DOI : https://dx.doi.org/10.26808/rs.st.i7v6.01
International Journal of Advanced Scientific and Technical Research Issue 7 volume 6 Nov.- Dec. 2017
Available online on http://www.rspublication.com/ijst/index.html ISSN 2249-9954

BIOACTIVE MATERIALS – A REVIEW

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ABSTRACT:
Need for invention and applications of newer materials are quintessential in every field, especially in dentistry. In the branch of conservative dentistry & endodontics, bioactive materials have been extensively used for repair, regeneration and reconstruction. These bioactive materials have evolved over the years with newer compositions & more applications.This article summarizes the concept of bioactivity, compares the various available bioactive materials and showcases the advancements in this class of dental materials.
Keywords: Bioactivity, Biomimetic materials, MTA

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INTRODUCTION :

In the field of conservative dentistry and endodontics, bioactive materials have been rapidly used, for regeneration, repair and reconstruction.Bioactive material is defined as a material that has the effect on or inducing a response from living tissue, organisms or cell such as the formation of hydroxyapatite. They directly act on vital tissues and promotes tissue healing and repair and maintain pulp vitality. It should be bactericidal, bacteriostatic and sterile in nature, as its ideal requirements[1].Biomimetics is the study of formation, structure or function of biologically produced substances and materials (such as silk or conch shells) and biological mechanisms and processes (such as protein synthesis or mineralization) for the purpose of synthesizing similar products by artificial mechanisms that mimic naturalstructures[1].The objective of this review is to summarise and appraise the different types of bioactive materials and its uses in the field of dentistry.

MECHANISM OF ACTION:

The performance of bioactive materials are largely attributable to its capacity to produce spontaneously an apatite layer when in contact with phosphate-containing physiological fluids[2, 3, 4, 5]. The apatite formation is promoted via an interaction of Ca^{2+} released from the material with phosphates and is considered as basis of several inorganic biomaterials such as glass ceramics.
Bioactive materials induce cytological and functional changes within pulpal cells, resulting in the formation of reparative dentin at the surface of exposed dental pulp in vital pulp therapy.When placed,

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it helps in proliferation, migration, and differentiation of odontoblast-like cells that produce a collagen matrix. This unmineralized matrix is then mineralized by osteodentin initially and then by tertiary dentin formation.[6]

MATERIALS:

Calcium hydroxide:[8]

Calcium hydroxide dissociates into calcium and hydroxyl ions. The capillary permeability is reduced by these released calcium ions by reducing the serum flow and reducing the levels of inhibitory pyrophosphates that cause the mineralization.Theacid produced by osteoclasts are neutralised by the hydroxyl ions thereby maintaining optimum pH for pyrophospahatase activity. It causes increase in levels of calcium-dependent pyrophosphatase which reduces the levels of inhibitory pyrophosphate and thereby promotes mineralization.[8]

According to a study done by Torabinejad et al on efficacy of osteogenic protein-1, MTA and calcium hydroxide in the formation of hard tissue in immature roots of dogs, it was found that the osteogenic potential of the three materials were similar .[9]

Another study by Maria Giovanna Gandolfi et al compared properties of novel calcium-silicate based cements to conventional calcium hydroxide-based biomaterials, and concluded that calcium-silicate based materials are biointeractive(ion-releasing), bioactive(apatite forming) with higher rate of calcium release, faster apatite formation and scaffolds for dentin bridge formation and clinical healing, as compared to calcium hydroxide-based biomaterials.[10]

Mineral Trioxide Aggregate :

MTA was introduced by Torabinejad in 1990. It is a bioactive material that is mainly composed of calcium and silicate. Major content of the mixture is dicalcium silicate, tricalcium silicate, tricalcium aluminate, gypsum,andtetracalciumaluminoferrite.[6]These calcium silicate containing materials have a common characteristic of apatite formation.[11] This is a material of choice for vital pulp therapy, apexification and apexogenesis, correcting procedural errors as well as for root-end filling material in apicoectomy procedures.

However, it was found that when MTA was used as a pulp capping agent, within pulpal cells it induces cytological and functional changes resulting in formation of fibrodentine and reparative dentin at the surface of mechanically exposed dental pulp. On its placement it causes proliferation, migration and differentiation of odontoblast-like cells that produce a collagen matrix. The formed unmineralizedmatrix is then mineralized initially by osteodentineand then by tertiary dentin formation.[11]

M.G Gandolfi et al confirmed in his study that ProRoot MTA forms a superficial layer of apatite within hours. He also stated that the excellent bioactivity of ProRoot MTA might provide a significant clinical advantage over the traditional cements used for root-end or root-perforation repair.[5]

Nathanael Salako et al compared BAG, MTA, ferric sulphate and formocresol as pulpotomy agents in rat molars. They inferred that among the materials tested, MTA was the only material that performed ideally as a pulpotomy agent causing dentine bridge formation while simultaneously maintaining normal pulpal histology.[12]

Calcium enriched mixture cement :

It was introduced by Asgary in 2006.[13,14]This cement releases both calcium and phosphorus ions leading to hydroxyapatite production.[15,16]It is also known as CEM. It is composed of calcium oxide, calcium phosphate, calcium carbonate, calcium silicate, calcium sulfate, and calcium chloride.

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Different studies have been done by Asgary et al proving that CEM had good regenerative periapical tissue response when used as root-end filling biomaterial[17], proving that the cement can be applicable for treatment of inflammatory external root resorption and obturation of immature necrotic teeth[18]. Asgary et al also states that CEM cement is able to stimulate dentinogenesis after direct pulp capping[19] and pulpotomy in animals and humans,[20] apexogenesis[21] and also cementogenesis after perforation repair or surgery.[22]CEM has similar pH, increased flow, but decreased working time, film thickness, and lower estimated price than MTA.[23]

Biodentine :
In 2011, Biodentine™, a quick-setting calciumsilicatebased dental cement, was introduced by Septodont (SaintMaur des Fosses – France). Biodentine™ was developed as a bioactive dentin replacement material having similar properties of dentin and has a positive effect on vital pulp cells stimulating tertiary dentine formation[24], a novel clinical application of this family of materials, intending it to function as a coronal restoration.

It is principally composed of a highly purified tricalcium silicate powder prepared synthetically in the lab de novo, di-calcium silicate,calcium carbonate and zirconium dioxide as a radiopacifer. The di-calcium and tri-calcium silicate phases form around 70% of the weight of Biodentine's dehydrated powder.The setting time is relatively short (around 12 min),which enables the use of this cement for restorative procedures.A specific feature of Biodentine™ is its capacity to continue improving over a period of time until reaching 300 MPa after one month.[25] This value becomes quite stable and is in the range of the compressive strength of natural dentine i.e., 297 MPa.[26]

L.Han et al showed that Biodentine had maximum concentration of calcium ion release & exhibited deep Ca & Si ion incorporation in human root canal dentine after immersion in phosphate-buffered saline(PBS) when compared to white ProRoot MTA and EndoSequence BC sealer.[27]

Z. Luo et al manifested that Biodentine favorably affected healing when placed directly in contact with the pulp by enhancing the proliferation, migration, and adhesion of human dental pulp stem cells, confirming the bioactive and biocompatible characteristics of the material.[28]

Bioaggregate:
Over the past decade, new developments likebioceramicnanotechnology, have been brought into endodontic material science.[29] BioAggregate (Innovative Bioceramix,Vancouver BC,Canada), was the first nanoparticular mineral cement introduced in the dental market. BioAggregate is produced under controlled conditions, resulting in a pure and fine white hydraulic cement-like powdercomposed of contamination-free bioceramicnanoparticles.[30]

Composition of Bioaggregate is similar to MTA. It is described by its manufacturer as an insoluble, radiopaque, and aluminum-free material primarily composed of calcium silicate, calcium hydroxide, andcalcium phosphate.[31]

BioAggregate when used for root end filling shows excellent sealing ability.[32]It exhibits antimicrobial action,excellent biocompatibility, and significant induction ofbone and periodontal regeneration, as shown in studies by Zhang H et al, Yuang Z et al.[33,34]

Moreover,BioAggregatedisplays superiorlocal and systemic biocompatibility in vivo comparedwith MTA.[35,36]With respect to pulp capping, arecent study showed that BioAggregate exerts a greaterpotential to induce odontoblastic differentiation andmineralization than that of MTA.[37]Another

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study showed that BioAggregate promotes better adhesion, migration, and attachment ofHDPCs, indicating its excellent cytocompatibilitycompared with MTA.[38]

Endosequence root repair material :

It is also a calcium silicate material available in paste or putty form.It is a bioceramic material that has excellent physical and biological properties and easy to work with. They are hydrophilic, insoluble, radiopaque, aluminum-free, and of high pH.This material sets and hardens in the presence of moisture.Endosequence root repair material simulates tissue fluid, phosphate buffered saline and results in precipitation of apatite crystals that become larger with increasing immersion times concluding it to be bioactive.[39]The applications are same as bioaggregate.[40]
Karen F Lovato et al demonstrated that Endosequence root repair material had similar antibacterial activity as compared to MTA and better handling properties.[41]

A study by Alsalleeh F et al found that Endosequence root repair material also had similar antifungal activity as compared to MTA, with substantial reduction in biofilm formation in wells of C.albicans.[42]In a study by Jeevani et al., Endosequence showed better sealing ability when compared to MTA and Biodentine as furcation repair materials.[43]

Bioactive root canal sealers :

It consists of calcium silicates, monobasic calcium phosphate, zirconium oxide, tantalum oxide, proprietary fillers and thickening agents.Bioceramic sealers because of its advantage of biocompatibility and physical properties have been introduced in themarket in an attempt to provide an obturation methodthat can be successfully and predictably performed by majority of practitioners.Eg. BC Sealer(Brasseler USA); iRoot SP (Innovative BioCreamixInc),is an injectable root repair material.[40]

These sealers result in a gap-free interface betweengutta-percha (GP), sealer, and dentin. Also, thesesealers are antibacterialbecause of their highly alkaline pH.[44] The use of these sealers should be done cautiously becauseof concerns regarding endodontic retreatment.

Bio Root RCS:

Bio Root RCS(Saint Maur des Fosses, France) is a latest generation mineral-based root canal sealer using tricalcium silicate setting system. The powder part additionally contains zirconium oxide as biocompatible radiopacifier and a hydrophilic biocompatible polymer for adhesion enhancing. The liquid part contains mainly water, calcium chloride as a setting modifier and a water reducing agent.
Bio Root RCS is bioactive by stimulating bone physiological process and mineralization of the dentinal structure. Therefore it creates a favourable environment for periapical healing and bioactive properties includingbiocompatibility, hydroxyapatite formation, mineralization of dentinal structure, alkaline pH and sealing properties.
Jean Camps et al compared interaction of Bio Root RCS with apical tissue to that of standard zinc oxide eugenol sealer, only to conclude that Bio Root RCS has a higher bioactivity than zinc oxide eugenol based sealer on human PDL cells.[45]F.Siboni et al found that BioRoot RCS had good bioactivity potential with calcium release, strong alkalizing activity and apatite-forming ability, and adequate radiopacity.[46]

Bioactive luting agents :

The most recent modification in bioactive chemicallybonded cements with a predominant use in restorativedentistry has been Ceramir. It is calcium aluminate cement used as a luting agent. It works on the principle of two cements they are calcium aluminate and glass ionomer cement.[40]This cement

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helps in luting of permanent crowns and fixed partial dentures, gold inlays and onlays, prefabricated metal and cast dowel and cores, and high-strength all-zirconia or all-alumina crowns.[37,38]

Glass ionomer component has advantages like: Low initial,short-duration pH, improved flow and settingcharacteristics, early adhesive properties to tooth
structure, early strength properties. Calcium aluminatecomponent in the cement contribute to; increasedstrength and retention over time,biocompatibility,sealing of tooth material interface, bioactivity-apatite formation, stable, sustained long-term properties, lackof solubility/degradation, ultimate development of astable basic cement pH.

CONCLUSION :

From this review of literature, it can be concluded thatbioactive materialscan be used in numerous clinical indications, including pulp capping, pulpotomy, root ending filling, repair of root resorption, repair of root perforations, and apexification. Pioneer bioactive materials such as Calcium hydroxide & MTA are still used effectively due to its bioactive potential, aswell as the newer generation materials such as Bioaggregate, Biodentine, Endosequence Root Repair Material, iRootBP, and BP Plus. Clinical indications for use of
bioactive cements have expanded further into uses such as lining and bases (Biodentine) and luting cements for crown and bridge applications with the introduction and laboratory/clinical validation of a calcium aluminate/glass ionomer luting cement (Ceramir). Newer mechanisms for adhesion,integration, and sealing of dentin are being developed usingbioactive technology, and these materialswill closely resemble natural teeth in more ways than one and will change thefuture of restorative dentistry.

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