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RESEARCH ARTICLE

BIOMIMETIC MATERIALS IN PEDIATRIC DENTISTRY; FROM PAST TOFUTURE

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Abstract

With the arrival of technology, during the last two decades, numerous changes have been made in the field of restorative dentistry. Biomimetic materials, with their biocompatible nature and excellent physico-chemical properties are widely used nowadays. They can function as long lasting esthetic and restorative materials, cements, root repair materials, root canal sealers and filling materials, which have the advantages of enhanced biocompatibility, high strength, sealing ability and antibacterial properties. New biomimetic materials have demonstrated the ability to overcome some of the significant limitations of earlier generation materials. Although in vitro studies, the uses of biomimetic materials in restorative dentistry endodontic have given encouraging results, randomized and double-blind clinical studies of sufficient length with these materials are needed to confirm long-term success following their use.

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Introduction:-

Dental evolution is one of the most dynamic developments taking place with constant stipulation for better dental materials. Since the birth of dentistry, there has been a constant quest for a restorative material which should be biologically inert, biocompatible and is close in mimicking the properties of a natural dental structure. [1]

Oral cavity has a dynamic heterogeneous environment where the teeth undergo a continuous process of demineralization and re-mineralization. At times, the natural process of remineralization is not efficient enough to prevent initiation and progression of dental caries leading to cavities. [2] Conventionally, based on G.V. black concept of “extension for prevention” practitioners have been using high-speed hand piece and burs for cavity preparation which in turn had many disadvantages such as i) Deleterious thermal effects ii) Adverse effects on pulpal pressure iii) removal of a healthy sound structure resulting in excessive tooth structure loss. But with the shift in paradigm from “drilling and filling” to “minimal intervention”, conservation of healthy sound structure during cavity preparation gained popularity [4]. Thus, there was a requisite to provide tooth a material which is mimics the natural structure to re-mineralize, repair or regenerateas well as that restores the strength, function, and esthetics of natural teeth.

‘Bioactivity’ has been defined as the ability of a material to elicit a response in a living tissue. The materials that can affect or educe response from living tissue, organisms or cell like initiating formation of hydroxyapatite are called as bioactive materials. [5,6] Biomimetics is the field of study that attemptsbiomimicry to design processes and materials. The term “biomimetic” comes from “bio” meaning life and “mimesis” meaning means imitate in Greek [7]. It is an interdisciplinary approach to develop novel synthetic materials by assimilating information from all fields of science. [8] Thus, a biomimetic material is formed utilising biomimeticconcepts and is based on the natural

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process. The principle behind biomimetic dentistry is provide materials that not only replace the lost tooth structure but also rehabilitates the functions and esthetic of the same. It works towards treating and preserving the tooth structure insteadof conventionaldrilling and filling. [7-12]

Biologically Inspired Mechanisms [8]:

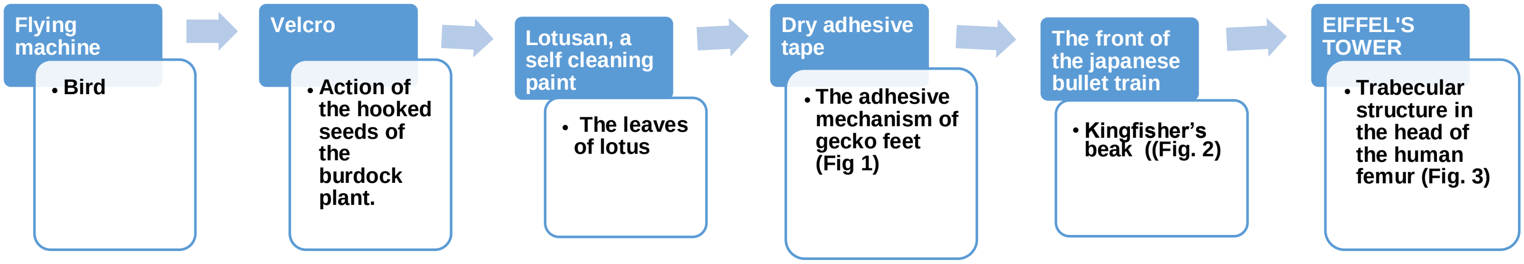



Fig. 1


Fig 2

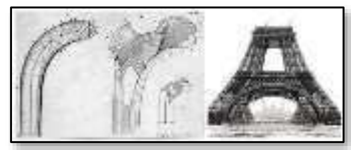
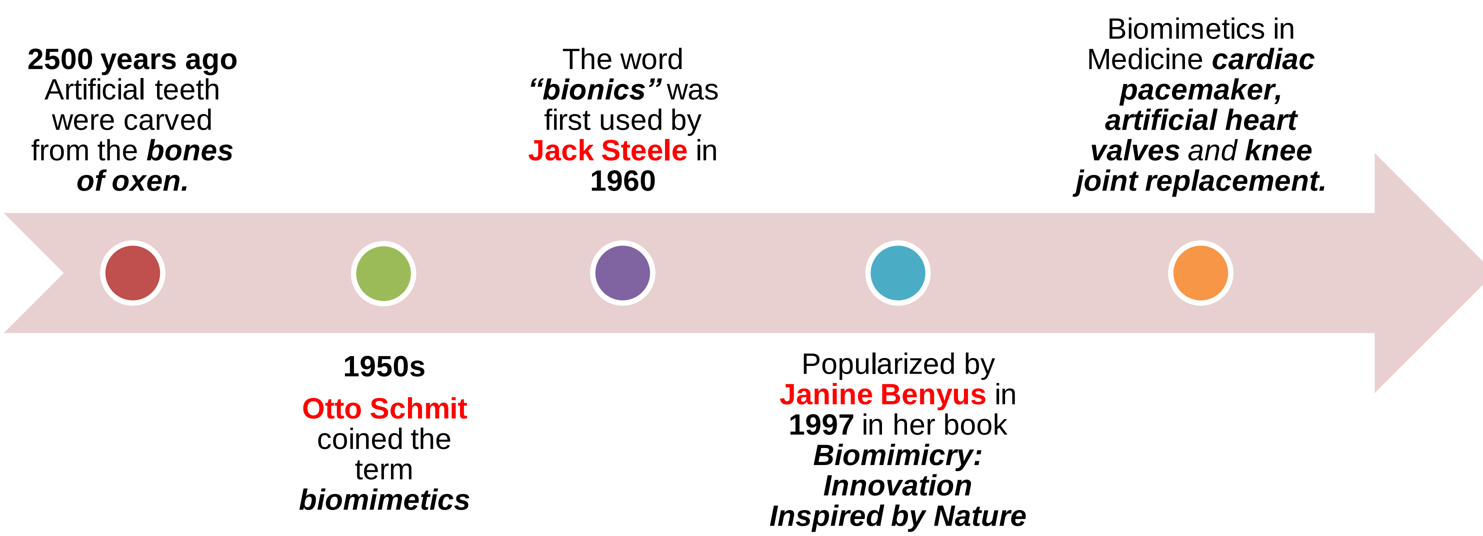


Fig. 3

History Of Biomimetic Materials [8,13]:



Biomimetic In Dentistry

The concept of biomimetics is extremely primitive, however, the implementation of the same has been recent. In the past 2 decades, the restorative dentistry has steadily evolved from mechanical retention to advanced adhesion. [14,15] **Natural Function, esthetics and strength**are the prime objectives of biomimetic dentistry. [7]

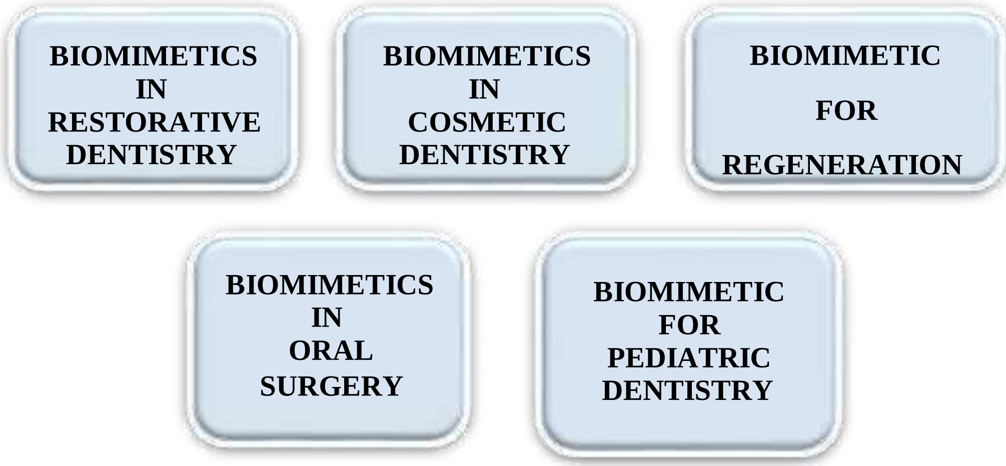
The quintessential properties of bioactive materials are that they should be bactericidal and bacteriostatic, sterile, they should initiate formation of reparative dentineand maintain pulp vitality [14]. The its modulus of elasticity and function of a biomimetic material should match the part of the tooth it is replacing. [13, 16-18]

A bioactive material can display one or more of the following actions [15]:

1. Remineralisation and strengthening of the tooth structure by release of **fluoride and/or other minerals.**
2. When immersed in body fluid or simulated body fluid (SBF) over time, it should form **an apatite-like material**.

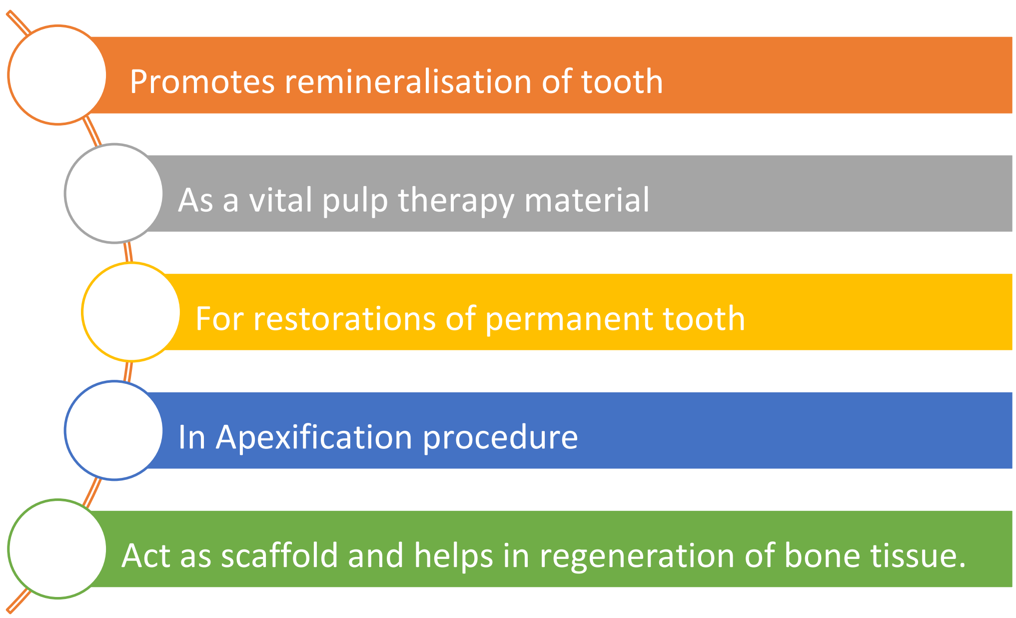
3. promote vitality of the tooth by r**ejuvenating the live tissue.**
4. **Osteoproductive / osteoconductive effects**

Biomimetic materials are utilised in the following aspects of dentistry:

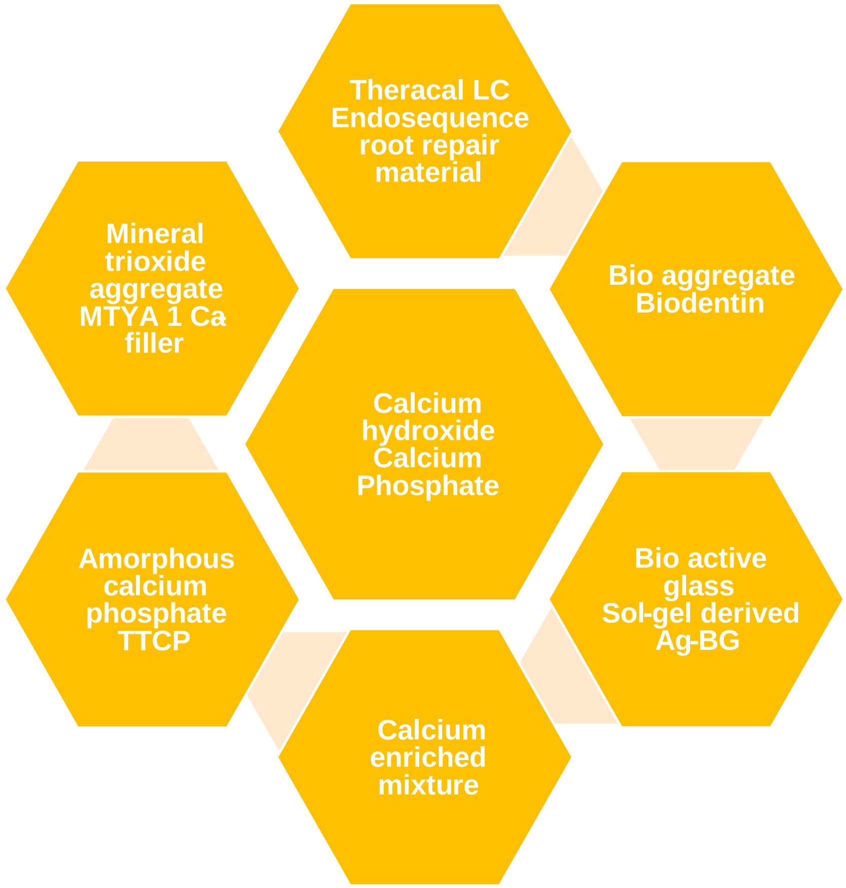


Biomimetic In Pediatric Dentistry

ROLE [5, 14]:



Various Bioactive Materials Used In Paediatric Dentistry
[5,14,15]:



I. Calcium Hydroxide

Calcium hydroxide was introduced by HERMAN in 1990. [5,13,19]

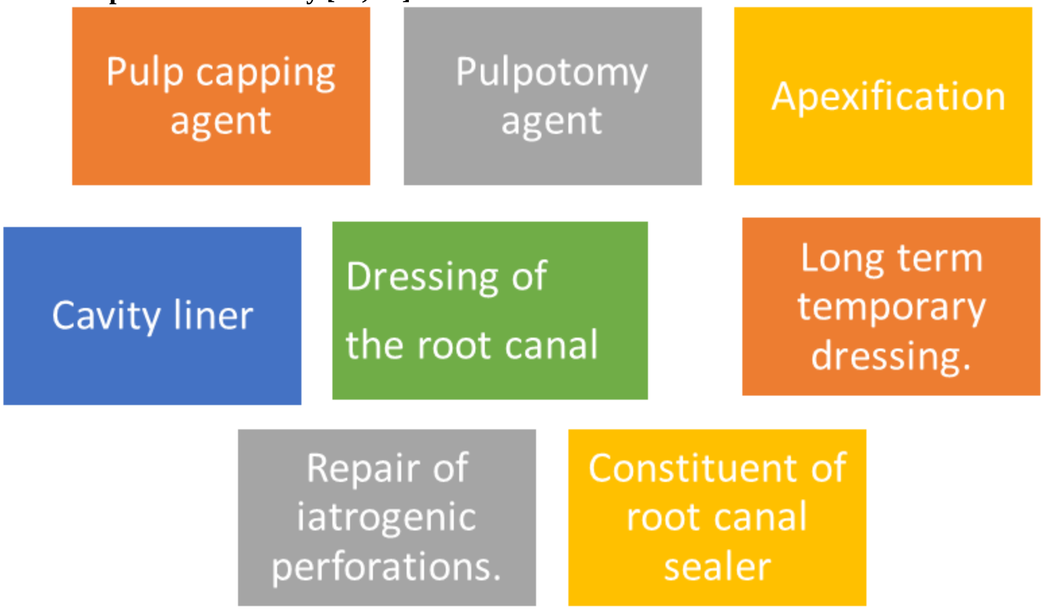
It exhibits high Ph. It has the ability to initiate mineralization and is antibacterial in nature.

It has shown to have various therapeutic actions and thus are manufactured in different forms. Its effectsdependon the tissue to which they are applied. [20]

Biological action:

Calcium hydroxide dissociates into calcium and hydroxyl ions. The calcium ions decrease the capillary permeability which helps in turn reducing the serum flow and reducing the levels of inhibitory pyrophosphates. The hydroxyl ions create an **alkaline environment** that prevents dissolution of the minerals by neutralizing lactic acid from osteoclasts. It also plays a key role in hard tissue formation by activating alkaline phosphatases. inorganic phosphatase released from alkaline phosphatasereact with calcium ions from the bloodstream and forms calcium phosphate precipitate in the organic matrix. This precipitate is the molecular unit of hydroxyapatite necessary for remineralization. [21-23]

Applications in pediatric dentistry [15, 24]



Clinical Case:

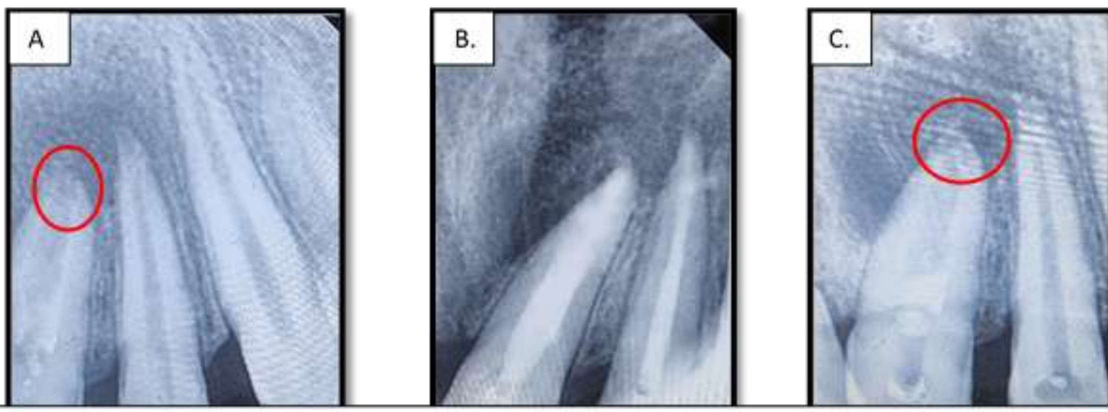


Figure 4: **Calcium Hydroxide Apexification wrt 21**

A) Preoperative radiographic picture wrt showing periapical radiolucency wrt 21, 22 and open apex wrt 21
B) Intraoperative radiographic picture showing calcium hydroxide dressing changed according every 2 – 3 weeks

Limitations of calcium hydroxide [5,25]
1.Time duration required for induction of coronal or apical hard tissue barriers. (2–3 months in the case of pulp capping and 6–18 months in the case of Apexification)
2. Incomplete coronal and apical hard tissue barriers because of vascular inclusions, which may allow bacterial invasion.
3. Changes in the physical structure of dentin related to the loss of inorganic and organic components which frequently leads to cervical root fractures.
4. Beginning of initial zones of sterile pulp necrosis.

Glass Ionomer Cement (GIC) [26]:
Glass ionomer cement (GIC) is treated as biomimetic material because of its properties that are similar to dentin, it adhesiveness and anticariogenicity owing to fluoride release. [7]

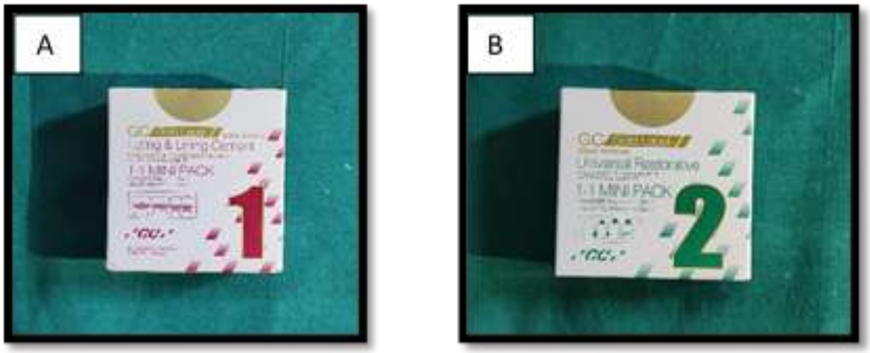


Figure 5: GLASS IONOMER CEMENT
A) Type I GIC B) Type II GIC

Biological action [27]
When GIC is used to replace dentine in the form of a restoration, it recreates the functional strength of dentin and remineralises the remaining affected dentin. Its mechanical properties are comparable to dentine. It also exhibits micromechanical interlocking and true chemical bonding, release of fluoride, making it an ideal material for restorative procedures**.**

Disadvantages:
1.Relative poor mechanical properties.

Mineral Trioxide Aggregate

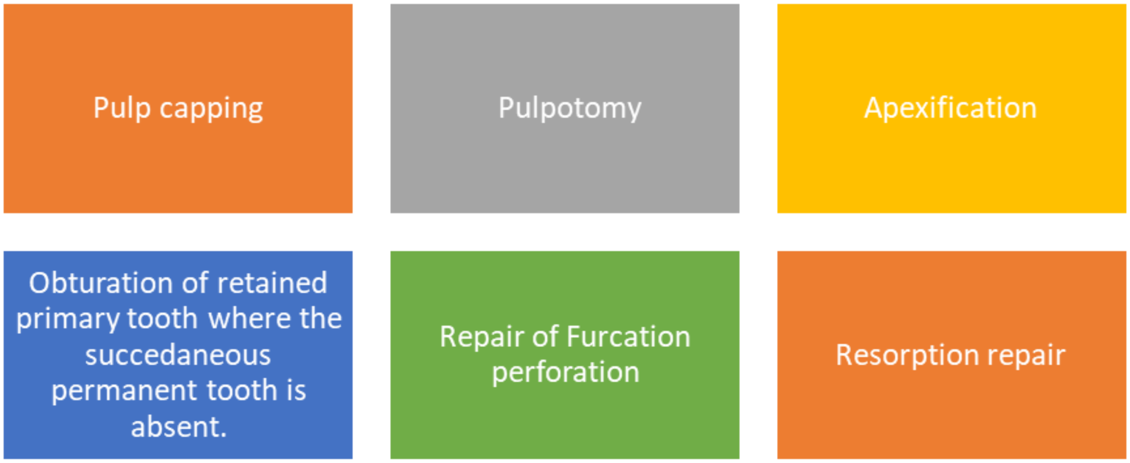
Figure 6: MINERAL TRIOXIDE AGGREGATE

Mineral Trioxide Aggregate (MTA) is a bio active material, which was introduced by Mahmoud Torabinejad in the year in 1993. [28]
MTA was developed and recommended for endodontic procedures because of it is nontoxic, noncarcinogenic, nongenotoxic, biocompatible, insoluble in tissue fluids, good sealing ability, excellent long term prognosis and dimensionally stable nature.

Biological Action of MTA [29,30]
MTA has a very similar effect when compared to that of Calcium Hydroxide. According to Parirokh and Torabinejad et al. when MTA is placed in direct contact with human tissues, material does the following [30]:
1. Calcium ions are released from the formedcalcium hydroxide that causes cell attachment and proliferation
2. It propagates an alkaline environment that renders it an antibacterial property.
3. It modulates production of cytokine.

4. It initiates the differentiation and migration of odontoblasts.
5. It also forms hydroxyapatite on the MTA surface and provides a biologic seal

Applications in Pediatric Dentistry [5,15,31]



Clinical Case:

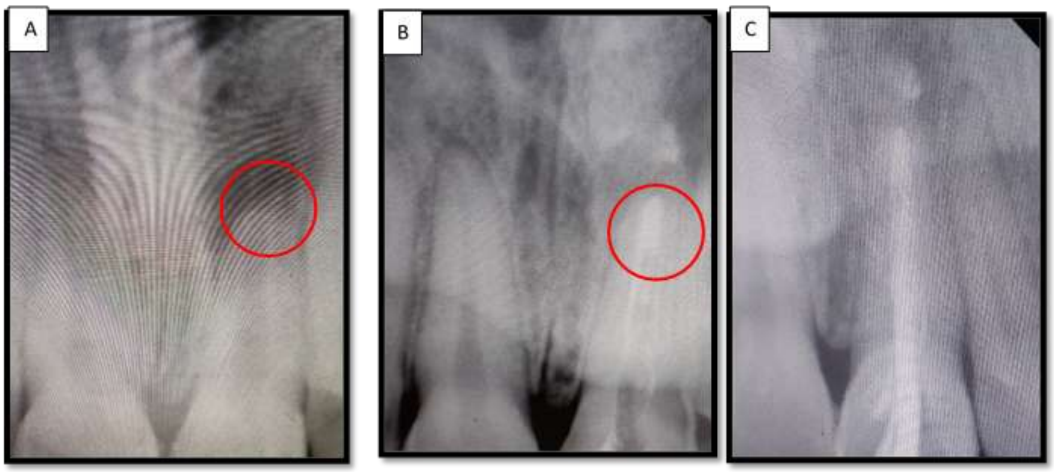


Figure 7: **MTA Apexification wrt 21**

A) Preoperative radiographic picture wrt showing periapical radiolucency and open apex wrt 21
B) Intraoperative radiographic picture showing 3 mm apical barrier formed using MTA
C) Post-operative radiographic picture showing Obturation 21

Limitations:
1.The handling of the material is difficult.
2.Causes discoloration
3.The setting time is long
4.Expensive
5.The difficulty of its removal

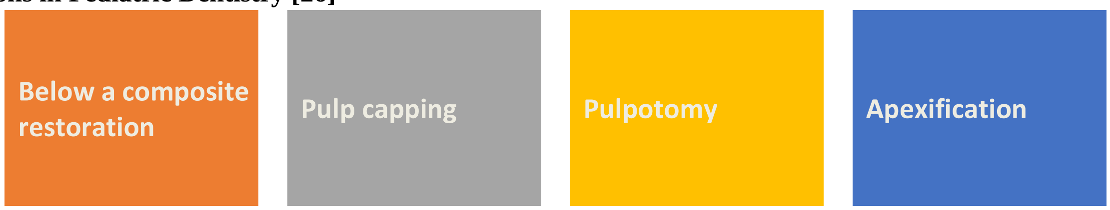
Biodentine

Biodentine, introduced by Gilles and Olivier in 2010, is a calcium silicate-based material. It has been articulated to be an effective substitute for dentin. It has a fast setting time (15 min) that allows immediate crown restoration and direct functional intraoral restoration without any detioration or distortion of the material. [33]It can be used in indirect pulp capping as a coronal restorative material as well as can be placed in contact with the pulp.

Biological Action [33,34]:

Biodentine expresses markers of odontoblasts & increases TGF-Beta1 secretion from pulpal cells. This leads to formation of osteodentine consequently causing early mineralization. Calcium hydroxide is formed during the setting action of the cement. This increase the high pH that causes irritation of the exposed area as well as shows inhibitory effect on the microflora. This zone of coagulation necrosis initiates cell division and migration of precursor cells to substrate surface, addition and cyto-differentiation into odontoblast like cells. Thus, apposition of reactionary dentine by odontoblastic stimulation and reparative dentin by cell differentiation occurs.

Applications in Pediatric Dentistry [26]



Amorphous Calcium Phosphate [26]

Amorphous calcium phosphate (ACP) is the first solid phase that precipitates from a supersaturated calcium phosphate solution. It gets converted into stable crystalline phases such as octa-calcium phosphate or apatitic products.

Biological Action [35]:

ACPhas a distinctive role in formation of dental hard tissues and remineralising potential. It increases the alkaline phosphatase activity of mesoblasts, enhances cell propagation as well as promotes cell adhesion.

Applications in Pediatric Dentistry [36 - 45]:

Bio-Ionomers [46]

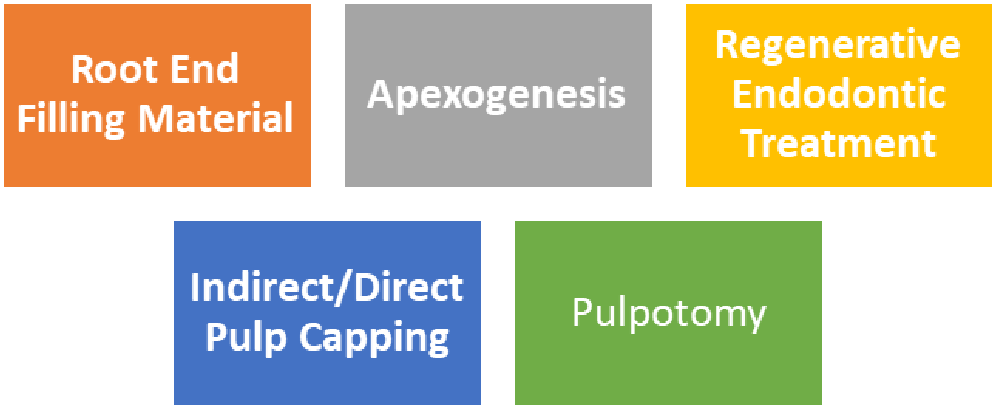
In the past decade, the remineralisation potential of glass ionomers has been articulate owing to its ability release ions such as fluoride, calcium and aluminium. This is possibly because of their capacity to buffer lactic acid. It was discovered that they can buffer acid at the pH of active caries (4.5) to the pH of arrested caries (5.5) in less than 30 seconds and with negligible erosion. This prevents development of secondary caries.

Calcium Enriched Mixture

Asgary introduced this Novel endodontic cement named calcium-enriched mixture (CEM) cement into dentistry in 2006 as an endodontic filling material. It exhibits adequate flow, film thickness and primary setting time. [47]

Biological Action [26, 48]
It induces formation of hard tissue, has the ability to initiate hydroxyapatite (HAP) formation in a saline solution and promote stem cell differentiation. It sets in a moist environment. It's setting time is lesser that MTA with a comparable sealing property.

Clinical Application in Pediatric Dentistry [5,26]



Root End Filling Material
CEM has the capacity to providing excellent apical seal with minimal micro-leakage. It has properties that are comparable to MTA and Portland cement. It has been recommended as an appropriate root-end filling material as it is highly biocompatible with low cytotoxic effect, antibacterial, exhibits good flow ability and good clinical handling. [49]

Regenerative Endodontic Treatment with CEM Cement
Nosrat et al. (2011) have reported by remarkable success using CEM as a new endodontic biomaterial in regenerating the formation of roots in necrotic immature molars. [50]

Also, another study, comparing the effects of CEM, MTA and Calcium Hydroxide on complete pulpotomy treatment in permanent teeth showed that the CEM group had lower inflammation and thickness of calcified bridge, superior pulp vitality status and morphology of odontoblast cells when compared to Calcium Hydroxide. [50]

Apexogenesis
A randomized clinical trial comparing the effects of MTA and CEM in complete pulpotomy of permanent molars with open apices showed successful apexogenesis using these biomaterials.**[51]**

Direct Pulp Capping
It was concluded by Zarrabi MH et al. that CEM exhibited higher thickness of dentinalbridge than MTA, lower pulpal inflammation when immunohistochemical examinations were performed. Also, the CEM groups had higher expression of fibronectin/tenascin as compared to MTA groups. [52]

Bio Active Glass [14, 53-55]
Bioactive glass is composed of a synthetic mineral (sodium calcium phospho silicate)that contains sodium, calcium, phosphorous and silica that are found naturally in the body. The mechanism of action is explained as a rapid release of sodium, calcium and phosphorous ions into the saliva on exposure to saliva or water which are then are available for re-mineralization of the tooth surface. They form hydroxycarbonate apatite directly without formation of amorphous calcium phosphate in between. After the initial application, they adhere to the surface of the tooth leading to continuous release of ions and hence re-mineralization of tooth.At the end, all the particles transform completely into which is the mineral of our teeth ie hydroxycarbonate apatite.

In a clinical trial that assessed the efficacy of a toothpaste (Fig 8) containing bioactive glass and strontium chloride toothpaste on a hypersensitive tooth showedthat the bio-active tooth paste decreased the sensitivity significantly greater than strontium chloride toothpaste. They have also exhibited to have significant anti-microbial properties against pathogens causing dental caries and periodontal problems. [53,54]

Bio Aggregate

Bio Aggregate is a new generation of bio ceramic material. Nanotechnology is employed to developed this material. Nano-ceramic particles are obtained that reacts with water to produce an aluminium free, biocompatible ceramic biomaterials. It stands as an ideal root canal filling material with a convenient working time of 5 min which can be increased by covering with a moist gauge sponge It showcases excellent handling properties and workability and radiopacity that aids in repair of the affected tooth. It has a thick paste like consistency upon manipulation. [56]

Figure 8: Toothpaste containing Bio-Active Glass

Clinical Applications [26,56]

- Cementogenesis
- Blocking the bacterial infection
- Root canal repair material.
- Root Resorption Repair
- Root end filling
- Apexification
- Vital Pulp Therapy

Theracal LC [5,14]

TheraCal LC is a 4th generation calcium silicate material which is a light-curable resin-modified tricalcium silicate. It is manufactured as a single paste calcium silicate-based material. It sets by hydration and thus is known to be a hydraulic silicate material.

Biological Action

This material releases calcium ions that stimulates proliferation and differentiation of human dental pulp cells leading to formation of new mineralized hard tissue. The amount of calcium ions is in an adequate concentration to initiate the actions of dental pulp cells and odontoblasts. Also, there is an increase in the pH withrelease of hydroxyl ions consequently leading to irritation of the pulp tissue. This causes superficial necrosis on exposed pulp and stimulates laying down of minerals against the necrotic zone. The repair of dentine is a result of the apatite coating hence formed. It provides an excellent biological seal owing to capability of the material to stimulate the formation of hydroxyapatite-like crystal that forms a chemical bond. [26, 57]

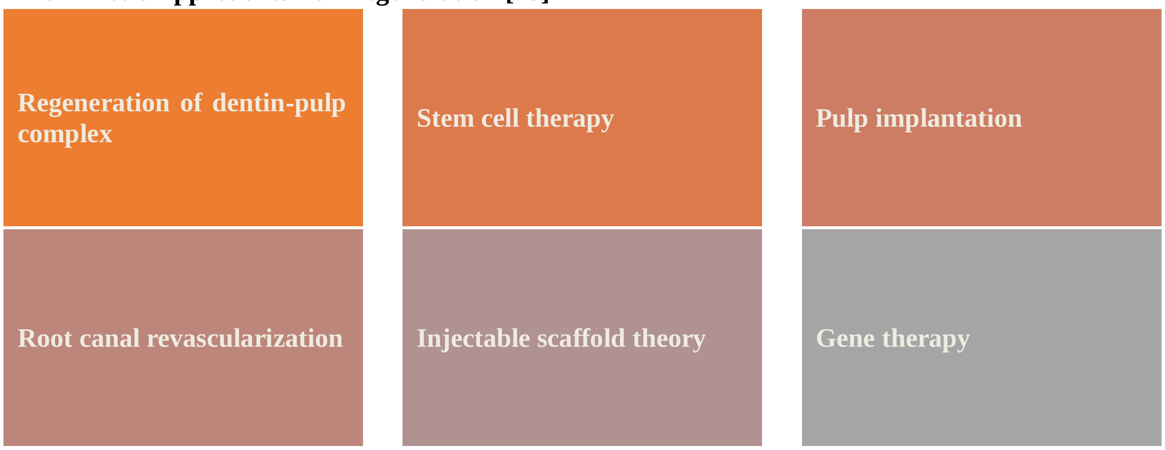
Applications in pediatric dentistry [5]

- **Direct Pulp Capping**
- **Indirect Pulp Capping**
- **Pulpotomy**
- **Revascularization**

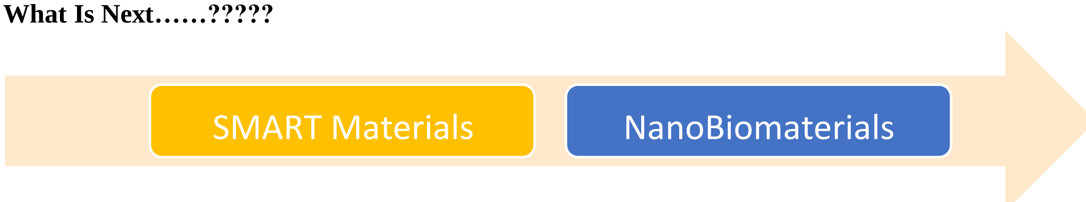
Endosequence Root Repair Material
Endo sequence root repair material (ERRM) has the following composition: Tricalcium silicate, tantalum pentoxide, calcium phosphate monobasic, zirconium oxide, dicalcium silicate, calcium sulfate, and filler agent. The setting of the material occurs in a moist environment and requires atleast 2hours to set completely. [14,58]

It is an insoluble and highly biocompatible material. Itgenerates calcium hydroxide, which is caustic in nature, when exposed to water. It has a pH of more than 12; displaying **antimicrobial action, radiopacity and an excellent sealing ability** when used as root-end fillings. It is also aluminum free. [5]

Biomimetic Approaches For Regeneration [13]



What Is Next……?????



McCabe et al defined "Smart materials" as those materials whose properties may be altered in a controlled manner by different mechanical or chemical stimuli, such as stress, temperature, moisture, pH, and electric or magnetic fields. [59]

Nanotechnology is another new and unexplored field, that has been gaining increased attention worldwide. The term nanotechnology was coined by Norio Taniguchi, Professor, Tokyo Science University defined in a 1974 in a paper that gave an insight to the mechanism of separation, consolidation and deformation of materials by one atom or by one molecule. Bioactive nanomaterials have well-defined nanostructures with respect to size, shape, channels, pore structure and the surface domain. They include nanoparticles, nanotubes, nanofibres, nanogels, nanofilms, and nanofoams. [15,60]

Conclusion: -

Dentistry is evolving rapidly and securely as Progress is impossible without change!
'"The conventional mind is passive – it consumes information and regurgitates it in familiar forms. The dimensional mind is active, transforming everything it digests into something new and original, creating instead of consuming."

- Robert Greene

In the current epoch of regeneration, remineralization of demineralized dental tissue is the need of the hour. The fast advancing field of dentistry has made it imperative to develop a biomimetic material that maintains and enhances the health of oral hard and soft tissue. It becomes of utmost important to have the knowledge and understanding of the physical and chemical properties, use and effect of the currently available bioactive materials to utilise the benefits. Further, depth research of this horizon is necessary to develop newer and better materials based on current concepts. Newer roads to conceptualise the mechanisms of adhesion and utilisation of these materials have to be explored that will enhance the process of treating tooth and outlook of dentistry.

Afterall, We Are Changing The World Through Dentistry!

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