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Research Article

BIOMATERIALS IN RESTORATIVE DENTISTRY AND ENDODONTICS: AN OVERVIEW

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Statement of problem: Dental biomaterial has evolved over years with progression from more bioinert materials to bioactive materials and following the trends into cellular and molecular response.
Objective: An ideal biomaterial has favorable biological response leading into regeneration of lost tissue. So the evolving nature of these materials are of interest of compilation.
Materials and Methods: A hand and online search of literature is followed and of recent developments on a specific topic as reported in the literature is done
Conclusion: Biomaterial is used to make devices to replace a part or a function of the body in a safe, reliable, economic, and physiologically acceptable manner

INTRODUCTION

The biomaterials and technologies are not only replacing missing or damaged tissues but also promoting the tissue regeneration[1]. The objectives of all these biomaterials and technologies not only are to replace missing or damaged tooth tissues but are also now to promote tissue regeneration and also prevent healthy tooth tissue[2]. Definition of biomaterials employed by the American National Institute of Health that describes biomaterial as any substance or combination of substances, other than drugs, synthetic or natural in origin, which can be used for any period of time, which augments or replaces partially or totally any tissue, organ or function of the body, in order to maintain or improve the quality of life of the individual[3]. Biomaterials are materials that possess some novel properties that makes them appropriate to come in immediate contact with the living tissue without eliciting any adverse immune rejection reactions. Biomaterials are used in dentistry, in restorative procedures such as dental restorations, dental implants and surgical procedures, endodontic materials, in devices such as orthodontic materials[4].

Types of biomaterials

1. ***Bioinert material[5]:*** The term bioinert refers to any material that once placed in the human body has minimal interaction with its surrounding tissue, examples of these are Metals (stainless steel and cobalt–chrome-based alloys, Ti and Ti alloys). Ceramics (Alumina Al_2O_3 and Zirconia ZrO_2). Polymers (silicone rubber, acrylic resins).
2. ***Bioactive material:*** A bioactive material is defined as a material that elicits a specific biological response at the interface of the material, which results in the formation of a bond between the tissue and that material[6], examples are bioactive glasses, hydroxyapatite, ceramics.
3. ***Bioresorbable materials:*** material that upon placement within the human body starts to dissolve (resorbed) and slowly replaced by advancing tissue (such as bone). Examples of bioresorbable materials are tricalcium phosphate [Ca3(PO4)2] and polylactic–polyglycolic acid copolymers. Calcium oxide, calcium carbonate and gypsum.

During the first decade of the twenty-first century, the concepts of bioactive materials and resorbable materials have converged; bioactive materials are being made resorbable and resorbable polymers are being made bioactive[7].

Bioinert Matrials

Metals: The main property required of a metal as biomaterial is that it does not illicit an adverse reaction when placed. As well, good mechanical properties, osseointegration, high corrosion resistance and excellent wear resistance are required. And should be nontoxic and should not cause any inflammatory or allergic reactions in the human body[8]. The mechanical properties that help to decide the type of metallic material are hardness, tensile strength, Young´s modulus and elongation. Material employed to replace the tissue must possess similar mechanical properties to that of tissue[9-10]. Various metals in different from as, base metal alloy, noble metal alloy wrought metal a finds in application in dentistry

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are crown and bridges, inlays orthodontics bands bracket and wires, cast post and implants.

Steels are still the main metallic materials in engineering applications. Stainless steel 316L is an example of the application of these alloys as biomaterial. It can be used in the manufacture of elements such as femoral stems and heads, combining good mechanical strength and corrosion resistance. However, the main advantage of steels in relation to other metallic materials is the cost-benefit ratio. In general, steels are versatile in terms of properties. There is a linear relationship between manufacturing process, structure and properties. For example, forging is a bulk deformation process in metal working commonly employed in the manufacture of stainless steel prostheses. Depending on the compressive loads applied to the material, structures (grain sizes) are formed which increase its mechanical strength.

Cobalt-based alloys are one of the only alloys with its good corrosion resistance and good mechanical strength in chloride environments, which is due to alloying additions and the formation of the chromium oxide Cr_2O_3 passive layer. Biomaterials are used in different parts of the human body as artificial valves in the heart, stents in blood vessels, replacement implants in shoulders, knees, hips, elbows, ears and orthodental structures[11-13].

Titanium alloys are fast emerging as the first choice for majority of applications due to the combination of their outstanding characteristics such as high strength, low density, high immunity to corrosion, complete inertness to body environment, enhanced compatibility, low Young´s modulus and high capacity to join with bone or other tissues. Their lower Young´s modulus, superior biocompatibility and better corrosion resistance in comparison with conventional stainless steels and cobalt-based alloys, make them an ideal choice for bio-applications[14]. Because of the mentioned desirable properties, titanium and titanium alloys are widely used as hard tissue replacements in artificial bones, joints and dental implants. Concerning the medical applications of these materials, the use of commercially pure Titanium is more limited to the dental implants because of its limited mechanical properties. In cases where good mechanical characteristics are required as in hip implants, knee implants, bone screws, and plates, Ti-6Al-4V alloy is being used[15- 16]

Ceramics: Dental ceramics are materials that are part of systems designed with the purpose of producing dental prostheses that in turn are used to replace missing or damaged dental structures. The literature on this topic defines ceramics as inorganic, non-metallic materials made by man by the heating of raw minerals at high temperatures[17]. Ceramics can be classified into one of the four category silicate, oxide, monoxide and glassed based ceramics[18]. Glass-based systems made from materials that contain mainly silicon dioxide (also known as silica or quartz), which contains various amounts of alumina. Aluminosilicates found in nature, which contain various amounts of potassium and sodium, are known as feldspars. Feldspars are modified in various ways to create the glass used in dentistry. Synthetic forms of aluminasilicate glasses are also manufactured for dental ceramics.Glass-infiltrated, partially sintered alumina was introduced in 1988 and marketed under the name In-Ceram. The system was developed as an alternative to conventional metal ceramics and has met with great clinical success. Solid-sintered, monophasic ceramics are materials that are formed by directly sintering crystals together without any intervening matrix to from a dense, air-free, glass-free, polycrystalline structure. There are several different processing techniques that allow the fabrication of either solid-sintered aluminous-oxide or zirconia-oxide frameworks[19]. Dispersion strengthening is a process by which the dispersed phase of a different material (such as alumina, leucite, zirconia, etc.) is used to stop crack propagation as these crystalline phases are more difficult to penetrate by cracks[20]. Dental ceramics are attractive because of their biocompatibility long term color stability, wear-resistance, and their ability to be formed into precise shapes some of the materials can be formed into inlays onlays veneers crowns and several of core ceramics can be resin bonded micromechanically to tooth structure[18].

Polymers: Synthetic polymers have been widely used in both restorative and prosthetic dentistry for over five decades. Applications for acrylic polymers based on functional methacrylates, include dentures, restorative materials, relining and repair material, soft liners, bonding agents, temporary crown and bridges. Elastomeric materials such as silicones, polysulphides and alginates are used for recording impressions of the hard and soft oral tissues, which are then utilized for constructing appliances outside the mouth[21].

Bioactive Material

Bioglass: **t**he original bioglass (45S5) composition is as follows: 45% silica (SiO_2), 24.5% calcium oxide (CaO), 24.5% sodium oxide (Na_2O), and 6% phosphorous pentoxide (P_2O_5) in weight percentage. Bioglass material is composed of minerals that occur naturally in the body (SiO_2, Ca, Na_2O, H, and P), and the molecular proportions of the calcium and phosphorous oxides are similar to those in the bones. The surface of a bioglass implant, when subjected to an aqueous solution, or body fluids, converts to a silica-CaO/P_2O_5-rich gel layer that subsequently mineralizes into hydroxycarbonate in a matter of hours[22]. Bioglass was used in particle form to fill periodontal osseous defects, endosseous implant-bioglass implants were placed in the extracted sockets of incisors, splinted to adjacent natural teeth for 3 months and then desplinted for another 3 months. Bioglass caused ankylosis, usually by direct deposition of bone on the implant surface, as remineralizing agent- Salonen *et al*[23]. proved that S53P4 induced tissue mineralization at the glass-tissue interface and elsewhere. The study widened the use of bioglass in treatment of caries prophylaxis, in dentinal hypersensitivity, as root apex sealer, and as metal implant coating. As drug delivery-Bioglass has been tried as a vehicle for drug delivery. Vancomycin on bioglass carrier has been tested for treating osteomyelitis with success[24].

Hydroxyapatite: Calcium phosphate materials, such as hydroxyapatite (HA), are used in orthopedic, dental, and maxillofacial surgery as a bone substitute, because they bond chemically directly to bone after implantation[25]. Calcium phosphate materials are similar to bone in composition and in having bioactive and osteoconductive properties[26]. It has properties such as good biocompatibility, superior compressive strength, and its transformation into hydroxyapatite over time. It induces bridge formation with no superficial tissue necrosis and significant absence of pulpal inflammation[27].

Calcium Hydroxide*:* Calcium hydroxide has been extensively used as the gold standard for direct pulp capping. And in

endodontic treatments, such as inter-appointment medication or root canal sealing, or as temporary medication for apexification in clinical dentistry[28-29]. The high alkaline pH of calcium hydroxide also can solubilize and release some growth factors from dentin, which are responsible for pulp repair[30]. Calcium hydroxide can also neutralize the lactic acid secreted by osteoclasts and prevent mineral tissue destruction[31]. A number of studies have demonstrated that Ca-releasing materials s promote osteoblastic differentiation[32-33]. Calcium hydroxide increase the recruitment, proliferation, cell migration, and mineralization of dental pulp stem cells[3]

Mineral Trioxide Aggregate: Mineral trioxide aggregate (MTA), is a bioactive inorganic compound, is a modified preparation of Portland cement, consisting of calcium silicate, calcium aluminate, calcium aluminoferrite, calcium sulfate, and bismuth oxide, has been clinically used for not only retrograde filling, vital pulp therapy, apicectomy, and apexification but also repair of accidental root perforations[35-36]. MTA causes limited pulp tissue necrosis shortly after its application. Thus, MTA seems less causative compared with calcium hydroxide, which is known to cause the formation of a necrotic layer along the material-pulp interface[37-38]. MTA induces osteoblastic differentiation using MC3T3-E1 cells, enhanced mineralization concomitant with alkaline phosphatase activity in a dose- and time dependent manner. MTA increased production of collagens (Type I and Type III) and matrix metallo proteinases (MMP-9 and MMP-13), suggesting that MTA affects bone matrix remodeling[39]. A number of studies suggests that MTA shows favorable biocompatibility and has physical properties suitable for dental application such as good sealing ability[40].

***Endosequence*® BC RRM™ (*Root Repair Material*):** Endosequence root repair material is composed of calcium silicates, monobasic calcium phosphate, zirconium oxide, tantalum oxide, proprietary fillers and thickening agents[41]. It's a bioceramic material, hydrophilic in nature, radiopaque, and a high pH, has been recommended for perforation repair, apical surgery, and pulp capping[42]. Bioceramic-based materials are able to form hydroxyapatite when in contact with moisture and ultimately form a bond between dentin and the filling material[43]. The setting reaction is a hydration reaction and contains monocalcium phosphate which is responsible for hydroxyapatite formation in situ[44-45]. Alanezi *et al*[46] compared ERRM with MTA (gray and white) using fibroblast cell culture from mice and evaluated cytotoxicity of these materials using the 3-(4,5-dimethylthiazol-2-yl)-2,5- diphenyl tetrazolium bromide (MTT) assay. The results of their study showed that ERRM had similar cytotoxicity.

Biodentine*:* Biodentine is similar to MTA, Biodentine has been shown to release calcium hydroxide, induce reparative dentin synthesis, and have antibacterial activity[47]. Biodentine is composed of the powder consisting of tricalcium silicate, dicalcium silicate, calcium carbonate and oxide filler, iron oxide shade, and zirconium oxide. Tricalcium silicate and dicalcium silicate are indicated as main and second core materials, respectively, whereas zirconium oxide serves as a radiopacifier. The liquid, on the other hand, contains calcium chloride as an accelerator and a hydrosoluble polymer that serves as a water reducing agent[48]. Biodentine is a tricalcium silicate-based cement that releases Ca(OH)2 as a by-product of hydration[49]. Therefore, it is believed that the mechanism of action of Biodentine is similar to that of $Ca(OH)_2$[50] Biodentine induces differentiation of odontoblast-like cells and stimulates mineralization of murine pulp cells. Biodentine is considered a suitable pulp capping material[51.] Biodentine also increases expression of transforming growth factor-beta 1 (TGF-b1) expression in human pulp cells and induces mineralization foci in a human tooth culture model[52]

Bioaggregate: 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, and calcium phosphate[53] Many in vitro studies have shown that BioAggregate exhibits potent antimicrobial action, excellent biocompatibility, and significant induction of bone and periodontal regeneration[54-56]. BioAggregate all have excellent sealing ability, which prevents microleakage and pulpal inflammation and thus provides a predictable barrier. BioAggregate is nontoxic to osteoblasts and human periodontal ligament fibroblasts and is able to induce mineralization and odontoblastic differentiation-associated gene expression in human dental pulp cells[57]. Bioaggregate stimulated odontoblastic differentiation and mineralization nodule formation thus this materials could be useful for regenerative endodontic procedure[58]

Calcium–Enriched Mixture Cement*:* Calcium–enriched mixture CEM cement is also called new endodontic cement NEC and was introduced by Asgary. It consists of calcium oxide, silica, and bismuth oxide as the major ingredients This cement releases both calcium and phosphorus ions leading to hydroxyapatite formation. It is composed of calcium oxide, calcium phosphate, calcium carbonate, calcium silicate, calcium sulfate, and calcium chloride and has been used for vital pulp therapy, apexogenesis, pulp capping, perforation repair, Root end filling material and Obturating material[59]. The biological mechanism by which CEM cement stimulates hard tissue formation is thought to be the result of several properties, i.e. sealing ability, biocompatibility, high alkalinity, antibacterial effect, hydroxyapatite formation, and similarity to dentine. The biocompatibility of CEM has been associated with its ability to release calcium ions during setting, and the subsequent binding of calcium with phosphorus to form hydroxyapatite crystals[60]. Recent direct pulp capping outcomes in prospective randomized controlled/clinical trials carried out on permanent teeth planned for orthodontic extraction have shown that under immune histochemical examinations, the thickness of dentinal bridge beneath CEM was higher than MTA at various time intervals and pulp inflammation was also lower in the CEM groups[61]

Theracal[62]*:* It is a light-cured, resin-modified calcium silicate–filled liner insulating and protecting the 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, indicated for use as liner under composite restorations aiming to achieve a bond between the different layers of materials, thus reducing microleakage. Theracal LC is a resin-modified Portland cement–based material that has demonstrated release of more calcium than ProRoot MTA and Dycal and thus was able to alkalinize the surrounding fluid. TheraCal displayed higher calcium releasing ability and lower solubility than either ProRoot MTA or Dycal. The capability of TheraCal to be

cured to a depth of 1.7 mm may avoid the risk of untimely dissolution. These properties offer major advantages in direct pulp-capping treatment The ability of TheraCal to provide free calcium ions could favour the formation of apatite and induce the differentiation of odontoblasts with the formation of new dentine

Ceramirs: It is a calcium aluminate cement used as a luting agent It works on the principle of two cements: calcium aluminate and glass ionomer cement. This cement 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 alumina Crown[63]. In physiological phosphate buffered saline solutions, hydroxyapatite (HA) is formed. This formation of hydroxyapatite, which appears after about 7 days, demonstrates that the cement possesses dynamic self-sealing properties[64].

Calcium phosphate: Calcium phosphate materials are similar to bone in composition and in having bioactive and osteoconductive properties[65]. It has properties such as good biocompatibility, superior compressive strength, and its transformation into hydroxyapatite over time. It induces bridge formation with no superficial tissue necrosis and significant absence of pulpal inflammation[66.]

Activa[tm] Bioactive[67]: Activa bioactive dual cure products are the first dental resins that mimic the physical and chemical properties of teeth. It contains: Bioactive ionic resin matrix, Shock-absorbing rubberized resin component, Reactive ionomer glass fillers. According manufacture there is greater release and recharge of calcium, phosphate and fluoride than glass ionomer. ACTIVA responds to pH cycles and plays an active role in maintaining oral health with release and recharge of significant amounts of calcium, phosphate and fluoride. These mineral components stimulate formation of a protective/connective apatite layer and a natural bonded-seal at the material-tooth interface.

Tetra calcium phosphate (TTCP): It can be used for biomedical purpose as it contains bioresorbable polylactide 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[68]. TTCP proves to be biocompatible and possessed osteoconductive properties[69]

Bioresorbable Biomaterials: The term bioresorbable/biodegradation is loosely associated with materials that could be broken down by nature either through hydrolytic mechanisms without the help of enzymes and/or enzymatic mechanism. Other terms such as absorbable, erodible, and resorbable have also been used in the literature to indicate biodegradation. Interest in biodegradable polymeric biomaterials for biomedical engineering use has increased dramatically during the past decade. This is because this class of biomaterials has two major advantages that non-biodegradable biomaterials do not have. First, they do not elicit permanent chronic foreign-body reactions due to the fact that they are gradually absorbed by the human body and do not permanently leave traces of residual in the implantation sites. Second, some of them have recently been found to be able to regenerate tissues, so-called tissue engineering, through the interaction of their biodegradation with immunologic cells like macrophages. Hence, surgical implants made from biodegradable biomaterials could be used as a temporary scaffold for tissue regeneration. This approach toward the reconstruction of injured, diseased, or aged tissues is one of the most promising fields in the 21st century. While aromatic polyesters are almost totally resistant to microbial attack, most aliphatic polyesters are biodegradable due to their potentially hydrolysable ester bonds: Naturally Produced: Polyhydroxyalkanoates like the poly-3-hydroxybutyrate (PHB), polyhydroxyvalerate & polyhydroxyhexanoate; Renewable Resource: Polylactic acid; Synthetic: Polybutylene succinate, polycaprolactone, Polyanhydrides, Polyvinyl alcohol, Most of the starch derivatives, Cellulose esters like cellulose, acetate and nitrocellulose and their derivatives (celluloid) are recently used[70]. During the first decade of the twenty-first century, the concepts of bioactive materials and resorbable materials have converged; bioactive materials are being made resorbable and resorbable polymers are being made bioactive

CONCLUSION

Biomaterial is used to make devices to replace a part or a function of the body in a safe, reliable, economic, and physiologically acceptable manner[71]. The current use of biomaterial in dentistry is studied with cell and gene activating material which are being incorporated into dentistry, pulp regeneration and stem cell technology is new area of interest, new horizons with regard to use of biomaterial on dentistry are being explored.

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