Bioceramic Materials: A Review

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Abstract: ***Bioceramic materials have gained significant attention in dentistry due to their unique properties and biocompatibility. Bioceramics are materials which has Alumina, Zirconia, Bioactive glass, Glass ceramics, Hydroxyapatite, resorbable calcium phosphate. They've been used in dentistry as root repair materials, apical filling materials, perforation sealing, filling up bone defects, endodontic sealers, and regeneration aids. They are comparable to hydroxyapatite in that they have an intrinsic osteoconductive activity and the capacity to induce regenerative responses in the human body. This review provide details on bioceramic materials. It also provides a detailed look at the various bio ceramic materials that are currently used in the field of restorative dentistry and endodontics.***

Keywords: Bioceramics, Portland cement, MTA, Biodentin, ERRM, MTA fillapex, Endo CPM sealer, Bioroot RCS, Bioaggregate, Ceramicrete, Tech biosealer, CEM

1. Introduction

The field of dentistry is constantly evolving because to the introduction of new methods and technical advancements. One of the rapidly developing materials that has transformed dentistry is bio-ceramics. [13]

Physical, chemical, and biological occurrences can have an impact on the tooth structure. The most common forms of tooth aggression are trauma and dental caries. Both situations have the potential to cause pulpal reactions that result in inflammation and/or tissue necrosis that is irreversible and the development of bioceramic materials broadens the scope for restorative and regenerative procedures in dentistry, and more specifically in endodontics. [6]

Bioceramics are ceramic substances created specifically for use in medicine and dentistry. They consist of alumina and zirconia, bioactive glass, glass ceramics, coatings and composites, hydroxyapatite, and resorbable calcium phosphates. Both dentistry and medicine today use a wide variety of bioceramics, although more so in medicine. The bioinert ceramics utilized for prosthetic devices include alumina and zirconia. There are several brand names for bioactive glasses and glass ceramics that can be used in dentistry. Porous ceramics, such as those made of calcium phosphate, have also been used to fill up bone defects. [1]

2. History

Bioceramics were developed in the 1960s and 1970s for application in the human body, including bone plates, bone cement, artificial ligaments, tendons, and joint replacement. LeGeros et al. were the first to use calcium phosphate as a Bioceramics restorative dental cement. L.L.Hench discovered that numerous glassware and ceramics may adhere to living bone and developed a novel substance called bioglass in 1969. [12]

What are Bioceramics

Bioceramics are defined as a type of biomaterial with optimal biocompatibility for use for medical and dental purposes. [12] They include alumina, zirconia, bioactive glass, coatings, composites, hydroxyapatite and resorbable calcium phosphate and radiotherapy glasses. Bioceramics are biocompatible, nontoxic, non-shrinking and usually chemically stable within the biological environment. In dentistry, bioceramic materials were introduced in the 1990s as root repair materials and then as retrograde filling materials. [13]

The ability of dentists to successfully treat conditions like pulp capping, pulpotomy, apexification, apicoectomy, and restoration of deformities brought on by unintentional perforation and resorption has been substantially enhanced by the advent of bioceramic-based materials.

2.1 Classification

In addition to being nontoxic, bioceramics can be classified as:
1) **Bioinert**: Noninteractive with biological systems (zirconia and alumina)
2) **Bioactive**: Interactive with surrounding tissues to encourage the growth of durable tissues (glass and calcium phosphate)
3) **Biodegradable, soluble, or resorbable**: Eventually replaces or gets incorporated into tissue. Particularly important with lattice frameworks. [1]

Bioceramic used in Vital Pulp Therapy

Grey MTA, White MTA, Pro- root MTA, MTA – Angelus, Biodentine and iRoot BP plus.

Bioceramic materials used in endodontics

1) Calcium silicate based bioceramic materials –
   a) Cements- Portland Cement, Biodentine (Septodont, France), Mineral trioxide aggregate (MTA).
   b) Sealers- Endo CPM Sealer (EGO SRL, Buenos Aires, Argentina), BioRoot RCS (Septodont, France), MTA Fillapex (Angelus, Brazil), TechBiosealer (Profident, Kielce, Poland).

2) Calcium phosphates/ hydroxyapatite based/ tricalcium phosphate
3) Mixture of calcium phosphatesand calcium silicates - iRoot BP, iRoot BP Plus,iRoot FS (Innovative Bioceramix Inc., Vancouver, Canada), EndoSequence BC Sealer (Brasseler, Savannah, GA, USA)/ Total Fill, Bioaggregate (Innovative Bioceramix Inc., Vancouver, Canada), Tech Biosealer, Ceramicrete (developed at Argonne National Lab, Illinois, USA)[15]

Uses of Bioceramics

1) Prosthetic uses- Implants, prosthesis, prosthetic devices, coatings to improve the biocompatibility of metal implants.
2) Surgical uses- Joint replacements, fill surgical bone defects, alveolar ridge augmentation, sinus obliteration, and correction of orbital floor fracture.
3) Endodontic uses- Sealers, obturation, perforation repair, retrograde filling, pulpotomy, resorption, apexification, regenerative endodontics.
4) Restorative uses- Dentin substitute, pulp capping, dentin hypersensitivity, dentin remineralization.[15]

Advantages:

1) Good biocompatibility properties and similarity with biological hydroxyapatite.
2) Non-toxic, non-shrinking, and chemically stable within the biological environment.
3) Able to form hydroxyapatite and ultimately create a bond between dentin and the material.
4) Have the ability to absorb osteoinductive substances in the vicinity of bone healing hence they are intrinsic osteoconductive.
5) Acts as a regenerative scaffold of resorbable lattices and provides a framework to rebuild tissue.
6) Dissolves over a period of time.
7) Fluoride ions are part of apatite crystals in these materials, and the resulted nanomaterial has antibacterial properties.
8) Porous powders in bioceramic material containing nanocrystals with diameters of 1 - 3 nm help prevent bacterial adhesion.[8]

Properties

1) Nontoxic
2) Biocompatible,
3) Do not shrink
4) Chemically stable with in the biological environment.
5) Does not cause inflammatory reaction if over fill occurs during the obturation process or in a root repair.
6) Has the ability to form hydroxyapatite and to create a chemical bond between dentine and appropriate filling materials.
7) Potential increased strength of the root following obturation
8) Strongly antibacterial
9) Good sealing ability
10) Ease of use.[20]

Portland Cement

Portland cement (PC), which was created by calcining a mixture of limestones from Portland, England, and silicon-argillaceous minerals, was invented by Joseph Aspdin in 1824. The primary composition of PC and MTA is identical, with the exception of bismuth oxide's absence and higher quantities of calcium aluminate and calcium sulphate. PC is a low-cost material. Grey and white PCs, similar to MTA, are available.[15]

Limitations:

Concerns about PC's safety with regard to the surrounding tissues have been raised due to reports of its increased solubility compared to MTA and reports of higher amounts of lead and arsenic released from PC. A higher solubility could compromise the restoration's long-term seal. PC setting expansion that is too high can result in tooth crack formation. When compared to MTA, which is essential for a bioactive material, biomineralization with PC is neither as efficient or as long-lasting.[8]

1) Mineral Trioxide Aggregate (MTA)

The first bioceramic material to be used successfully in endodontics was MTA cement. In the year 1993, Dr. Torabinejad introduced it. Its properties include osteo conductive, inductive, and biocompatibility. It was initially created as a material for root-end fillings and has since been utilised in a number of treatments, including pulpotomies, pulp capping, apexogenesis, the repair of root perforations, the development of apical barriers in teeth with open apexes, and, most recently, as a root canal filling material. In order to address the issue of tooth discolouration associated with grey MTA, Dentsply Endodontics, Tulsa, OK, USA, introduced white MTA (WMTA) called ProRootMTA in the year 2002. [8]

MTA Composition

MTA is comprised primarily of Portland cement Powder

1) Purified Portland cement
2) Mixture of dicalciumsilicate [$Ca2SiO_4$](75%),
3) Tricalciumsilicate[Ca_3SiO_5],
4) Tricalciumaluminate[$Ca_3Al_2O_6$],
5) Calciumsulphate[$CaSO_4$, gypsum], (5%)
6) Tetra-calcium aluminoferrite [$4CaOAl2O_3Fe2O_3$])
7) Bismuth oxide (20%)
8) Small quantities of SiO_2, CaO, MgO, K_2SO_4, andNa_2SO_4

Liquid

1) Distilled water [13]

Difference between Grey and White MTA

Due to the fact that WMTA had 54.9% less Al2 O3, 56.5% less MgO, and 90.8% less FeO than GMTA, it was concluded that the reduction in FeO was most likely the

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reason for the colour change. Additionally, it was claimed that WMTA had particles that were overall smaller than GMTA. [15]

Advantages

Forms Calcium hydroxide that releases calcium ions to promote cell adhesion and growth provides an atmosphere that is antimicrobial due to its alkaline pH changes the cytokine production encourages hard tissue-producing cells to migrate and differentiate, and forms carbonated apatite (or hydroxyapatite) on the MTA surface, providing a biologic seal. [15]

Drawbacks of MTA

1) Long setting time - Torabinajad M et al., MTA demonstrated the longest setting time in comparison to that amalgam.
2) Difficult to manipulate - Mooney GC and North S found that manipulating MTA was messy when moisture was excessive and difficult to use.
3) Toxic elements in composition - Asgary S et al. discovered that MTA contains ingredients including arsenic that may potentially cause toxicity.
4) 4.High Cost [13]

2) Biodentine

"Biodentine" is a calcium silicate-based substance that was developed specifically as a "dentine replacement" material. Biodentine, often known as "dentine in a capsule," is a "biocompatible and bioactive dentine substitute" that lacks the drawbacks of Calcium hydroxide and Mineral trioxide aggregate. Septodont made it commercially available in 2009. The material is formulated utilising MTA-based cement technology and provides improvements to some aspects such as physical properties and handling.

Composition

Powder
1) Tricalcium silicate ($3CaO.SiO_2$),
2) Dicalcium silicate ($2CaO.SiO_2$),
3) Calcium carbonate ($CaCO_3$),
4) Calcium oxide (CaO),
5) Zirconium oxide (ZrO_2)

Liquid
1) Water
2) Calcium Chloride ($Cacl_2$),
3) Hydrosoluble polymer (Plasticizing agent)

Unique Features

1) High purity as a result of monomer-free composition.
2) High biocompatibility and bioactivity.
3) Short setting time of 10-12 minutes
4) Simple material handling.
5) It is easy to apply, requires no preparation or bonding, and does not discolour.
6) 6.Superior mechanical qualities--mechanical properties that are comparable to sound dentine.
7) Excellent sealing capabilities, including the capacity to create mineral tags in dentinal tubules and outstanding micro leakage resistance, complemented by the lack of shrinking due to the resin-free formula.
8) Excellent antibacterial properties-the calcium hydroxide ions generated by the set Biodentine result in a high alkaline pH, which promotes an unfavourable environment for bacterial growth and results in the disinfection of contiguous hard and soft tissues.
9) Less expensive than comparable materials[13]

Advantages

When compared to MTA, the advantage of Biodentine is its improved handling property, which is better suited to clinical use. It also offers superior mechanical qualities over MTA and does not necessitate a two-step restoration technique, as MTA does. Because the setting is faster than MTA, there is less chance of bacterial contamination. [8]

3) Endosequence Root Repair Material (ERRM)/ iROOT BP Plus

ERRM is a recently developed premixed bioceramic material of the calcium phosphate silicate cement group. These materials is used for permanent root canal repair .11Also used for Perforation repair, apical surgery, apical plug, and pulp capping. [13]

Composition

Ready-to-use paste or putty Composed of
1) Tri and di calcium silicates (Ca_2SiO_4)
2) Monobasic calcium phosphate ($Ca[H_2PO_4]2$)
3) Zirconium oxide (ZrO_2)
4) Tantalum oxide ($Ta2O_5$)
5) Proprietary fillers, and thickening agents[13]

Advantages:

Improved handling properties and shorter setting times. The material is aluminium-free, resistant to wash out, and does not shrink during setting.[11]

4) Endosequence BC Sealer / iROOT SP

It is a ready-to-use injectable bioceramic cement paste designed for permanent root canal filling and sealing.

EndoSequence BC Sealer is an insoluble, radiopaque, and aluminum-free substance based on a calcium silicate composition that sets and hardens in the presence of water. [13]

Composition
Composed of tricalcium silicate, dicalcium silicate, colloidal silica, calcium phosphate monobasic, calcium hydroxide and thickening agent. Zirconium oxide as radiopacifier. [11]

Advantages:
Its key advantages are that it is aluminum-free, non-soluble, antimicrobial, and simple to use. It takes less time to set and does not shrink during the process. According to certain research, it eliminates all bacteria within two minutes of contact and creates a gap-free interface between gutta-percha (GP), sealer, and dentin. [16]

5) MTA Fillapex
MTA Fillapex (Angelus SolucoesOdontologicas, Londrina, PR, Brazil) is a calcium silicate-based bioceramicsealer that was recently introduced. MTA Fillapex was developed to combine the physicochemical qualities of a resin-based root canal sealer with the biological properties of MTA. [13]

Composition
MTA Fillapex is composed of mineral trioxide aggregate, salicylate resin, natural resin, silica and bismuth .[13]

Advantages:
MTA Fillapex has an adequate working time, high radiopacity, and is easy to handle.[3]

6) ENDO-CPM-SEALER
This was introduced in 2004 to combine the physicochemical features of a root canal sealer with the biological properties of MTA. End-CPM had an antibacterial impact on E. faecalis before setting, but it lost its antibacterial activity after setting. Calcium carbonate was added to reduce the pH from 12.5 to 10.0 after it had been established to limit the surface necrosis of cells in contact with the substance, resulting in the deposition of mineralized tissue. [21]

Composition
Powder: mineral trioxide aggregate, bismuth oxide, barium sulfate, silica dioxide
Liquid: aqueous solution of calcium chloride, sodium citrate, propylenglycolalginate, propylenglycol

Advantages:
The addition of calcium chloride to MTA shortens the setting time, increases sealing ability, and enables insertion into cavities without affecting its biocompatibility. [21]

7) Bioroot RCS
BioRoot RCS (Septodont, SaintMaurdes-Fosses, France), a new tricalcium silicate-based sealer, was introduced in 2015. It is a water-based sealer.

Composition
Bioroot is composed of up of tricalcium silicate and zirconium oxide. [13]

Advantages:
After setting, BioRoot RCS produces calcium hydroxide, which MTA Fillapex does not. When compared to EndoSequence BC Sealer, BioRoot RCS leaches twice as much calcium. When it comes into touch with a physiologic solution, it also produces a calcium phosphate phase. [13]

8) Bioaggregate
Bioaggregate is an endodontic repair calcium silicate cement, which is considered as a modified version of MTA. Innovative BioCeramix Inc. (IBC) has successfully developed BioAggregate root canal repair filling material as a new generation of a dental root canal filling material, which is a fine white hydraulic powder cement mixture for dental purposes. It makes use of modern nanotechnology to create ceramic particles that, when combined with water, produce biocompatible and aluminum-free ceramic biomaterials. The hydrophilic BioAggregate Powder promotes cementogenesis and produces a hermetic seal inside the root canal. BioAggregate is used in: root perforation repair, root resorption repair, root end filling, apexification, and pulp capping due to its effectiveness in clinically inhibiting the bacterial infection, ease of manipulation, and high quality.[13]

Composition
The major constituents are tricalcium silicate and dicalcium silicate, but it is an aluminate-free bioceramic material. Tantalum pentoxide, which is more chemically inert, is used as radiopacifying agent.[11]

Advantages:
BioAggregate is new generation of a root canal repair filling materialIt is a contamination-free and aluminum-free ceramic biomaterial. It has excellent handling characteristics after mixing with water. It has good radiopaque properties.[13]

9) Ceramicrete
Ceramicrete is a self-setting phosphate ceramic developed at Argonne National Laboratory in Illinois, USA, that sets in an ambient environment formed by the acidbase reaction of an acid phosphate (KH2PO4) and a minimal soluble basic metal oxide (calcinedMgO).

A biocompatible, radiopaque Ceramicrete-based dental/bone material has recently been developed by adding hydroxyapatite powder and cerium oxide radiopaque filler into the phosphosilicate ceramic. [15]

10) Tech Bio Sealer
This material contains phyllosilicate [montmorillonite] in addition to tricalcium silicate, calcium sulfate, calcium chlorite, bismuth trioxide and sodium fluoride in the powder. [11]

Calcium-Enriched Mixture (CEM)

Agsary et al. introduced calcium-enriched mixture (CEM) cement to dentistry in 2006 as a tooth-colored, water-based endodontic repair cement with comparable applications to MTA but a distinct chemical composition. It has the ability to enhance hydroxyapatite production in saline solution and may increase stem cell differentiation and hard tissue development. This substance possesses antibacterial properties equivalent to calcium hydroxide and superior to MTA and Portland cement (PC). [13]

Future of Bioceramics
In recent years, bioceramic materials have gained significant attention in dentistry due to their unique properties and potential applications. As we look into the future, several directions can be identified for the development and utilization of bioceramic materials in dentistry:

1) Root Canal Treatment: Bioceramic materials, such as calcium silicate-based cements (e.g., mineral trioxide aggregate, or MTA), have shown excellent biocompatibility and sealing ability. In the future, further improvements in these materials may enhance their handling characteristics, setting time, and antimicrobial properties. This could lead to their increased use in root canal treatment, particularly for complex cases or regenerative endodontics.
2) Dental Implants: Bioceramic materials have the potential to revolutionize dental implantology. Future advancements may involve the development of bioceramic coatings or surfaces with improved osseointegration properties. These materials could enhance the initial stability of implants, promote faster and more predictable bone healing, and reduce the risk of peri-implantitis.
3) Bioactive Scaffolds: Bioceramics can be used as bioactive scaffolds for tissue engineering applications. In the future, researchers may focus on optimizing the composition and structure of bioceramic scaffolds to better mimic the natural extracellular matrix and promote cell adhesion, proliferation, and differentiation. This could enable the regeneration of dental tissues, such as dentin, enamel, and periodontal ligament.
4) Restorative Dentistry: Bioceramic materials have shown promise in restorative dentistry, particularly for direct and indirect pulp capping, as well as in the treatment of dental caries. Future developments may involve the improvement of esthetic properties, mechanical strength, and bond strength to tooth structure. This could expand their applications in restorative procedures, reducing the need for traditional materials like amalgam or composite resin.
5) Drug Delivery Systems: Bioceramics can serve as carriers for controlled drug delivery in dentistry. Future research might focus on developing bioceramic-based drug delivery systems that can release therapeutic agents (e.g., antimicrobials, growth factors) at a controlled rate, targeting specific dental conditions such as periodontal diseases or dental pulp regeneration.
6) Digital Dentistry Integration: As digital dentistry continues to advance, bioceramic materials can be integrated into computer-aided design and manufacturing (CAD/CAM) systems for the fabrication of customized dental restorations. Future developments may involve the optimization of bioceramic materials for milling or 3D printing, allowing for the efficient production of precise and biocompatible dental prostheses

3. Conclusion

In conclusion, bioceramic materials have emerged as a promising option in the field of dentistry. These materials, which are typically composed of inorganic compounds, have demonstrated several advantageous properties that make them suitable for various dental applications. The use of bioceramic materials in endodontics has altered both surgical and non-surgical therapy. These materials offer a viable path forward in the preservation of patients' teeth. MTA is the long-standing standard bioceramic material used in endodontics. Advances in these materials have constantly attempted to overcome MTA's disadvantages and improve its qualities, resulting in bioceramics materials being widely employed in both endodontics and restorative dentistry. A thorough understanding of these new bioactive materials is required to ensure the selection of the most appropriate material in various clinical circumstances.

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