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Assessment of nickel oxide substituted bioactive glass-ceramic on in vitro bioactivity and mechanical properties

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ABSTRACT

Many type of oxide substituted glass-ceramics like strontium, cobalt, barium and titanium have shown bioactivity with improved mechanical properties. The present work reports the in vitro bioactivity and mechanical properties of nickel oxide substituted in bioactive glass-ceramic and results were compared with 45S5 bioactive glass-ceramic. Bioactive glass ceramics were processed through controlled crystallization of their respective bioactive glasses. The formed crystalline phases in bioactive glass-ceramics were identified using X-ray diffraction (XRD) analysis. The formation of HA layer was assessed by immersing them in the simulated body fluid (SBF) for different soaking periods. The formation of hydroxyapatite was confirmed by FTIR spectrometry, SEM and pH measurement. Densities and mechanical properties of the samples were found to increase considerably with an increasing the concentration of nickel oxide. A decrease in glass transition temperature (Tg) with NiO addition showed that the nickel oxide had acted as an intermediate in smaller quantities in the bioactive glass. The cell culture studies demonstrated that the samples containing low concentration of NiO from 0 to 1.65 mol% were non-cytotoxic against osteoblast cells. Finally, this investigation clearly concluded that NiO doped bioactive glass would be potential biomaterials for biomedical applications.

Evaluación del efecto de la sustitución de SiO_2 por NiO sobre la bioactividad y las propiedades mecánicas de vitrocerámico bioactivos

Palabras clave:
Vidrios bioactivos
Bioactivos-vidrio-cerámica
Propiedades mecánicas
Óxido de níquel

RESUMEN

La sustitución de óxidos en la composición de vitrocerámicos bioactivos por otros como son los de estroncio, cobalto, barrio y titanio han demostrado bioactividad con una mejora de sus propiedades mecánicas. En el presente trabajo se muestra el efecto de la sustitución de SiO_2 por NiO, en vitrocerámicos basados en la composición del biovidrio 45S5, sobre la bioactividad y las propiedades mecánicas, comparándose los resultados obtenidos. Los

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Espectrometría FTIR y célula de la cultura

vitrocerámicos se obtuvieron mediante cristalización controlada de los respectivos biovidrios. Las fases cristalizadas se identificaron mediante Difracción de Rayos X (DRX). La formación de una capa de hidroxiapatita se evaluó mediante inmersión, durante varios periodos de tiempo, en Suero Fisiológico Artificial (SFA). La formación de dicha capa se confirmó mediante Espectroscopia Infrarroja con Transformada de Fourier (FTIR), Microscopía Electrónica de Barrido (SEM) y medidas de pH. Tanto la densidad como las propiedades mecánicas de las muestras aumentan al aumentar la concentración de NiO, a la vez que se produce una disminución de la temperatura de transición vítrea (Tg). Estudios en cultivos celulares con células osteoblásticas demostraron que las muestras que contienen baja concentración de NiO (0 a 1,65%) en moles no son citotóxicas. Por último, esta investigación concluye claramente que estos biovidrios dopados con NiO son potenciales biomateriales para aplicaciones biomédicas.

Introduction

Bioactive glasses used in biomedical application must have the ability to form chemical bond with bones and help in new bone growth [1,2]. Traditional melting method is considered as simple and suitable for mass production [3,4]. Hench and his team had invented first bioactive glass named as 45S5 bioglass® [5]. The bioactivity of the 45S5 bioglass® is mainly due to its composition which consists of low SiO_2 (glass network former) content, high CaO/P_2O_5 ratio and high Na_2O and CaO (glass network modifier) contents [6]. Bioactive material should possess good biochemical behavior and biomechanical strength. The 45S5® bioactive glass has very good capability to bond with both the soft and hard tissues [7]. However, poor mechanical properties like brittleness are the main disadvantage of 45S5® bioactive glass. A lot of researches have been carried out for preparation and characterization of bioactive glass and bioceramics with incorporation of some oxides such as CoO, ZnO, NiO and Fe_2O_3 in glasses which changed their mechanical, physical, chemical and bioactive properties [8–10]. The significant effects of oxide doped bioactive glass are on osteoblastic cell proliferation, differentiation and thus bone mineralization [11–14]. Another studies showed that substitution of B_2O_3, MgO, CaF_2 or TiO_2 in phosphate glasses and its ceramic derivatives had also shown bioactivity [15,16]. Substitution of bioactive glasses with different transition metals such as copper, zinc, manganese, iron, magnesium and silver to change their biological and bioactive response has been studied by a number of research groups [17–21]. Medical application of glass-ceramics is limited due to their inherent properties such as brittleness, low tensile strength and difficulty in coating onto other materials [22,23]. Hoppe et al. [24] investigated cobalt oxide releasing 1393 bioactive glass derivative scaffolds for bone tissue engineering applications as cobalt was known as angiogenesis agent. Smith et al. [25] studied the structural characterization of hypoxia-mimicking 45S5 glass prepared with 4.0 mole% of CoO and NiO. They found that bioactive glass containing NiO had offered an existing route for potential delivery system of Ni^{2+} ions with tissue regeneration scaffolds due to its ability to incorporate a large variety of elements such as Ca, P and their appreciably controlled dissolution properties within physiological fluids. It has been also reported earlier that up to 4.0 mole% NiO incorporated into bioglass® has proved physiologically to be appropriate concentrations [26,27] but the cell culture studies have revealed that low concentration NiO doped bioactive glasses are non-cytotoxic against osteoblast cells and suitable for biomedical applications.

The primary aim of the present study is to develop nickel oxide substituted glass-ceramic using the traditional melting method by incorporating varying amount of nickel oxide and study the effect doping of nickel oxide in silica-based bioactive glasses in order to determine its bioactivity and mechanical behavior.

Material and methods

Glass-ceramic preparation

The compositions of bioactive glass-ceramic as given in Table 1, were prepared by substitution of nickel oxide (0–1.65 mol%) in place of SiO_2 using the normal melting and annealing technique. Materials used include fine-grained quartz for silica. Lime and soda were introduced in the form of their respective anhydrous carbonates. P_2O_5 was supplementary in the form of diammonium hydrogen phosphate. The weighed batches were mixed thoroughly for 40 min and melted in alumina crucibles. The melting was carried out in an electric furnace at $1400 \pm 5\,^{\circ}C$ for 3 h in air as furnace atmosphere and homogenized melts were poured on preheated aluminum sheet. The prepared bioactive glass samples were directly transferred to a regulated muffle furnace at 480 °C for annealing. After 2 h of annealing the muffle furnace was cooled to room temperature with controlled rate of cooling at 10 °C/min. Nickel oxide substituted bioactive glass and base

Table 1 – Composition of bioactive glass-ceramics (mol%).

Sample	SiO_2	Na_2O	CaO	P_2O_5	NiO
45S5C	46.14	24.40	26.91	2.55	0.00
NiO-1C	45.64	24.41	26.94	2.60	0.41
NiO-2C	45.20	24.44	26.96	2.61	0.82
NiO-3C	44.71	24.46	26.98	2.61	1.23
NiO-4C	44.25	24.49	27.01	2.61	1.65

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