Original Review Article

Mechanical properties and Biological behavior of bioactive glass in restorative dentistry

Ola M. Sakr[1,2*]

[1]Department of Conservative Dentistry, College of Dentistry, Qassim University, Kingdom of Saudi Arabia
[2]Department of Operative Dentistry, College of Dentistry, Misr University for Science and Technology, Egypt
[*]Corresponding author email: **olasakr2004@yahoo.com**

International Archives of Integrated Medicine, Vol. 5, Issue 12, December, 2018.

Available online at http://iaimjournal.com/
ISSN: 2394-0026 (P) **ISSN: 2394-0034 (O)**
Received on: 12-11-2018 **Accepted on:** 16-11-2018
Source of support: Nil **Conflict of interest:** None declared.
How to cite this article: Ola M. Sakr. Mechanical properties and Biological behavior of bioactive glass in restorative dentistry. IAIM, 2018; 5(12): 146-151.

Abstract

Generally recent bioactive glasses are finding increasing applications in dentistry due to their potential of hard tissue remineralization stimulation. New compositions of bioactive glasses incorporating specific ions added in polymers will be the most important direction for future restorative dentistry researches. Until now, it shows weaker mechanical properties than commercially available restorative materials. Studying of new compositions for enhancing their mechanical properties with bioactivity maintaining is a big challenge in restorative dentistry.

Key words

Bioactive glass, Restorative dentistry, Mechanical properties, Biological behavior.

Introduction

With the development of science and technology and reported living standards improvement, rapid development of biomaterials with great qualitative improvement of life and longevity of human beings has occurred [1, 2]. There are several dental bioactive materials available in the market including implants, impression materials, core materials, dental cements, restorative materials and bonding agents [3, 4].

Researchers report expected that the global dental implants and prosthetics market will reach approximately $10.5 billion in 2020 and growing rate per year will be of 7.2% from 2015 to 2020. Therefore, competition exists between a lot of companies in developmental researches, marketing and product prices, which lead to continuous technological improvement in dental material. Also, different research groups have expected that the bioactive restoratives, dental cements, core build-up materials and bonding agents will significantly increase in market value in the 2010–2020 decade [5-7].

Some restorative dentistry researchers reported that certain restorative categories might decline including amalgam and resin-based restoratives, which will be, step by step, replaced by more modern bioactive materials processed by CAD/CAM, 3D printing and tissue engineering technologies [8–16].

Bio glass show excellent biological properties, mainly ion release induced differentiation but bio glass are brittle materials showing low tensile strength and fracture toughness representing cracks easily. These properties considered as an obstacle to their use for stress or load-bearing areas [17].

Nowadays It is a challenge to develop a new bioactive glass containing dental material with improved mechanical, physical characteristics and superior biological behavior through incorporation of different elements while material synthesis.

It was found that glass crystallinity shows improved mechanical characteristics but decrease glass bioactivity.

Many studies showed that glass amorphous structure preserved with addition of silver, magnesium, strontium, zinc, boron, aluminum, fluoride, potassium, gallium, barium and zirconia. Also Silver and boron addition improve the glass mechanical characteristics and develop antibacterial and antimicrobial behavior of the material. Addition of Calcium shows a great rule in osteoblast proliferation [18-22].

Recently, bioactive glass particles containing dental material are commercially available as conventional composites fillers and in field of tissue engineering, Several attempts studied composite scaffolds for bone tissue engineering to obtain materials that shows improved mechanical characteristics and biocompatible to host tissue. Increase in bioactivity recorded when polymeric bioactive glass composite scaffolds used. It was noted that proper bioactivity degree can be adjusted by shape, size and bio glass filler arrangement. Improved mechanical properties were shown as increased volume fraction ratio of bioactive glass fibers instead of particles [23].

Many groups of bioactive glass have been studied like: A- Silicate-based glasses, e.g. 45S5, are silica (SiO_2) glasses network-former. Its basic unit is SiO_4 tetrahedron, it could share up to 4 oxygen atoms with other elements. B- bioactive glass system based on Phosphate ($CaO–Na_2O–P_2O_5$). This group is formed by PO_4 units and has a tetrahedral structure. It has a charge of 5+ so it contains at least one terminal oxygen. It has a limited connectivity which act as a cause of unique dissolution properties in aqueous-based fluids for these types of glasses [24] .C- Borate-based glasses group with a B_2O_3 as basic network. it shows a very good results in bone regeneration due to its conversion to apatite crystals through a series of dissolution-precipitation reaction [25].

Mechanical properties of bioactive glass in dentistry

Bioactive behavior of dental materials is directly proportioned to its filler size. As increasing in Bioactive glass filler surface areas allow faster ion leaching [26].

Bioactive fillers coatings are important for improve restorative material performance by providing strong bonding between the resin cement and hard dental tissues [27].

45S5 bio glass are applied to commercially available dental products and pastes for the treatment of early enamel demineralized lesions [28] dentin hypersensitivity [29] and teeth bleaching agents [30].

A lot of studies described methods used to achieve particular mechanical properties. These researches are focused especially on silicate systems. Although dental bioactive glass composition used in most commercially available materials is always well detailed [31].

Some studies analyzed the effect of different elements added to a silicate system. Improved mechanical properties were detected through addition of Barium, Nitrogen, Calcium, Silicon and Aluminum into the glass composition [32-35]. Barium addition which acts as a sintering additive mean of melting acceleration and increase glass homogeneity and more rigidity. Barium ions shows a larger ionic radius than Silicon ions, and this situation allows formation of a denser network in the glass structure. Also, Barium addition increase the flexural strength [35].

Nitrogen addition increases microhardness and modulus of elasticity. Also, it can influence the network structure by subsuming the trivalent N3−ions for the divalent O2−ions and affects the network contraction with subsequent increases the density [36].

Increase of the modulus of elasticity was detected with increasing the CaO/P2O5 ratio [34].

Addition of Silicon and Aluminum which act as network former elements improves compressive strength of tested material and the Young's modulus [32, 33].

Addition of Sodium cations results in weaker ionic links between two non-bridging oxygens in the glass structure resulting in a less rigid glass network. This was shown to decrease the Vickers's hardness of the material [37].

The Bioactive material synthesis method affects the mechanical properties; foaming sol–gel synthesis delivers an enhanced porosity and consequently a weaker compressive strength [38].

Immediate thermal treatment after bio silicate material synthesis can improve the load bearing capacity and help the material crystals nucleation producing a glass-ceramic like material [39].

Many studies investigated the influence of the addition of polymers forming bioactive glass based composites. These composites combine bioactivity and the mechanical properties of glass with flexibility and elasticity of the polymers.

Incorporation of bioactive glass in Polycaprolactone polymer improve modulus of elasticity. Also, mechanical properties were improved when bioactive glass powders mixed with Polylactic acid and its copolymer poly-l-lactic-*co*-glycolic acid (PLGA) [40-42].

Biological behavior of bioactive glass in dentistry

Bioactive glass is recently use in restorative dentistry. Jamie Kruzic stated that Bioactive glass, which is a type of crushed glass that is able to interact with the body, has been used in some types of bone healing for decades [43].

Restorative Bioactive powdered glass is made with variety of compounds such as silicon oxide, calcium oxide and phosphorus oxide. It categorized as bioactive as human body shows a response and reaction to it [29].

Many researches mentioned that bioactive glass help prolong the fillings life span, researchers explained that the depth of bacterial penetration into the interface with bioactive glass-containing fillings was significantly smaller than for composites lacking the bioactive glass [44-45].

Davis H et al studied that fillings made with bioactive glass showed slow secondary tooth decay, and also provide some minerals that could help replace those being lost [46].

Sliver Dopped Bioactive Glass Composite (Ag-BGCOMP) is a new bioactive dental composite incorporating quaternary ammonium dimethacrylate (QADM) and silver nanoparticles

(AgNP). This new generation of dental bioactive composite have been manufactured and observed to inhibit action of streptococcus mutans and enhances remineralization. Combined antibacterial and regenerative action have been the ultimate aim of the new generation of bioactive dental composites. While the total bond strength of the newly developed material is not significantly affected [47].

Conclusion

The investigation of new bioactive glass compositions in dental restorative materials offer a very promising area for future researches which should be conducted.

References

1. JS Temenoff, AG Mikos, in: Biomaterials: The Intersection of Biology and Materials Science, Pearson/Prentice Hall, 2008.
2. H.F. Li, Y.F. Zheng, L. Qin, Progress of biodegradable metals, Prog. Mater. Sci., 2014; 24: 414–422.
3. Sakaguchi RL, Powers JM. Craig's: Restorative Dental Materials, 13th edition, Netherland: Elsevier; 2011.
4. Powers JM, Wataha JC. Dental Materials: Foundations and Applications, 11th edition, Netherland: Elsevier; 2016.
5. Research and Market Ltd., U.S. market for dental materials, December 2013, USA. Available from: https://www.researchandmarkets.com/
6. Markets and Markets Inc., Dental implants and prosthetics market by material (Titanium, Zirconium, PFM, All Ceramics), stage (Two Stage, Single Stage), connectors (External hexagonal) & product type (Crowns, Bridges, Dentures, Abutments)—global forecast to 2020, June 2015, USA. Available from: https://www.marketsandmarkets.com/Market-Reports/dental-implants-prosthetics-market-695.html.
7. Research and Market Ltd., Global dental market report, October 2015, USA. Available from: https://www.businesswire.com/news/home/20151028006760/en/Research-Markets-Global-Dental-Market-Report-2015.
8. Zanotto ED. A bright future for glass-ceramics. Am Ceram Soc Bull, 2010; 89: 19–27.
9. Hench LL. Glass and glass-ceramic technologies to transform the world. Int J Appl Glass Sci ., 2011; 2: 162–176.
10. Rosa V, Della Bona A, Cavalcanti BN, N€or JE. Tissue engineering: From research to dental clinics. Dent Mater., 2012; 28: 341–348.
11. Abou Neel EA, Chrzanowski W, Salih VM, Kim HW, Knowles JC. Tissue engineering in dentistry. J Dent., 2014; 42: 915–928.
12. Mauro JC, Zanotto ED. Two centuries of glass research: Historical trends, current status, and grand challenges for the future. Int J Appl Glass Sci., 2014; 5: 313–327.
13. Denry I, Kelly JR. Emerging ceramic-based materials for dentistry. J Dent Res., 2014; 93: 1235–1242.
14. Ruse ND, Sadoun MJ. Resin-composite blocks for dental CAD/ CAM applications. J Dent Res., 2014; 93: 1232–1234.
15. Montazerian M, Singh SP, Zanotto ED. An analysis of glass ceramic research and commercialization. Am Ceram Soc Bull, 2015; 94: 30–35.
16. Hench LL. The future of bioactive ceramics. J Mater Sci 2015;26: 1–4.
17. Thompson ID, Hench LL. Mechanical properties of bioactive glasses, glass-ceramic and composites. Proc Inst Mech Eng H, 1998; 212(2): 127–36.
18. Balamurugan A, Balossier G, Laurent-Maquin D, Pina S,Rebelo AHS, Faure J, et al. An in vitro biological and anti-bacterial study on a sol–gel derived

silver-incorporated bioglass system. Dent Mater., 2008; 24: 1343–51.

19. Liu X, Huang W, Fu H, Yao A, Wang D, Pan H, et al. Bioactive borosilicate glass scaffolds: improvement on the strength of glass-based scaffolds for tissue engineering. J Mater Sci Mater Med., 2009; 20: 365–72.
20. Dietrich E, Oudadesse H, Lucas-Girot A, Mami M. In vitro bioactivity of melt-derived glass 46S6 doped with magnesium. J Biomed Mater Res A, 2008; 1087–96.
21. Maeno S, Niki Y, Matsumoto H, Morioka H, Yatabe T, Funayama A, et al. The effect of calcium concentration on osteoblast viability, proliferation and differentiation in mono layer and 3D structure. Biomaterials, 2005; 26(23): 4847–55.
22. Kasuga T, Nakajima K, Uno T, Yoshida M. Preparation of zirconia-toughened bioactive glass-ceramic composite by sinter-hot isostatic pressing. J Am Ceram Soc., 1992; 75(5): 1103–7.
23. Rezwan K, Chen QZ, Blaker JJ, Boccaccini AR. Biodegradable and bioactive porous polymer/inorganic composite scaffold for bone tissue engineering. Biomaterials, 2006; 27: 3413–31.
24. Neel EAA, Pickup DM, Valappil SP, Newport RJ, Knowles JC. Bioactive functional materials: a perspective on phosphate based glasses. J Mater Chem., 2008; 19: 690–701.
25. Kaur G, Pandey OP, Singh K, Homa D, Scott B, Pickrell G. A review of bioactive glasses: their structure, properties, fabrication and apatite formation. J Biomed Mater Res A, 2013; 102(1): 1254–74.
26. Jones JR. Review of bioactive glass: from hench to hybrids. Acta Biomater., 2013; 9: 4457–86
27. Moezzizadeh M, Nojedehian H, Valizadeh Haghi H. Effect of bioglass and silica coating of zirconia substrate on its bond strength to resin cement. Dent Mater J., 2017; 36: 54–62.
28. Bakry AS, Takahashi H, Otsuki M, Tagami J. Evaluation of new treatment for incipient enamel demineralization using45S5 bioglass. Dent Mater., 2014; 30(3): 314–20.
29. Bakry AS, Tamura Y, Otsuki M, Kasugai S, Ohya K, Tagami J. Cytotoxicity of 45S5 bioglass paste used for dentine hypersensitivity treatment. J Dent., 2011; 39(9): 599–603.
30. Deng M, Wen HL, Dong XL, Li F, Xu X, Li H, et al. Effects of45S5 bioglass on surface properties of dental enamel subjected to 35% hydrogen peroxide. Int J Oral Sci., 2013; 5(2): 103–10.
31. Simpson RL, Nazhat SN, Blaker Bismark A, Hill R, Boccaccini AR, Hansen UN, et al. A comparative study of the effect of different BA fillers. J Mech Behav Biomed Mater., 2015; 50: 277–89.
32. Rabiee SM, Ravarian R, Mehmanchi M, Khoshakhlagh P, Azizian M. Effect of alumina on microstructure and compressive strength of a porous silicated hydroxyapatite. J Appl Biomater Funct Mater., 2012; 12(2): 102–6.
33. Castan˜o O, Sachot N, Xuriguera E, Engel E, Planell JA, Park J, et al. Angiogenesis in bone regeneration: tailored calcium release in hybrid fibrous scaffolds. Appl Mater Interfaces, 2014; 6: 7512–22.
34. Lin C, Cheng S, Leung K, Shen P. Effects of CaO/P2O5ratio on the structure and elastic properties of SiO2–CaO–Na2O–P2O5bioglasses. J Mater Sci Mater Med., 2012; 23: 245–58.
35. Arepalli SK, Tripathi H, Vyas VK, Jain S, Suman SK, Pyare R, et al. Influence of barium substitution on bioactivity, thermal and physico-mechanical properties of bioactive glass. Mater Sci Eng., 2015; 49: 549–59.

36. Bachar A, Mercier C, Tricoteaux A, Hampshire S, Leriche A, Follet C. Effect of nitrogen and fluorine on mechanical properties and bioactivity in two series of bioactive glasses. J Mech Behav Biomed Mater., 2013; 23: 133–48.
37. Farooq I, Tylkowski M, Muller S, Janicki T, Brauer D, Hill RG. Influence of sodium content on the properties of bioactive glasses for use in air abrasion. Biomed Mater., 2013; 8: 06500.
38. Chen Q, Thouas GA. Fabrication and characterization of sol–gel derived 45S5 bioglass-ceramic scaffolds. Acta Biomater., 2011; 7: 3616–26.
39. Granito RN, Rennò AC, Ravagnani C, Bossini PS, Mochiuti D, Jorgetti V, et al. In vivo biological performance of a novel highly bioactive glass-ceramic (biosilicate): a biomechanical and histomorphometric study in rat tibial defects. J Biomed Mater Res B Appl Biomater., 2011; 97B: 1139–47.
40. Eqtesadi S, Motealleh A, Pajares A, Guiberteau F, Miranda P. Improving mechanical properties of 13–93 bioactive glassrobocast scaffold by poly(lactic acid) and poly(-caprolactone) melt infiltration. J Non-Cryst. Sol., 2016; 432: 111–9.
41. Filipowska J, Pawlik J, Cholewa-Kowalska K, Tylko G, PamulaE, Niedzwiedzki L, et al. Incorporation of sol–gel bioactive glass into PLGA improves mechanical properties and bioactivity of composite scaffolds and results in their osteo inductive properties. Biomed Mater., 2014; 9: 065001.
42. Simpson RL, Nazhat SN, Blaker Bismark A, Hill R, BoccacciniAR, Hansen UN, et al. A comparative study of the effect of different BA fillers. J Mech Behav Biomed Mater., 2015; 50: 277–89.
43. Jamie Kruzic. Bioactive glass could help prolong fillings. BDJ, 2016; 220(2).
44. D. Khvostenkoa, T.J. Hiltonb, J.L. Ferracaneb, J.C. Mitchellc, J.J. Kruzica. Bioactive glass fillers reduce bacterial penetration into marginal gaps for composite restorations. Dent Mat J., 2016; 32: 73–81.
45. Brown ML, Davis HB, Tufekci E, Crowe JJ, Covell DA, Mitchell JC. Ion release from a novel orthodontic resin bonding agent for the reduction and/or prevention of white spot lesions. An in vitro study. Angle Orthod., 2011; 81: 1014–20.
46. Davis H, Ferracane JL, Mitchell JC. Ion release from, and fluoride recharge of a composite with a fluoride-containing bioactive glass. Dent Mater., 2014; 30(10): 1187–94.
47. Xanthippi Chatzistavrou, Anna Lefkelidou, Lambrini Papadopoulou, Eleni Pavlidou, Konstantinos M. Paraskevopoulos, J. Christopher Fenno, Susan Flannagan, Carlos González-Cabezas, Nikos Kotsanos, and Petros Papagerakis. Bactericidal and Bioactive Dental Composites. Front physical, 2018; 9: 103.