

REVIEW ARTICLE

Bioactive dental materials redefining the dental health –an updated concept

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ABSTRACT

Bioactive materials have been used in every field of dentistry and medicine. It gained popularity in the field of dentistry in the past two decades and have been in demand ever since. The aim of the review is to understand how interactions take place at the material tissue interface, which gives rise to bioactivity of the material. This review is an attempt to understand the studies which have been carried out by researchers to understand the bioactivity of different dental materials and how particular characteristic of bioactivity attribute to other characteristics of the dental materials.

Keywords: Bioactive materials, biomimetic substances, conservative dentistry, regeneration

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materials, materials which were relatively biologically inert or did not elicit any biological response when coming in contact with oral tissues were considered as ideal for restoration. But with the rise and success of bioactive materials, this notion changed and there was an increasing attempt to understand the concept of bioactivity. Various interactions occur at the interface of bioactive material and tissue surface. There are various factors which make bioactive materials stand out from the rest of the restorative materials, which are their potential to start remineralisation of the tissue surface directly in contact with the material. They also have regenerative properties and lead to regeneration of bone and tooth surface. They are also effective in treatment of hypersensitivity of dentinal tubules by decreasing the permeability of dentine. They can act as pulp capping agents and also as final restorative material. Due to these characteristics, bioactive

Introduction

Recently introduced materials mainly concentrate on the bioinductive activity. The separately. Bioactive material is defined as a material that has the effect on or eliciting a response from living tissue, organisms or cell such as inducing the formation of hydroxyapatite. The bioinductive property is defined as the capability of a material for inducing a response in a biological system. Biomaterial is defined as any matter, surface or construct that interacts with biological systems. [1] Before the advent of bioactive

materials are considered a blessing for dentistry and have garnered a lot of interest.

Classification Of Bioactive Materials

Different bioactive materials differed on their mechanism of bonding, the strength of the bond, the time it took for the bond to establish, hence initially their classification was based on these parameters. In 1994, Hench introduced a new classification for bioactive materials [2].

Class A materials demonstrated osteoproduative qualities. The interface of these materials gave both intracellular as well as extracellular response. The definition of osteoproduction, as given by Wilson is “the process whereby a bioactive surface is colonized by osteogenetic stem cells free in defect environment as a result of surgical intervention.”[3]

Class B materials are osteoconductive in nature. The interface of osteoconductive materials is biocompatible along which migration of bone occurs. Therefore the interface of such materials only demonstrates extracellular response.

Calcium Hydroxide

Calcium Hydroxide was introduced by Herman in the year 1920 as a pulp capping agent [4]. It is highly alkaline and has a pH of about 12.5-12.8. Calcium hydroxide dissociates into Calcium ions and hydroxyl ions. Calcium ions lead to reduction in permeability of capillaries, which in turn causes reduced flow of serum. Due to reduction in the inflow of serum, the amount of inhibitory pyrophosphates is reduced and thus mineralization begins to start at the site. The alkaline nature of hydroxyl ions would neutralize the

acid produced by osteoclasts. This leads to increase in pH and provides a favourable environment for the activity of pyrophosphatase. Hence, this results in the increase in amount of pyrophosphatase, which are also dependent on Calcium ions. The end result would be reduced amount of inhibitory pyrophosphates, leading to mineralization.[5]

Mineral Trioxide Aggregate (Mta)

MTA introduced by Torabinejad in 1990. It's a bioactive material that is mainly composed of calcium and silicate. It constitutes of three powder ingredients which are mixed mechanically to form MTA. Powder ingredients are Portland cement, which is the major constituent and forms 75% of the mixture, bismuth oxide, which accounts for 20% of the mixture followed by gypsum which is 5% of the mixture.[6] The main constituent of this mixture is Portland cement, which is formed by dicalcium and tricalcium silicates, tricalcium aluminate and tetracalciumaluminoferrite.

According to a study carried out by Sarkar et al [7] to determine the physicochemical reactions of MTA. This study concluded that MTA has two peculiar characteristics, which are its sealing ability and biocompatibility. One of the interesting findings of the study was the presence of a peculiar interfacial layer which formed in close relation to MTA[7]. This layer was initially thought to be made of Calcite as it had Calcium and carbonate [8]. But the large proportion of phosphate ions as compared to carbonate, strongly suggested the structure to be made of hydroxyapatite crystals rather than calcite [9]. The presence of the hydroxyapatite crystals plays a major role in the bioactivity of MTA since

hydroxyapatite crystals release calcium and phosphate ions and both are important factors in the metabolism of bone [7].

It is a material of choice for procedures like root canal filling, root end filling, root perforation repair, as pulp capping agent, for pulpotomy, for the purpose of formation of apical barrier in necrotic pulps and open apices.[10,11]

Biodentine

Biodentine is made up of tricalcium silicate which is highly purified in nature and also contains minute proportions of dicalcium silicate, calcium carbonate and radiopaque material. The setting time of Biodentine is 12 minutes which is very less as compared to the setting time of MTA which is 3-4 hours [12]

According to Atmeh et al demonstrated an interfacial layer. This layer lies just below the cement and fluorophores leaching from the cement are found in abundance in this layer. This layer is named as Mineral Infiltration Zone (MIZ) and demonstrated a change in the optical properties and structure of the interfacial dentin [12]. The Mineral Infiltration Zone is formed by a two step mechanism attributing to release of Calcium hydroxide from the cement. The first step leads to caustic degradation responsible for etching on the surface. This degradation is caused due to highly alkaline nature of calcium hydroxide and leads to breakdown of collagen fibril proteins. The next step is diffusion of minerals which occurs when collagen fibril bonds are broken down, their water absorption increases and causes swelling in this layer [13, 14].

Bioaggregate And iRoot Bp Plus

Bioaggregate and iRoot BP are Calcium silicate materials but Bioaggregate is available as powder and liquid form, iRoot BP is available in paste and putty form. The use of iRoot BP in the form of injectable root repair material and Bioaggregate finds its application in pulp capping, apexification, root perforation and root end filling material [15].

According to a study carried out by Zhang et al, proliferation of human dental pulp cells, under the effect of Bioaggregate and iRoot BP was evaluated. Alkaline Phosphatase is present in the early differentiation stage and plays a crucial role in deposition of mineral [16]. Osteoblasts, Odontoblasts and cementoblasts on maturation secrete Osteocalcin [17], hence the presence of Osteocalcin signals towards hard tissue regeneration [18]. To confirm the odontoblastic differentiation of BioAggregate and iRoot BP, Dentine Sialophosphoprotein and Dentin Matrix Protein-1 were selected. The reason for their selection was that Dentin Sialophosphoprotein is one such protein (non-collagenous), which contributes in mineralization of dentine [19] and it is expressed very well in odontoblasts [20], whereas it is hardly present in bone and kidney tissues [21]. The reason for selection of Dentin Matrix Protein-1 is its specificity for dentine [22] and has been found to regulate mineralization of dentine[23]. The reason for non-selection of Alkaline Phosphatase and Osteoclastin for evaluating odontoblastic differentiation of Bioaggregate and iRoot BP is that they are not odontoblast specific. Hence, the presence of Dentine Sialophosphoprotein and Dentin Matrix Protein-1 signal towards mature odontoblasts. They

concluded that when human dental pulp cells come in direct contact with BioAggregate and iRoot BP, they demonstrate higher ability of mineralization as compared to MTA. Moreover, they also show better predictable gene expression related to odontoblast, as compared to MTA. Better mineralization ability and odontoblast related gene expression are instrumental in reparative dentine formation [24].

Endosequence Root Repair Material (Errm)

The bioceramic material is composed of calcium silicate, oxides of zirconium and tantalum, calcium phosphate and filler agents. It is available in both putty form as well as paste form [25].

According to a study by Shokouhinijad et al to evaluate the bioactivity of Endosequence Root Repair Material, BioAggregate and MTA. ERRM was immersed in Phosphate Buffered Saline and after 1 week, small particles were found distributed in this amorphous matrix. ERRM has calcium phosphate and calcium silicate in its composition and due to its availability in putty form, it also has fillers and thickening agents. All of these are responsible for varying surface morphology of ERRM, which changed even more drastically by increasing the immersion time in Phosphate Buffered Saline. It demonstrated the presence of apatite crystals on its surface. The presence of apatite crystals was also seen at the interface (of ERRM and dentine). These crystals were mainly composed of Ca, P and O [25].

Ceramir Crown And Bridge (C&B)

Ceramir C&B is a luting agent, which is bioceramic in nature. It was prepared by Doxa Dental AB,

Sweden. The composition of this material consists of Calcium Aluminate cement and Glass Ionomer Cement [26]. It is used as a luting agent for prosthesis like fixed partial dentures, permanent crowns, prefabricated metal and cast dowel and cores, for inlays and onlays of gold [27, 28].

The Calcium aluminate in the cement comes in contact with water and two end products known as gibbsite and katoite are formed, which are known to remarkably raise the pH of the surrounding environment to as high as 11. When phosphate and carbonate ions from the body fluids come in contact with the surface of Calcium aluminate, they form precipitates of calcium carbonate and calcium phosphate on the surface. The result is increase in mineral density at the interface of material and tooth, hence initiating the process of mineralization [29]. The presence of Phosphate ions on the tooth surface is a prerequisite for a layer of hydroxyapatite to precipitate at interfacial layer. The material also has the presence of glass ionomer cement and Strontium and Phosphate ions are a part of GIC. The presence of strontium is responsible for variation in the morphology of precipitated layer, resulting in the formation of strontium substituted hydroxyapatite crystals [30]. The growth of hydroxyapatite on the interfacial surface is attributed to few reasons such as negative charge of the material surface, the low solubility of hydroxyapatite, the highly alkaline pH of the environment and the presence of Calcium, Carbonate and Phosphate ions in the environment. Hence, it can be concluded Ceramir C&B, composed of Calcium aluminate cement,

provides a good environment for the growth of hydroxyapatite crystals and is thus bioactive in nature [31].

Theracal

It is made up of a single paste which has Oxide and silicate particles of Calcium, sulphates and zirconate of Barium, Strontium glass, silica and resin containing BISGMA and PEGDMA [32]. The leaching of Calcium ions from the material is responsible for initiating the process of mineralization as Calcium ions play a significant role in mineralization [33] and catalyze the differentiation of osteoblasts [34].

Conclusion

Bioactive materials can be considered as boon to dentistry because of its regeneration potential. After understanding the reason for bioactivity of materials, it can be safely concluded that the use of these materials in various indications such as pulp capping, root end filling, root perforation repair, apexification, for pulpotomy, can all be attributed to bioactive nature of these materials. These materials are increasingly finding their usage as liners/bases and as luting agents. The attempts are now towards to continuously increase the strength of these materials to widen their spectrum of usage.

References

1. Anusavice KJ, Shen C, Rawls HR. Emerging trends. In: Phillip's Science of Dental materials. 12th ed., Ch. 21. ST. Louis, Missouri: Elsevier Saunders; 2013. p. 519.

2. HENCH, L. L., Bioactive ceramics: Theory and clinical applications. In *Bioceramics*, Vol. 7, ed. O. H. Andersson & A. Yli-Urpo. Butterworth-Heinemann, Oxford, 1994, pp. 3-14.
3. WILSON, J., CLARK, A. E., DOUEK, E., KRIEGGER, J., SMITH, W. K. & ZAMET, J. S., Clinical applications of bioglass implants. In *Bioceramics*, Vol. 7, ed. O. H. Andersson & A. Yli-Urpo. Butterworth-Heinemann, Oxford, 1994, pp. 415-422.
- 4) Hermann BW. Calcium hydroxide Mittelzahn, Behandeln und Füllen von Wurzelkanalen [Thesis] Würzburg: 1920.
- 5) Chandra BS, Krishna VG, editors. Vital pulp therapy, pulpotomy and apexification. In: Grossman's Endodontic Practice. 12th ed. New Delhi: Wolters Kluwer; 2010. p. 315.
- 6) PROROOT MTA, Product Literature, Dentsply Tulsa Dental, Tulsa, OK 74136
- 7) Sarkar NK, Caicedo R, Ritwik P, Moiseyeva R, Kawashima I. Physicochemical basis of the biologic properties of mineral trioxide aggregate. *J Endod* 2005;31:97-100.
- 8) Cole AS, Eastoe JE. Biochemistry and oral biology. 2nd ed. London: Wright, 1988:452-67.
- 9) LeGeros RZ. Calcium phosphates in oral biology and medicine. Basel: Karger, 1991:154-71
- 10) Camilleri J, Pitt Ford TR. Mineral trioxide aggregate: a review of the constituents and biological properties of the material. *Int Endod J* 2006;39:747-54.

- 11) Roberts HW, Toth JM, Berzins DW, Charlton DG. Mineral trioxide aggregate material use in endodontic treatment: a review of the literature. *Dent Mater* 2008;24:149–64.
- 12) Atmeh AR, Chong EZ, Richard G, Festy F, Watson TF; Dentin–cement interfacial interaction: calcium silicates and polyalkenoates. *J Dent Res.*,2012;91:454–459.
- 13) Bowes JH (1950). The swelling of collagen in alkaline solutions; swelling in solutions of bivalent bases. *Biochem J*46:530-532
- 14) Kemp GD, Tristram GR (1971). The preparation of an alkali-soluble collagen from demineralized bone. *Biochem J*124:915-919.
- 15) Jefferies S. Bioactive and biomimetic restorative materials: A comprehensive review. Part II. *J EsthetRestor Dent* 2014;26:27-39.
- 16) Garimella R, Bi X, Anderson HC, Camacho NP (2006) Nature of phosphate substrate as a major determinant of mineral type formed in matrix vesicle-mediated in vitro mineralization: an FTIR imaging study. *Bone*38, 811–7.
- 17) Sun H, Wu C, Dai K, Chang J, Tang T (2006) Proliferation and osteoblastic differentiation of human bone marrow-derived stromal cells on akermanite-bioactive ceramics. *Biomaterials* 27, 5651–7.
- 18) Zhang W, Walboomers XF, van Osch GJ, van den Dolder J, Jansen JA (2008) Hard tissue formation in a porous HA/TCP ceramic scaffold loaded with stromal cells derived from dental pulp and bone marrow. *Tissue Engineering Part A* 14, 285–94
- 19) Butler WT, Ritchie H (1995) The nature and functional significance of dentin extracellular matrix proteins. *International Journal of Developmental Biology*39, 169–79.
- 20) MacDougall M, Nydegger J, GuTTet al(1998) Developmental regulation of dentin sialophosphoprotein during ameloblast differentiation: a potential enamel matrix nucleator. *Connect Tissue Research*39,25–37
- 21) Verdelis K, Ling Y, Sreenath Tet al.(2008) DSPP effects on in vivo bone mineralization. *Bone*43, 983–90
- 22) MacDougall M, Gu TT, Simmons D (1996) Dentin matrix protein-1, a candidate gene for dentinogenesis imperfecta. *Connective Tissue Research*35, 267–72
- 23) Narayanan K, Gajjeraman S, Ramachandran A, Hao J, George A (2006) Dentin matrix protein 1 regulates dentin sialophosphoprotein gene transcription during early odontoblast differentiation. *Journal of Biological Chemistry*281, 19064–71.
- 24) Zhang S, Yang X, Fan M; BioAggregate and iRoot BP Plus optimize the proliferation and mineralization ability of human dental pulp cells. *Int Endod J.*,2013;46:923–929.
- 25) N.Shokouhinejad, M.H.Nekoofar, H.Razmi, S.Sajadi, T.E.Davies, M.A.Saghiri, H.Gorjestani, P.M.H.Dummer. Bioactivity of Endosequence Root Repair Material and

- Bioaggregate, International Endodontic Journal, 45, 2012, 1127-1134.
- 26) Jefferies S. Bioactive and biomimetic restorative materials: A comprehensive review. Part II. J EsthetRestor Dent 2014;26:27-39.
- 27) Doxa Dental AB. 510(k) Summary, XeraCem TM, K081405, August 21; 2008. Available from: <https://www.dentalaegis.com/id/2014/12/primary-incisor-and-canine-restoration-in-a-child-with-amelogenesis-imperfecta>
- 28) Doxa Dental AB. 510(k) Summary, CeramirR Crown and Bridge, K100510, March 25; 2010. Available from: <https://www.dentalaegis.com/id/2014/12/primary-incisor-and-canine-restoration-in-a-child-with-amelogenesis-imperfecta>.
- 29) H. Engqvist, J. E. Schultz-Walz, J. L'öf et al., "Chemical and biological integration of a mouldable bioactive ceramic material capable of forming apatite in vivo in teeth," *Biomaterials*, vol. 25, no. 14, pp. 2781–2787, 2004.
- 30) W. Xia, C. Lindahl, J. Lausmaa et al., "Biomaterialized strontium-substituted surfaces," *Acta Biomaterialia*, vol. 6, no. 4, pp. 1591–1600, 2010.
- 31) Engstrand J, Unosson E, Engqvist H. Hydroxyapatite formation on a novel dental cement in human saliva. *ISRN Dent*. 2012;2012:624056.
- 32) Suh B, Cannon M, Yin R, Martin D (2008) Polymerizable dental pulp healing, capping, and lining material and method for use. International Patent A61K33/42; A61K33/42 Application Number WO2008US54387 20080220; Publication number WO2008103712 (A2); Publication date 2008-08-28.
- 33) Schroder U (1985) Effects of calcium hydroxide-containing pulp-capping agents on pulp cell migration, proliferation, and differentiation. *Journal of Dental Research* 64, 541–8.
- 34) Lopez-Cazaux S, Bluteau G, Magne D, Lieubeau B, Guicheux J, Alliot-Licht B (2006) Culture medium modulates the behaviour of human dental pulp-derived cells: technical note. *European Cells & Materials Journal* 11, 35–42.

How to cite this article Bioactive dental materials redefining the dental health –an updated concept. S Singh, R B, A Kar, D Chowdhary, A Chowdhary. *Chronicles of Dental research* 2017; Vol6(2):10-15

