

ORIGINAL ARTICLES

Bioactivity, physical and chemical properties of B₂O₃-doped calcium phosphate glasses

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ABSTRACT

Three bio-phosphate glass-specimens have been prepared using the conventional melting method and doped with B₂O₃. Their bioactivity behavior towards the simulated body fluid (SBF) biological solution was tested. The results revealed that B₂O₃ has significant effect on the ability of bio-glass-specimens to form the hydroxyl carbonate apatite layer on their surface. This layer was indicated by Fourier transform infrared (FTIR) spectroscopy, energy dispersive x-ray analysis (EDAX), scanning electron microscopy (SEM) and inductive coupled plasma (ICP) analysis. Also, the effect of B₂O₃ on the mechanical properties was studied by measuring the Vickers microhardness (H_V) of the glass samples. The hardness increased by adding 5 wt.% B₂O₃, then decreased with increasing this content to 10 wt.%. Density was found to increase in case of addition of 5 wt.% B₂O₃ to the glass sample, then decreased with increasing the B₂O₃ content to 10 wt.%. Chemical durability of the samples towards alkaline and acidic solutions has been also studied. The rate of dissolution of the sample containing 5 wt.% B₂O₃ was low then increased with increasing the B₂O₃ content to 10 wt.% in the glass.

Key words: Bioactive glass; FTIR; SEM; Mechanical properties

Introduction

In the recent years, biomaterials, specially, traditional ceramics, metals, bioactive glass and bioglass-ceramics or a combination of these materials have gained more interest in the field of medicine in view of their variety of potential applications such as replacement of damaged or diseased body parts (Hench *et al.* 1972; Andersson *et al.* 1988; Nakamura *et al.* 1985; Nakamura *et al.* 1992). The most important biomaterial in this series, which finds immense application in the field of medicine, is bioactive glass. Some of the bioactive glasses and bioglass-ceramics with a specific composition can form bond with natural bone and hence, they are known as bioactive glass-ceramics (Hench, 1982). For the effective bonding of the bioactive glass to bone, a selection of proper composition is more essential. Bioactive glasses and glass-ceramics are suitable bone bonding materials (Hench, 1991; Kokubo *et al.* 1990). Calcium phosphates (Ca-P) are of special interest to oral biology and medicine because of their occurrence in normal (e.g., enamel, dentin, cementum, bone) and pathological (e.g., dental calculi, salivary stones) calcifications, their association with the formation, progression and arrest of enamel and dentin caries, and their use in preventive and restorative dentistry. These Ca-P include amorphous calcium phosphate (ACP), brushite or dicalcium phosphate dehydrate (DCPD), monetite or dicalcium phosphate anhydrous (DCP), octacalcium phosphate (OCP), whitlockite or tricalcium phosphate (TCP) and hydroxyapatite (HA). A number of different types of ceramic materials have been developed that have osteoconductive and osteoinductive properties. Such materials are effective in the repair and regeneration of bones. These include hydroxyapatite, Bioglass[®], apatite and wollastonite containing glass-ceramics (A-W GC) and other inorganic phosphates, including glasses (LeGeros, 1991). Calcium phosphate based glasses and glass-ceramics have been of interest for medical uses due to their unique properties. In particular, a bioactive calcium phosphate based/implant after integration with bone can form a biologically active hydroxycarbonate apatite layer at the bone/ implant interface which favors bonding with bone and soft tissues. The first reported bioglass and one of the most common and well-characterized is the 45S5 Bioglass (45wt% SiO₂, 24.5CaO, 6P₂O₅ and Na₂O) (Hench, 1991). After this, a variety of similar glasses and glass-ceramics were developed but all with the following key compositional features: SiO₂ content smaller than 60 mol%, high Na₂O and CaO content and high CaO/P₂O₅ ratio (Peitl *et al.* 2001).

Bioactivity of calcium borosilicate glasses has been examined to derive a conclusion that substitution of appropriate amounts of B₂O₃ for SiO₂ achieved better bioactivity because the greater susceptibility of B-O bonds to water corrosion than Si-O bonds favored earlier formation on the hydrated silica layer and release of calcium ions (Ohtsuki *et al.* 1995). Invert phosphate glasses based on the system Na₂O-CaO-P₂O₅ have been

developed as resorbable biomaterials which can be considered as regenerator of bone defects, that is favored (Radin *et al.* 1997) compared with bone substitutes, in that resorbable materials can be dissolved after sometimes necessary for the filling of defect with new bone, without any toxic effect on the human life. Due to their nature, resorbable materials are usually utilized in short term non-load bearing applications such as sutures and drug delivery devices. However, applications for medium term such as fracture fixation are being considered as novel materials are researched.

Hydrolytical durability is often an important property required from a glass. However, glasses that are intended to be used in the human body as implant materials and become attached to living tissue must have certain solubility. Also, for long-term implants, it may be important to decrease the solubility as much as possible without losing bioactivity. This, in turn, requires an understanding of how compositional changes influence solubility and bioactivity (Alkemper and Fuess, 1997). Biomaterials have a key underpinning role in the delivery of medical devices as implants and prostheses for regenerative medicine. As a minimum, biomaterials should be non-toxic, relatively bio-inert, and mechanically appropriate-criteria which allowed the development of a first generation of prostheses, notably total joint replacement, based on suitable existing engineering materials. This process was enhanced by the subsequent innovation of novel biomaterials which, additionally, were bioactive in a skeletal site, i.e. producing bone apposition rather fibrous encapsulation. The key insight was provided by Hench (Hench, 1998) in his work on "Bioglass[®]" which in certain silicate glass compositions could bond to bone. These glasses were termed bioactive glasses.

In the current work, B₂O₃ has been added to the composition of selected phosphate glass in order to study its effect on the bioactivity, chemical and mechanical properties of the parent glass.

Experimental:

Glass preparation:

Glasses shown in Table 1 were prepared by the conventional melting and annealing method using reagent grade Ca(H₂PO₄)₂, CaCO₃, Na₂CO₃, MgO, Al₂O₃ and B₂O₃. The raw materials were mixed and melted in a platinum crucible at temperatures in the range 1100-1150 °C for 2h. Stirring of the melt each 20 min. is necessary to achieve good homogeneity. All glasses were cast as blocks in pre-heated stainless-steel molds, annealed at 350°C and cooled to room temperature with a rate 25 °C/h.

Table 1: Chemical composition of the investigated calcium phosphate glasses (wt.%)

Glass No.	P ₂ O ₅	CaO	Na ₂ O	Al ₂ O ₃	MgO	B ₂ O ₃
P0	60	20	15	2.5	2.5	0
P1	60	20	15	2.5	2.5	5
P2	60	20	15	2.5	2.5	10

Soaking in the simulated body fluid (SBF):

Each glass sample was soaked in 50 ml of Tris-buffered SBF solution, which resembles the human blood plasma (Kokubo, 1990), as shown in Table 2, at 37±0.5 °C, for 2 and 7 days. The SBF was prepared by dissolving reagent grade NaCl, NaHCO₃, KCl, K₂HPO₄·3H₂O, MgCl₂·6H₂O, CaCl₂ and Na₂SO₄ into deionized water. The solution was buffered to pH= 7.4 with Tris-(hydroxyl methyl)-amino methane [(CH₂OH)₃CNH₂] and hydrochloric acid.

Table 2: Ion concentration (mM) in the simulated body fluid (SBF) and human plasma

Solution	Ion concentration (mM)							
	Na ⁺	K ⁺	Mg ²⁺	Ca ²⁺	Cl ⁻	HCO ₃ ⁻	HPO ₄ ²⁻	SO ₄ ²⁻
SBF	142.0	5.0	1.5	2.5	147.8	4.2	1.0	0.5
Body plasma	142.0	5.0	1.5	2.5	103.0	27.0	1.0	0.5

Surface analysis of samples:

The immersed glass samples were taken out after immersion in the SBF then washed with deionized water and air dried. Surface analysis was conducted using Fourier transform infrared (FTIR) using FT-IR spectrometer (type Jasco FT/IR-430, Japan) and the energy dispersive x-ray analysis (EDAX-SEM) using SEM mode Philips XL30 attached with EDAX unit.

Elemental concentration analysis:

Changes in the concentration of calcium and phosphorus of the SBF solution due to soaking of the samples for 2 and 7 days were measured using inductive coupled plasma (ICP, atomic absorption spectrometer, Spectra AA).

*Properties measurements:**Microhardness measurement:*

The microhardness of the investigated samples was measured by using Vickers microhardness indenter (Shimadzu, Type-M, Japan) at normal atmospheric condition. The eyepiece on the microscope of the apparatus allowed measurements with an estimated accuracy of ± 0.5 mm for the indentation diagonals. Grinding and well polishing were necessary to obtain polished, smooth and flat parallel surfaces of the glass samples before indentation testing. At least five indentations were measured for each sample. Testing was conducted using 100 g load for 15 s loading time.

Density measurement:

The density (ρ) of glasses were determined by Archimedes method. The weights of the samples were determined both in air (a) and after immersion in xylene at room temperature (b). The density was calculated according to the equation:

$$\rho = (a/b) \times 0.86$$

where the density of xylene is 0.86. The measured density values were converted to the molar volume as it is also a structure related parameter. The molar volume (V_m) of glass is defined as the mean molecular weight of its constituents divided by its density (ρ) as given by the equation:

$$V_m = M / \rho$$

where (M) is the mean molar weight of the glass expressed as the mole fractions of the oxides multiplied by their molecular weights.

Durability tests:

The bulk-test was used to evaluate the average total rates of dissolution of the investigated glasses. The glass samples were subjected to the attack of solutions for 7 days at 37 °C. Finely polished glass samples in the form of rectangular slabs of the dimensions $4 \times 1.25 \times 0.5$ cm³ were prepared for chemical durability tests. The corner and edges were polished and slightly rounded in order to avoid any sharp edges. The surface area of each sample was calculated then the samples were weighed and placed in the polyethylene beakers (250 ml) containing different selected solutions at a temperature of 37 °C for different time periods. After the specified duration, the glass samples were removed from the corroding solutions, rinsed with distilled water, dried in oven at about 120 °C for 2 h then placed in a desiccator and the samples were reweighed after corrosion. The weight loss of the samples has been determined by subtracting the weight of the treated sample from its original weight. Dissolution rates were calculated from the surface area, dissolution time and weight loss as mentioned in the following equation:

$$\text{Rate of dissolution} = \text{weight loss (g)} / \text{surface area (cm}^2\text{)} \times \text{time (h)}$$

Results And Discussion

In theory, exactly the same should happen if the glass dissolves in a tissue environment, with the glass being replaced by bone. Using different chemical ratios will give different solubility rates to cover the requirements of hard and soft tissue replacements. The development of phosphate glasses for use in orthopaedics has attracted much interest because their chemical and physical properties make them suitable for use as bone/bonding materials. These glasses make use of an inorganic phosphate network for their main of other oxides. However, so far, to our knowledge, the formation of apatite on phosphate glasses without silica has not been detailed reported. For example, it has been reported that, addition of B₂O₃, CaF₂, MgO or TiO₂ generally leads to glass-ceramic materials which also show bioactivity (Kasuga *et al.* 1999). Fig. 1 shows the

FTIR spectra of sample P0 before and after immersion in SBF solution for 2 and 7 days. It appears, from this figure, that the spectrum before immersion reveals peaks at about 1300 cm^{-1} , 1274 cm^{-1} , shoulders at 1155 cm^{-1} , 1100 cm^{-1} , 998 cm^{-1} , 890 cm^{-1} , 780 cm^{-1} , 725 cm^{-1} , broad bands at 666 cm^{-1} , 515 cm^{-1} and a relatively weak band at about 442 cm^{-1} . By increasing the soaking time of the glass sample in SBF, the hydroxycarbonate apatite (HCA) layer begins to crystallize and the bands indicating its formation appear at about 560 and 604 cm^{-1} . These peaks start to appear after 2 days and their intensity increased after 7 days.

The interpretation of the characterizing peaks of FTIR spectra (Fig. 1) could be summarized as follow:

(a) The peaks at about 1300 and 1274 cm^{-1} are assigned to PO_2 asymmetric stretching vibration modes, while the peaks at 1100 and 998 cm^{-1} are assigned to PO_3 asymmetric and symmetric stretching vibration, respectively. The vibration mode of the doubly bonded $\text{P}=\text{O}$ can be also found at about 1275 cm^{-1} .

(b) The double peaks at 780 and 725 cm^{-1} are due to the symmetric stretching vibration of $\text{P}-\text{O}-\text{P}$ bond, while that at 890 cm^{-1} to its asymmetric stretching one.

(c) The peaks at 666 and 510 cm^{-1} are assigned to the bonding vibration of $\text{P}-\text{O}$ bonds.

(d) The weak band at about 442 cm^{-1} can be assigned to the $\text{P}-\text{O}-\text{Al}$ bond vibrational motion. Presence of aluminum, even in low content, results in strengthening of the glass network by cross-linking phosphate chains (Abo-Naf *et al.* 2004).

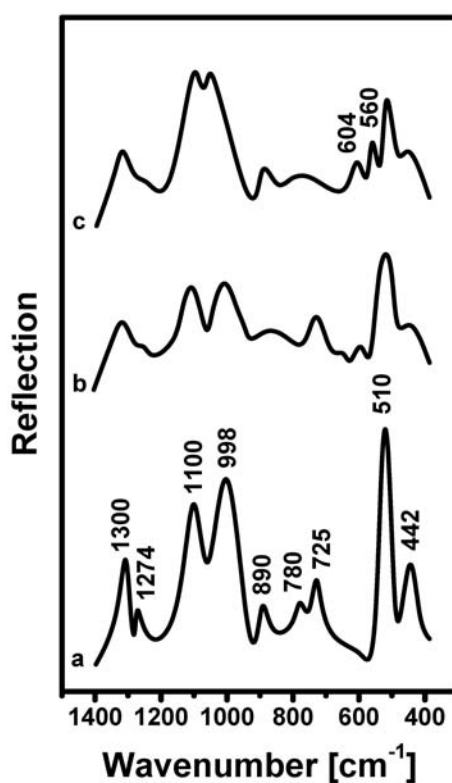


Fig. 1: FTIR spectra of the base glass sample (P0): (a) before, (b) after soaking in SBF for 2 days and (c) 7 days.

After 7 days immersion in SBF solution, the intensities of the characteristic peaks of metaphosphate structural units decrease. This is due to the formation of hydroxycarbonate apatite layer (at 604 and 560 cm^{-1}) on the glass surface. A new peak was appeared after 2 days of immersion in SBF solution at 560 cm^{-1} , which is due to carbonate compounds. The presence of this carbonate layer has been shown to be important (Filgueiras *et al.* 1993) as it is the precursor layer on which the apatite film appeared. Fig. 2 shows the SEM micrographs of sample P0 surface before and after immersion in SBF for 2 and 7 days, which confirms the results obtained from the FTIR spectroscopy mentioned above. Fig. 2a shows the surface of the base glass before immersion where no layer can be observed. It can be seen that, after immersion in SBF for 2 days (Fig. 2b), nucleation took place and traces of the HCA layer were formed. After 7 days immersion (Fig. 2c), a layer possessing granular structure of HCA can be observed on the surface. This layer is responsible for the combination between the bioactive material and the bone tissue for optimum healing (Langstaff *et al.* 1999).

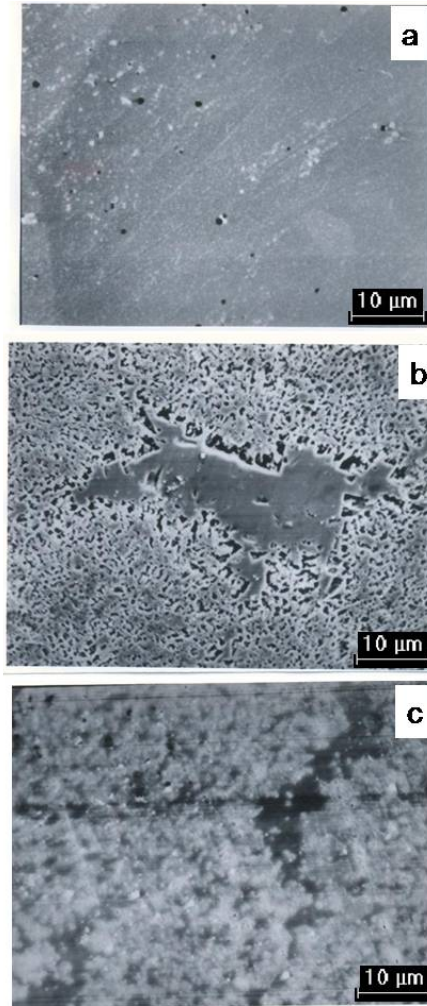


Fig. 2: SEM micrographs of the base glass (P0): (a) before, (b) after immersion in SBF for 2 days and (c) 7 days.

Fig. 3 shows the FTIR spectra of the glass specimens in case of absence and presence of B_2O_3 in the glass composition after soaking in SBF for 1 week. From this Fig., the effect of addition of B_2O_3 on the formation of the HCA layer on the surface of the bioactive glass can be deduced. It is indicated that the intensity of the two peaks, related to the formation of HCA layer (at about 604 and 560 cm^{-1}) on the glass surface, increased with increasing B_2O_3 content (up to 10 wt.%). It is, therefore, suggested that the presence of boron in the glass network has seemingly favored the bioactive performance of the studied phosphate glass. This can be attributed to the greater susceptibility of B–O bonds to water corrosion and the ability of boron to change coordination and attach hydroxyl (OH^-) groups at the surface of the resultant glasses and, consequently, facilitates the formation of HCA layer on the glass surface. The role of B_2O_3 in the phosphate glasses was previously studied by Saranti *et al.* (Saranti *et al.* 2004) who found that boron atoms incorporated in the phosphate network create BO_3 and BO_4 units in the glass network. In these units, a trigonal or tetrahedral boron atom bridges neighboring phosphate tetrahedra, since the available number of Ca^{2+} cations per phosphorus negative units ($P-O^-$) is smaller in case of glass containing B_2O_3 than in boron-free glass, and the structure of glass will result in the enhancement of dimensionality of the phosphate network by creation of larger phosphate units which leads to a higher degree of network modification of the B_2O_3 containing glass.

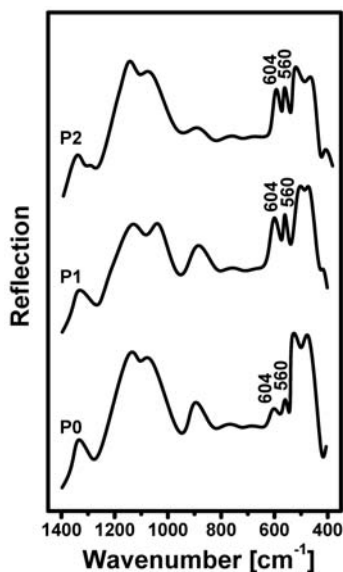


Fig. 3: FTIR spectra of the investigated glass samples after soaking in SBF for 7 days.

Fig. 4 represents the SEM micrographs of the investigated phosphate glass containing B₂O₃. It can be observed that the rate of hydroxyapatite layer crystallization, after their immersion in SBF solution for 7 days, increased with increasing B₂O₃ content in the glass composition from 5 to 10 wt.%. The crystallization of HCA layer was improved and distributed overall the glass surface. It can be also noticed that the particle size increased with increasing B₂O₃ content.

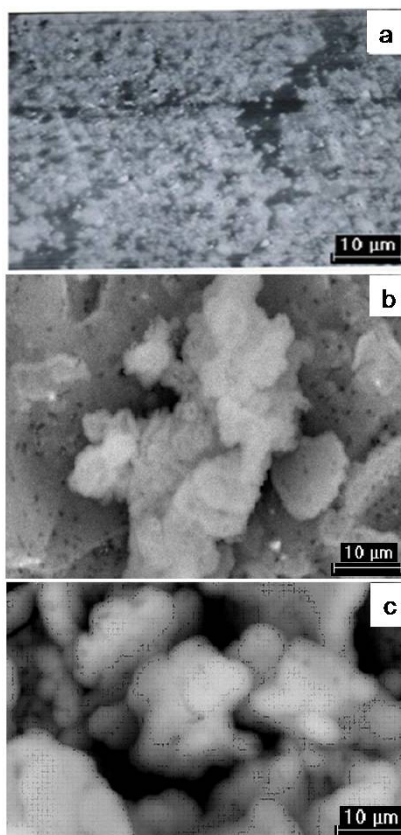


Fig. 4: SEM micrographs of the studied glasses after immersion in SBF for 7 days: (a) sample P0, (b) P1 and (c) P2.

Table 3 gives the evolution of ion extraction by the simulated body fluid solution (SBF) with time in relation to the initial elemental composition of the glass. A marked release of Ca and P ions takes place, which is governed by the bioactivity behavior of the glass, the effect of ions released on the pH value of the solution and the composition of the bioactive glass. These elemental concentration analyses are some kind of confirmation for the formation of HCA layer on the glass surface. The quantitative analysis of the Ca and P ions during and after SBF immersion tests is important to understand the kinetics of surface reaction in the bioactive materials. The decrease in Ca and P concentrations with a continuous glass soaking in SBF solution is consistent with the formation and growth of Ca-P₂O₅ layer on the glass surface. The phosphate glass dissolves easily in aqueous solutions and the fast release of the phosphorus ions at early time of immersion leads to lowering in the pH value by time. It is obvious that the release of acidic phosphorus ions lowered the pH of solution. Generally calcium phosphate apatite crystals are precipitated in alkaline medium (Kasuga *et al.* 2001), but in case of the presence of some inhibitors which affect the fast HCA layer formation, Ca and P concentrations in the solution increased by dissolving of the glass in the solution. Inspection of the elemental analysis given in table 3 indicates that, after immersion for 7 days, Ca and P concentrations decrease with increasing B₂O₃ content from 5 to 10 wt.%. Therefore, this may lead to the assumption that B₂O₃ enhances the HCA layer formation through the fast consumption of Ca and P ions.

Fig. 5 shows the EDAX patterns of glasses P0, P1 and P2 surfaces after immersion in SBF for 7 days. Peaks indicating the presence of P, Na, Ca and minor amount of Mg and Al appeared. It can be clearly observed that the peaks related to P and Ca, which indicate the precipitation of calcium phosphate apatite layer after 7 days, have been obviously increased from P0 to P2 with increasing B₂O₃ content, which continues to confirm the suggestions concluded from both of the FTIR spectroscopy and SEM micrographs.

Table 3: Elemental concentrations in the SBF solution after immersion of glass samples for 2 and 7 days

Sample No.	Time (days)	Elemental concentrations (ppm)	
		Ca	P
SBF (standard)		89.05	34.0
P0	2	91.9±0.5	36.5±0.5
	7	85.1±0.5	28.5±0.5
P1	2	90.0±0.5	35.2±0.5
	7	79.5±0.5	25.6±0.5
P2	2	98.2±0.5	45.0±0.5
	7	76.2±0.5	22.3±0.5

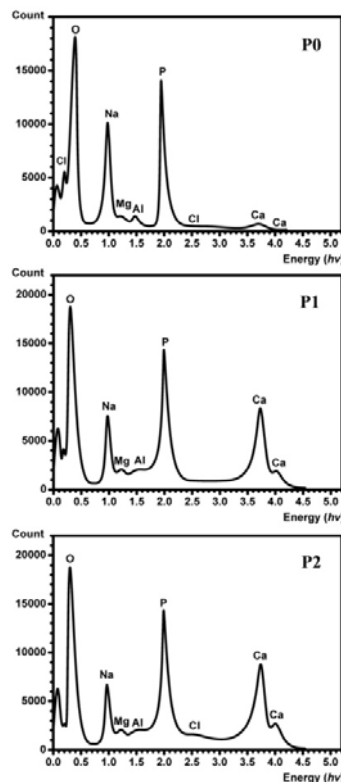


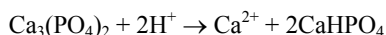
Fig. 5: EDAX patterns of glass surfaces of the investigated glasses after immersion in SBF for 7 days

Density and microhardness, which are considered as important physical properties for characterization of such bio-phosphate glasses, were also measured. Molar volume values of the glasses were calculated from the density values. These data are given in Table 4. It is indicated that introduction of 5 wt.% of B₂O₃ into glass structure increases its density and, conversely, decreases its molar volume. This can be explained by the logic suggestion of the formation of P-O-B linkages and BO₄ tetrahedral structural units that cross-link neighboring phosphate chains, and in turn, relatively increase the compactness of the glass structure, as observed in previous work (Shah *et al.* 2006; Hadj Youssef *et al.* 2000). Such compactness, consequently, resulted in a slight increase in the value of Vickers microhardness (H_v). Infrared bands resulted from the formation of BO₄ tetrahedra can be observed in Fig. 3 at about 890 cm⁻¹ (Kamitsos *et al.* 1990; Pisarski *et al.* 2005). In this case, better chemical durability, expressed as lower dissolution rates in both acidic and alkaline solutions as given in Table 4 and shown in Fig. 6, can be reasonably expected from such properties trend. Further increase in B₂O₃ content to 10 wt.% (glass P2) results in a reversed property trend, i.e. a decrease in both of the glass density and microhardness; and an increase of the molar volume. Also, this glass exhibits lower chemical durability than that of both of the glasses P0 and P1. This behavior implies a relative weakening in the glass network in case of glass P2. Calcium phosphate glasses, in particular, can be biocompatible materials. They are more or less degradable, resulting in relatively moderate chemical durability in the biological solutions, and as a consequence can be conveniently used for filling bone defects or for reconstructing bony tissues (Ducel and Videau, 1993). Interpretation of such property changes can be understood in terms of the dependence of these properties on the structure of glassy network which, in turn, is very sensitive to the density of cross-links and the strength of the metal-oxygen cross-links. Therefore, it might be suggested that, for the higher boron content specified in the current study (10 wt.%), some diborate structural units and/or BO₃ triangles are evolved and gradually substituted for the rigid boro-phosphate network that contains only 5 wt.% of B₂O₃. Previous work (Krogh-Moe, 1965) concluded that the fundamental building structural units in vitreous B₂O₃ is the BO₃ groups as a random network of boroxol rings beside some fraction of BO₃ triangles connected by B-O-B linkages constituting bridging oxygen atoms. The boroxol group is composed of three corners sharing BO₃ triangles which form a very highly planar ring. Recent studies (Almeida *et al.* 2001; Mozzi and Warren, 1970) concluded that any model which attempts to give a full description of the structure of vitreous B₂O₃ must include a considerable concentration of boroxol groups beside both of the (BO₄) tetrahedrons and (BO₃) triangles in the phosphate glass structure. When plenty of divalent metal oxides (such as CaO) are available, it is preferable to form BO₄ tetrahedrons (Ducel *et al.* 1994), which may join in the phosphate glass structure to improve its durability through strengthened P-O-B bonds. Then by gradual increase of B₂O₃, the BO₃ triangles are formed which may result in the weakening of phosphate glassy matrix and deterioration of its chemical durability. Generally, infrared bands belonging to the BO₃ triangles can be found in the region around 1300 cm⁻¹. This band can be observed at about 1325 cm⁻¹ in the FTIR spectrum of glass P2 given in Fig. 3. Strict inspection of this band indicates that it becomes slightly intenser and broader in the spectrum of glass P2 than those recorded in the spectra of glasses P0 and P1 in the same figure.

Table 4: Density, molar volume, microhardness and dissolution rates in both of 0.05 N HCl and 0.05 N NaOH of the studied calcium phosphate glasses

Glass No.	Density (ρ) (gm cm ⁻³)	Molar volume (V _m) (cm ³ mol ⁻¹)	Vickers microhardness (H _v) (kg mm ⁻²)	Dissolution rate in 0.05 N HCl (g cm ⁻² day ⁻¹)	Dissolution rate in 0.05 N NaOH (g cm ⁻² day ⁻¹)
P0	2.8553	38.257493	322	5.92 x 10 ⁻³	5.59 x 10 ⁻⁴
P1	2.9276	49.202971	354	3.94 x 10 ⁻³	3.72 x 10 ⁻⁴
P2	2.7452	42.327925	297	6.63 x 10 ⁻³	6.41 x 10 ⁻⁴

Chemical durability behavior obtained in the present study indicates that the dissolution rates of the investigated calcium phosphate glasses in aqueous NaOH solution are generally less than those found in aqueous HCl solution. These results are in good agreement with previous studies (Dorozhkin, 1997; Liang *et al.* 2006) carried out on calcium phosphate glasses in acidic and alkaline media. It was pointed out that the dissolution rate increases with decreasing pH of the leaching solution. The authors suggested an attack mechanism at acidic pH that can be expressed by the following equation:



According to the above analysis of the hydration mechanism of calcium phosphate glasses, the breakage of P—O—P bonds between the [PO₄] tetrahedra under the attack of H⁺ ions in hydrated layer caused the destruction of the glassy matrix and disentanglement of short-chain polyphosphates into solution with different degrees of polymerization. Because the network breakage reaction is highly sensitive to the attack of H⁺ ions, decreasing the pH value of aqueous media could conspicuously increase the dissolution rate of the phosphate glasses. On the other hand, the breakage of P—O—P will release other H⁺ ions, which result in a further decrease of solution

pH. While, if the pH of the solution increases, i.e. in case of using alkaline leaching solutions which possess higher ionic strength, the dissolution rate decreases resulting in relatively better chemical durability. Such behavior could be attributed to the increased electrostatic interactions preferably occurred in the hydrated layer more than the solubility process due to the formed protective hydroxide layer.

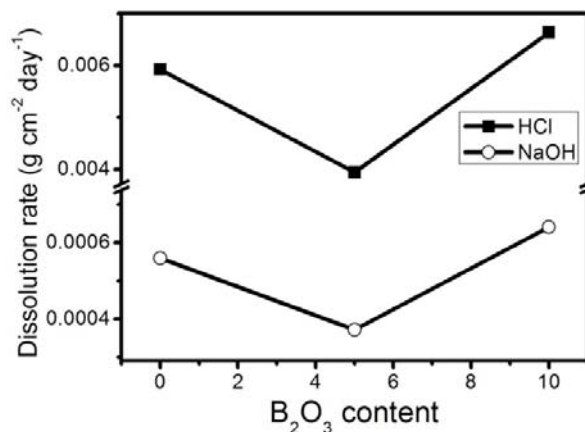


Fig. 6: Dissolution rates of the studied glasses after leaching in 0.05 N solutions of both of HCl and NaOH for 7 days at room temperature as a function of the B₂O₃ content.

Conclusions:

Bioactivity behavior of B₂O₃-doped calcium phosphate glasses was tested towards the simulated body fluid (SBF) biological solution. The results showed that B₂O₃ has significantly increased the ability of the investigated glass-specimens to form the hydroxyl carbonate apatite layer on their surface. The formation of this layer and its growth have been indicated by recording its corresponding bands in the FTIR spectra and EDAX patterns where the intensity of these bands increased with increasing B₂O₃ content. This observation has also reached as a result of the crystal growth shown in the obtained SEM micrographs. Density, microhardness and chemical durability, which are considered as important physical and chemical properties for characterization of such bio-phosphate glasses, were also measured. The dependence of these properties on the chemical composition and the corresponding structure of the studied glasses has been explained and discussed in view of the obtained results.

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