: The research was carried out based on own funds in R&D laboratory WSM Bialystok. The author would like to thank Spofa Dental for providing materials for research.

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