Bioactive Material in Pediatric Dentistry.

Abstract:

A new generation of bioactive materials which has been developed during the last ten years has been used in every field of dentistry and medicine. These bioactive materials are able to release calcium,phosphate and other specific ions to help rebuild demineralized dentin and enamel. These materials are broadly used in the field of conservative dentistry for regeneration, repair and reconstruction. These materials are available in different form and composition that acts directly on vital tissue inducing its healing and repair. These materials directly function because of induction of various growth factors and different cells. New innovations are necessary to continue to help reinforce existing technologies and to introduce new paradigms for treating dental disease and restoring teeth seriously compromised by caries lesions via biomimetic and more biological operative approaches. Bioactive materials with nanoscale structure, including nanomedicine, nanodevices, nanomaterials, such as nanofibres and nanocomposites, can be designed and produced from natural biopolymers, synthetic polymers and inorganic substances. The nanocomposite-based scaffold allows for cell growth, yielding a unique composite system.

Keywords: Bioactivity, BioresponsiveBiomimetic,Biocompatibility, Biomineralization, Repair/ regeneration, Nanocomposite.

Introduction:

The evolution of dentistry is closely associated with the advancements in dental materials. From the dawn of history dental practitioners have been in the quest of ideal restorative dental materials. Though initially ideal restorative materials were thought to be the one which were biologically inert and hence biocompatible, but the past two decades have seen the emergence of bioactive materials as a promising alternative. The interaction between restorative dental materials and tooth tissue encompasses multiple aspects of dental anatomy and materials science.[1]

The terms bioactive, bioinductive, biomaterial and biomimetic are different and have been defined 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. Biomimetics is the study of formation, structure or function of biologically produced substances and materials and biological mechanisms and processes for the purpose of synthesizing similar products by artificial mechanisms that mimic natural structures.[2]

The various bioactive materials such as Calcium hydroxide, Mineral trioxide aggregate (MTA), Calcium-enriched mixture (CEM), Biodentine, MTYA1-Ca filler, Tetra-calcium phosphate (TTCP), Sol-gel-derived bioactive glass (BAG), Calcium phosphate, Endosequence root repair material, HX-BCG, Theracal, Bioaggregate, Resin impregnation with titanium oxide, Emdogain are discussed in this article.

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[1]AKHAND PRATAP SINGH, [2]GUNJAN YADAV, [3]ABHAY MANI TRIPATHI, [4]SONALI SAHA

[1-4]Department of Pedodontics and Preventive Dentistry, Sardar Patel Postgraduate Institute of Dental and Medical Sciences, Lucknow

Address for Correspondence: Dr. Akhand Pratap Singh
Department of Pedodontics and Preventive Dentistry, Sardar Patel Postgraduate Institute of Dental and Medical Sciences, Lucknow
Email: bzywidexm@gmail.com

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What is bioactivity:

The term bioactivity has several meanings depending on context. In the widest meaning, materials that are able to have a biological effect or be biologically active, and form a bond between the tissues and the material, are called bioactive materials. In the field of tissue engineering the term bioactivity is also related to the cellular effects induced by the release of biologically active substances and ions from the biomaterial.3

A bioactive restorative material can display one or more of the following actions:

1. Remineralizes and strengthens tooth structure through fluoride release and/or the release of other minerals.
2. Forms an apatite-like material on its surface when immersed in body fluid or simulated body fluid (SBF) over time.
3. Regenerates live tissue to promote vitality in the tooth.4

Classification of Bioactive Materials

Bioactive materials are divided into 2 groups:

Class A: Osteoproductive Materials:

In osteoproductive materials the bioactive surface is colonized by osteogenic stem cells. which elicits both an intracellular and an extracellular response at its interface. These materials are both osteoproductive and osteoconductive.
Example: 45S5 Bioglass.

Group B: Osteoconductive Materials:

The osteoconductive materials simply provide a biocompatible interface along which bone migrates. Osteoconductive bioactivity occurs when a material elicits only an extracellular response at its interface.
Example: Synthetic hydroxyapatite (HA).1

Uses of Bioactive Materials:

1. As pulp capping material
2. Used for permanent restorations
3. It can be used for dentinal tubule occlusion.
4. Act as scaffold and helps in regeneration of bone tissue.
5. Promotes tooth remineralization.2

Various Bioactive material used in paediatric dentistry

1. Calcium hydroxide:

Calcium hydroxide is a material which has been used for a variety of purposes since its introduction into dentistry in the early part of the twentieth century. In its pure form, the substance has a high pH, and its dental use relates chiefly to its ability to stimulate mineralization, and also to its antibacterial properties. A range of products has been formulated with different therapeutic actions, the effects of which are partially dependent upon the tissue to which they are applied.5

Calcium hydroxide dissociates into calcium and hydroxyl ions. These calcium ions reduce capillary permeability thus in turn reducing the serum flow and reducing the levels of inhibitory pyrophosphates that cause the mineralization. The hydroxyl ions neutralize acid produced by osteoclasts maintaining optimum pH for pyrophospahatase activity leading to increase level of calcium-dependent pyrophosphatase which reduced the levels of inhibitory pyrophosphate and causing mineralization.[2]

Uses of calcium hydroxide:

1. Cavity liner
2. Indirect pulp capping.
3. Direct pulp capping.
4. Pulpotomy.
5. Dressing of the root canal.
6. Long term temporary dressing.
7. Treatment of infected root canals and periapical lesions.
8. Apical closure.
9. Prevention of root resorption.
10. Repair of iatrogenic perforations.
11. Treatment of horizontal fracture.
12. Constituent of root canal sealer.[5]

Advantages of Calcium hydroxide

- Initially bactericidal then bacteriostatic.
- Promotes healing and repair.
- High pH stimulates fibroblasts.
- Neutralizes low pH of acids.
- Stops internal resorption.
- Inexpensive and easy to use.

Disadvantages of Calcium hydroxide:

- Does not exclusively stimulate dentinogenesis.
- Does exclusively stimulate reparative dentin.
- Associated with primary tooth resorption.
- May dissolve after one year with cavosurface dissolution.
- May degrade during acid etching.[6]

2. Mineral trioxide aggregate (MTA):

Mineral trioxide aggregate (MTA) was developed at Loma Linda University in the 1990s by Torabinejadas a root-end filling material. It received acceptance by the US Federal Drug Administration and became commercially available as ProRoot MTA (Tulsa Dental Products, USA). Until recently, two commercial forms of MTA have been available (ProRoot MTA) in either the grey or white forms. Recently MTA-Angelus (Angelus Soluco˜esOdontolo´gicas, Londrina, Brazil) has also become available.[7]

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, and tetracalciumaluminoferrite. These calcium silicate containing materials have a common characteristic of apatite formation.

When MTA was used as a pulp capping agent it induces cytologic and functional changes within pulpal cells, resulting in formation of fibrodentine and reparative dentin at the surface of mechanically exposed dental pulp. When placed it causes proliferation, migration and differentiation of odontoblast-like cells that produce a collagen matrix. This formed umineralized matrix is then mineralized by osteodentin initially and then by tertiary dentin formation.2

Clinical Applications of MTA:

In Primary teeth:

- Pulp capping.
- Pulpotomy.
- Root canal filling.
- Furcation perforation repair.
- Resorption repair.

In Permanent teeth:

- Pulp capping
- Partial Pulpotomy
- Perforation repair - Apical, lateral, furcation
- Resorption repair - External and internal
- Repair of fracture - Horizontal and Vertical
- Root end filling
- Apical barrier for tooth with necrotic pulps and open apex
- Coronal barrier for regenerative endodontics
- Root canal sealer.8

3. Calcium-enriched mixture (CEM):

It is also known as NEC and was introduced by Asgary. It is composed of calcium oxide, calcium phosphate, calcium carbonate, calcium silicate, calcium sulfate, and calcium chloride. Calcium-enriched mixture cement is composed of different calcium compounds, that is, calcium phosphate, CH, calcium sulfate, calcium silicate, calcium chloride, calcium carbonate and calcium oxide. CEM cement is a white powder consisting of hydrophilic particles that sets in the presence of the water base solution. The hydration reaction of powder creates a colloidal gel that solidifies in less than an hour and forms hydroxyapatite.This cement has a working time of 5 min and setting time of <1 h.The greatest distribution of CEM particle size was within 0.5-2.5 m range, allowing penetration of particles into dentin tubules and, therefore, providing a better seal.2

Clinical Applications:

- Vital pulp therapy
- Apexogenesis
- Pulp capping
- Perforation repair
- Root end filling material
- Obturating material
- Management of inflammatory external root resorption.9

4. Biodentine:

In 2011, Biodentine TM, a quick-setting calciumsilicate based dental cement, was introduced by Septodont. Biodentine TMwas developed as a dentine replacement material, a novel clinical application of this family of materials, intending it to function as a coronal restoration.

Biodentine TMis principally composed of a highly purified tri-calcium silicate powder that is pre-pared synthetically in the lab de novo, rather than derived from a clinker product of cement manufacture. Additionally, Biodentine TM contains di-calcium silicate, calcium carbonate and zirconium dioxide as a radiopacifer. The powder is dispensed in a two-part capsule to which is added an aliquot of hydration liquid, composed of water, calcium chloride, and a water reducing agent.The relatively short setting time (around 12 min), can enable the use of this cement for restorative procedures; impossible with MTAs that achieve an initial setting 3–4. MTAs include impurities and contaminating heavy metals such as chromium, arsenic, and lead. Biodentine TM has been produced under more stringent production conditions from raw materials, in an attempt to avoid any potential contamination of the basic constituents, and to avoid the incorporation of aluminum oxide.

A specific feature of Biodentine™ is its capacity to continue improving with time over several days until reaching 300 MPa after one month. This value becomes quite stable and is in the range of the compressive strength of natural dentine i.e., 297 MPa.[1]

Advantages of Biodentine:

Amongst the wide range of advantages of this dentin substitute, the ones with clinical significance are:

- Reduced setting time
- Better handling & manipulation
- Improved mechanical properties
- Bioactivity of material

Uses/Clinical Applications of Biodentine:

- It is used as a dentine substitute under a permanent restoration, and can be categorized as Indirect pulp capping material.
- Used as a direct pulp capping material
- Partial pulpotomy.
- Pulpotomy in primary molars
- Apexification.
- Repair of perforated root canals and/or pulp chamber floor
- Root end filling material.10

5. MTYA 1 Ca-filler:

The powder of MTYA 1-Ca is composed of 89.0% microfiller, 10.0% calcium hydroxide and 1.0% benzoyl peroxide and was mixed with liquid (67.5% tri ethylene glycol dimeth acrylate, 30.0% glyceryl methacrylate, 1.0% o-methacryloyl tyrosine amide, 1.0% dimethyl amino ethyl methacrylate, and 0.5% camphorquinone). MTYAl-Ca have good physical properties, and it was not inferior to Dycalhistopathologically. MTYA1-Ca promises to be a good direct pulp capping material.[11]

6. TTCP:

It can be used for biomedical purpose as it contains bioresorbablepolylactide composite that was incorporated with more basic filler for biomedical application. It was proved that it reduces inflammation and allergic effect resulting from acidic substances.[2]

7. Sol-gel derived Ag-BG:

In the field of dental repair and restoration sol-gel derived bioactive glass-ceramic materials hold an important key position. The development of a cement-like behaviour of dental ceramics could provide the biological surface required for selective spread and attachment of specific cell types able to promote tissue attachment.

The fabrication of a new sol-gel derived bioactive glass-ceramic in the system SiO2(58.6), P2O5 (7.2), Al2O3(4.2), CaO(24.9), Na2O (2.1), K2O (3) (wt%), with attractive physicochemical and mechanical properties, has already been presented.[12]

8. Calcium Phosphate:

Calcium phosphate biomaterials provided additional advantages in endodontic therapy because they are biocompatible, nontoxic and can induce mineralized tissue formation. Moreover, these biomaterials are bioactive since they can elicit specific tissue responses, depending on their dissolution–reprecipitation and biodegradation–bioresorption. These processes are of primary importance for neo-osseous formation or dentin bridging. Partial dissolution of calcium phosphate ceramics leads to precipitation of apatite microcrystals in the center and on the surfaces of the biomaterial. The calcium phosphate biomaterials also sustain cellular degradations (phagocytosis and osteoclasis) and are replaced by new hard calcified tissue. The biomaterial can favor the osteoconduction process by its porosity, allowing colonization of either bone or the dental pulp implantation site by osseous cells such as osteocytes and osteoblasts. The calcium phosphate biomaterials act as scaffolds for the formation of new mineralized tissue.[13]

9. Endosequence root repair materials:

Brasseler USA (Savannah, GA) has recently introduced the Endo Sequence Root Repair Material (RRM) and Endo Sequence Root Repair Putty (RRP), which use bioceramic technology. These new materials are produced as a premixed product to provide the clinician with a homogeneous and consistent material. Particle size has been shown to affect the early strength of a material. The particle size also affects the ease of handling, which is clinically relevant. Both of the bioceramic materials from Brasseler report their largest particle size of 0.35 µm, with approximately 50% of the particles being nano (1 X 10-3µm) in size. The drastic reduction in particle size introduced with the Brasseler products directly addresses one of the chief complaints of MTA users i.e. handling characteristics. They have excellent physical and biological properties and are easy to work with. They are hydrophilic, insoluble, radiopaque, aluminium-free, and of high pH –[12.8.1]

10. HX-BGC:

It is novel BAG-ceramic available in powder form and containing SiO_2-P_2O_5-CaO-Na_2O-SrO. It was used to reduce dentine permeability and works by the property of occluding dentinal tubule.[14]

11. Theracal:

It is a light cured, resin modified calcium silicate filled liner insulating and protecting dentin-pulp complex. It can be used in direct and indirect pulp capping, as a protective base/liner under composites, amalgams, cements, and other base materials. When this material was compared with ProRoot MTA and Dycal, it was found that calcium release was higher and solubility was low.[1]

12. Bioaggregate:

BioAggregate(Innovative Bioceramix, Vancouver, BC, Canada), a novel laboratory-synthesized water-based cement. As the first nanoparticular mineral cement introduced in the dental market, BioAggregate is produced under controlled conditions, resulting in a pure and fine white hydraulic cementlike powder composed of contamination-free bioceramic nanoparticles.It is insoluble, radiopaque, and aluminum-free material primarily composed of calcium silicate, calcium hydroxide, and calcium phosphate. BioAggregate has shown excellent sealing ability when used for root-end filling.[1]

13. Resin impregnation with titanium oxide (TiO_2):

The TiO_2nanoparticles can be impregnated in dental resins such as dental monomers and dentin bonding adhesives. It has found that with this type of restorations hydroxyapatite formation is promoted further enhancing the strength and bactericidal property. These nanoparticles help in remineralization of both enamel and dentin by restoring the marginal gaps. Thus, because of this property it reduces the incidence of secondary caries and other properties of implant surface.[2]

14. Emdogain (EMD):

Emdogain Gel (BioraAB,Malmo , Sweden) is a commercial product containing EMD. Amelogenin and amelin are proteins that have been suggested to participate in the final differentiation of odontoblasts and subsequent dentine formation during dentinogenesis. According to Bosshardt (2008), commercial Emdogain consist of enamel matrix derivate, water and a carrier, i.e. propylene glycol alginate.

In addition, EMD contains non amelogenin proteins including enamelin, tufelin and ameloblastin. It is generally assumed that EMD also contains other biologically active factors besides enamel proteins detected TGF-b1- or TGF-b-(transforming growth factor), like substances in EMD, and suggested that they are the main functional components of the product. In addition, EMD has been documented to contain a BMP-like growth factor (bone morphogenic protein), which belongs to the TGF-b family.[15]

What is Next......?????

Nanotechnology is an attractive subject, receiving increasing public and private investment on a worldwide basis.16 The term 'nanotechnology' was defined by the Tokyo Science University Professor Norio Taniguchi in a 1974 paper as follows: "Nanotechnology' mainly consists of the processing of, separation, consolidation, and deformation of materials by one atom or by one molecule.'17,18 Bioactive nanomaterials have well-defined nanostructures in terms of the size of the material, the shape, the channels, pore structure and the surface domain. They include nanoparticles, nanotubes, nanofibres, nanogels, nanofilms, and nanofoams.[19]

A nanocomposite can be formed by mixing synthetic polymers or biopolymers with nanomaterials as fillers to form the composite. The size of the filler or at least one dimension should be nanoscale. The applicability to biomedical/ biotechnological applications of nanocomposites is a rapidly emerging area of development.[20]

There are three major advantages of using nanocomposites to fabricate bioactive materials. First, improved mechanical properties of the materials can be achieved. Second, the presence of the nanomaterials within the polymer base can produce a barrier effect, creating a tortuous path, and thus reducing the rate of active agent release. Third, cell interactions with the surface of the polymer nanocomposites can be modified without modifying the bulk chemistry of the base polymer.[21]

In the medical field, the nanocomposite-based scaffold allows for cell growth, yielding a unique composite system for clinical applications. Nanotechnology has become one of the most active research areas in terms of both theoretical interest and practical applications.[22]

Conclusion;

Modern approaches implicate the use of biomaterials that can actively interact with tissue and induce their intrinsic repair and regenerative potential. The next generation of regenerative treatment techniques may involve the synthesis and assembly of bio proteins by the nano-robots. Where, these entities are simply injected to the desired location, and they weave up the collagen framework onto which the proteins are assembled, also are the possibilities where dental tissues are grown to specific requirements and transplanted on a regular basis. Genetic engineering, nanotechnology and ozone therapy will change dentistry, healthcare, and human life more extremely than other developments of the past. Osseointegration is a very complex method then there are many micro and macro molecular aspects of bone-implant interface that need to be understood and illuminated. Although, a huge study has been conceded out on bioactive materials and they are of enormous use for dentistry and biomedical development.

The possibilities are infinite and coveting. These ground breaking strategies may provide an innovative and novel biology-based new generation of clinical treatments for dental disease. "No one can know for certain what the future of dentistry will hold. I think we will see an integration of dentistry into comprehensive health care and an increased focus on the link between oral health and overall health as we enter the 21st century.

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