BIOCOMPOSITES AND ITS APPLICATIONS AS DENTAL RESTORATIVE MATERIAL: A REVIEW

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ABSTRACT

Objective-The main goal of this review is to provide a detailed and comprehensive description of the previously published work regarding different dental restorative materials. Some conventional to recent materials used in dentistry are addressed, underlining their advantages and drawbacks. Results-Composites are mainly preferred now-a-days in dentistry to restore/replace damaged or missing teeth, due to their enhanced mechanical, tribological properties and esthetics. As the restorative material must withstand mechanical forces as a result of biting and chewing action, a greater focus is to be put on optimizing the mechanical properties of restorative material. Different composites are compared based on their mechanical properties like flexural strength, microhardness, compressive strengths, wear and tensile strengths etc. Significance- There is no unique material capable of fulfilling of every patient. Although composites of different material combination for achieving even better properties remains understudied and further work is required to come up with better options in dentistry.

Keywords: composites, restorative material, flexural strength, esthetics, microhardness.

1. INTRODUCTION

Numerous bacteria are present in mouth, which cause decay. Care is to be taken regarding oral hygiene. From decades we are dealing with the tooth decay problem by using various materials and methods. Nowadays composites are emerging as one of the solutions to this problem.

Biomaterials- these are the materials, be it natural or synthetic, alive or lifeless, and usually made up of multiple components that interact with biological systems. Biomaterials are often used in medical applications to augment or replace a natural function. Some of the biomaterials are alumina, zirconia, titanium, tantalum, cobalt, ploylactic acid and hydroxyapetite. When two or more biomaterials unite they form a new class of biocomposites.

Biocomposites have emerged over past twenty years along with the development of biotechnology. Composites consist of organic and inorganic materials as fillers and matrix [1]. They are further classified as polymer, ceramic and metal composites. Composites are new class of biomaterials with enhanced properties than single material used alone [2]. Biomaterial mimics the original tissues of body both in structure and properties and thus they are able to withstand high biting force and harsh environmental conditions of mouth [3]. Biomaterials prove to be promising in not only in dentistry but also in tissue engineering, scaffold usage applications, bone regeneration, etc. In dentistry it is used for dentin, enamel substitute, alveolar bone, esthetic applications, etc.

1.1 Biomaterials

A biomaterial is a term used to indicate material that constitute parts of medical implants, extracorporeal devices and disposables that have been utilized in medicine, surgery, dentistry, veterinary medicine as well as in every aspect of patient health care.

Biocompatibility is another term associated with biomaterials. It is the ability of material to perform with an appropriate host response in a specific application. Different applications of biomaterials are briefly described in the Figure-1.

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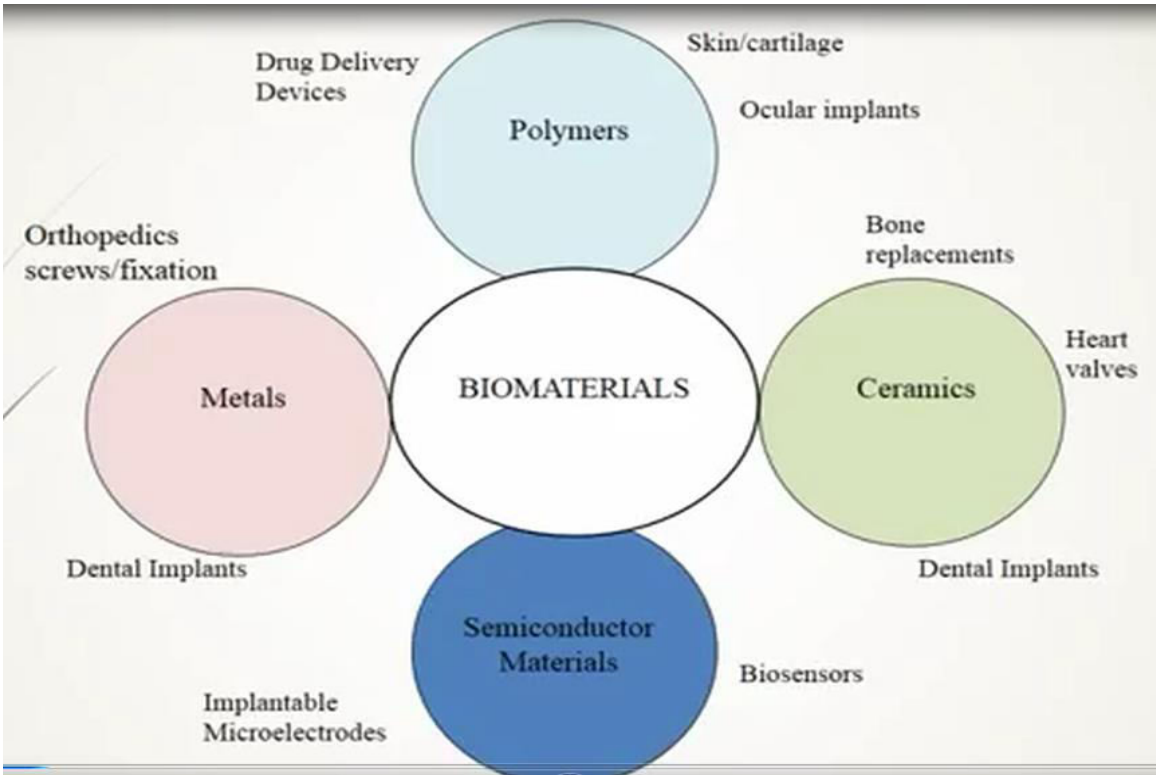

Figure-1. Biomaterials and its various applications.

2. MATERIALS

2.1 Hydroxyapetite

Hydroxyapatite (HA) is a type of calcium phosphate which shows similar properties to that of human bones and human hard tissues, it shows hexagonal structure and Hydroxyapatite has got Ca/P ratio of 1.67. Taking into account physiological conditions like temperature, pH, composition of body fluids of human body, Hydroxyapatiteis the most thermodynamically stable and suitable for body. As compared to other calcium phosphates, Hydroxyapatite is most convenient calcium phosphate group of inorganic compounds. [4, 6]

Human Bones and teeth are naturally composed of Hydroxyapatite. Amongst many biomaterials Hydroxyapatite is used as artificial substitute for parts of body because it exhibits similar crystal structure, size and chemical composition with human bones and hard tissue. Bones and teeth are largely composed of a form of this mineral. Some of its outstanding properties are: Biocompatibility, Bioactivity, Osteoconductivity, non-toxicity and non-inflammatory nature. [5]

Medical use: Titanium and stainless steel are widely used for making implants. But there are chances of rejection of these implants. To deals with this problem scientists have done a trick. They covered these implants with hydroxyapatite coatings so the human body gets tricked. Hydroxyapatite, in the form of powder, blocks is placed to fill the voids or cure the bone defects. Hydroxyapatite has got excellent property of bioactivity. This means Hydroxyapatite helps in faster growth of bones. It is seen that after using Hydroxyapatite, the tissue healing time is reduced.

Oral care use:

a) Composition of Enamel is 97 wt. % nano-hydroxyapatite and 3 wt. % organic material and water.

b) Composition of dentin is nano-hydroxyapatite represents 70wt. %.

c) It shows Hydroxyapatite is the main component of Enamel and Dentin. Synthetic Hydroxyapatite is used in enamel repair conditions. Also Hydroxyapatite is used in toothpastes for restoration of demineralized enamel. A brief description of Hydroxyapetite is given in Table-1.

Hydroxyapetite (HA) is one of the ceramics which is best suited for dentistry, bone surgery, and as an implantation material. Many researchers have proved that Hydroxyapatite shows good mechanical properties, chemical stability and thermal stability. Also crack resistance can be improved by adding zirconia phase to it [20].

Table-1. IUPAC description of hydroxyapatite [4].

IUPAC Name	Pentacalcium hydroxide triphosphate
CAS number	12167-74-7
EC number	235-330-6
Synonyms	Hydroxyapatite (CAS n. 1306-06-5), Hydroxyapatite, Calcium Hydroxyapatite
Chemical formula	$Ca_{10}(PO_4)_6(OH)_2$
Molecular Weight	1004.6 g/mol

2.2 Zirconia

In early decadesof twentieth century, zirconia as a ceramic material was introduced as an implant material used for dental surgery. Advantages of zirconia is that it is a biocompatible with oral cavity tissues, it has got very good mechanical properties, ease of machining. They possess high strength, hardness, wear resistance, and fracture toughness [7].

2.3 Alumina

Alumina has been widely for fabrication of dental implants, endodontic brackets, crowns, bridges. The ceramic compounds have high purity, high density and finer microstructure which make it a good material for dentistry [8].

2.4 Composites

When two or more chemically different constituents combine macroscopically to yield a useful material, they form composite. Composites are gaining large popularity in dentistry because they possess combined enhanced properties of both constituents. Some of the currently used dental composites are silica- zirconia composite, hydroxyapetite- polylactic acid (HA-PLA) composite, alumina-zirconia composites. These composites are less susceptible to low temperature degradation due to biological fluids [9].

3. MECHANICAL PROPERTIES

An extensive literature survey was conducted on past additive manufacturing techniques. Use of 3D printing technology for producing ceramic implants was taken into study. The main findings of the review paper are given in the Figure-2. Some applications and main mechanical properties of some restorative materials are given in it [7].

Mohammad Reza Khosravani performed a research work, in which 3 different types of restorative materials were taken for study viz. QuiXfil, Filtek^{TM} Z250 and Filtek^{TM} Z350. Compressive tests were performed under static and dynamic loading conditions. At the same force, the composite Filltek^{TM} showed highest strength. And overall static loading conditions have higher compressive strength as compared to dynamic loading conditions. And also, the study showed that dynamic loading gives smoother surface [10].

Biocomposites, are recently used as substitutional materials for enamel and dentin structure in tooth over conventional resin composites. (Bis-GMA) bis phenol Aglycidal methacrylate monomer consisting of organic matrix and other base monomers such as triethylene glycol dimethacrylate (TEGDMA), urethane dimethacrylate (UDMA), ethoxylated bisphenol-A-dimethacrylate (Bis-EMA), decanediol dimethacrylate, bis (methacryloyloxymethyl) tricyclodecane, and urethane tetramethacrylate (UTMA) are most commercially used dental composites [16].

To overcome the lack of mechanical properties and polymerizing shrinkage, modern dental resin composite systems contain Fillers such as quartz, colloidal silica, and silica glass containing barium, strontium, and zirconium. These Fillers increase strength and modulus of elasticity and reduce polymerization shrinkage, the coefficient of thermal expansion, and water absorption. Along with the nanotechnology development, nanoparticles were introduced in dental resin composites due to the high loading capability and ion releasing potential [17].

(BisGMA) bis phenol Aglycidal methacrylate /triethylene glycol dimethacrylate (TEGDMA) are mostly used matrix material for dental composites. A study was done on BisGMA/TEGDMA dental composite with Hydroxyapatite reinforcement along with the silica filler material. Two types of samples were prepared. One with small fraction of hydroxyapatite fibre impregnated into BisGMA/TEGDMA resins (upto 3% and other with somewhat larger fraction of Hydroxyapatite (5-10%). Results obtained were that samples with lower mass fraction of Hydroxyapatite showed enhancement in biaxial flexural strength and other mechanical properties whereas larger mass fraction composite showed reduction in mechanical properties. The main reason behind this was assumed to be the amount of dispersion of Hydroxyapatite fibres into the matrix.

Material	Main features	Main applications
Zirconia- based ceramics ZrO_2	- Modulus of elasticity: 100–250 GPa - Flexural strength: 177–1000 MPa - Fracture toughness: 1-8 $MPa.m^{1/2}$ - Hardness: 5–15 GPa - Tensile strength: 115–711 MPa	- Implants - Orthodontic brackets - Abutments - Copings - Crowns - Bridges
Alumina - based ceramics Al_2O_3	- Modulus of elasticity: 380 GPa - Flexural strength: 500 MPa - Fracture toughness: 3.5 - 4 $MPa.m^{1/2}$ - Hardness: 22 GPa - Tensile strength: 267 MPa	- Implants - Endodontic posts - Orthodontic brackets - Abutments - Crowns - Bridges - Filler for dental composites and bone cement materials
Leucite –based ceramics	- Modulus of elasticity: 65–67 GPa - Flexural strength: 55-134 MPa - Fracture toughness: 0.8–1.3 $MPa.m^{1/2}$ - Hardness: 5.3–7.9 GPa	- Metal-ceramic restorations
Lithium disilicate glass-ceramic $Li_2Si_2O_5$	- Modulus of elasticity: 90–100 GPa - Flexural strength: 250–365 MPa - Fracture toughness: 2-3.5 $MPa.m^{1/2}$	- Crowns - Bridges - Veneers - Inlay/onlay
Mica based ceramics	- Modulus of elasticity: 48–164 GPa - Flexural strength: 140–160 MPa - Fracture toughness: 0.6–2.2 $MPa.m^{1/2}$ - Microhardness: 3.2–4.5 GPa	- Ceramic restorations

Figure-2. Main mechanical properties of most common biomedical grade ceramic materials [7].

3.1 Flexural Strength

Five different materials (5 sample each) were taken; then compressive flexural strength was measured experimentally (UTM) and micro hardness test (vickers micro hardness tester) and then ANOVA was performed to find which material is better optimum. One of the composites showed higher compressive, flexural strength and hardness as compared to other. One type of composited showed minimum values. The reason behind this variation in results of properties was found to be composition of composites (filler composition in the matrix), shape, size and percentage volume of the filler material. [12].

Five different composite samples were prepared and on them compressive and flexural strength was measured. UTM was used for both of these tests 3mm/min speed force was applied. The mechanical properties, Compressive strength, Hardness, Flexural strength, Elastic modulus is directly proportional to amount of inorganic filler material and polymerization shrinkage decreases as the amount of inorganic filler increases. Thus higher filler percentage and lower particle size of filler material is recommended for improved mechanical properties [14].

3.2 Fracture Resistance

Fracture resistance of microhybrid, fibre reinforces and nanohybrid was compared. All samples were subjected of compressive axial loading in UTM at spindle speed 5mm/min. 60 samples per group of composite were used. The force at which tooth fractured was calculated as fracture resistance. Statistical analysis was perfomed using ANOVA (Analysis of variance technique) and results were obtained. Amongst these three restorative composites, fibre reinforced composite showed greater fracture toughness values as compared to other two restorative materials [15].

3.3 Compressive Strength

Amalgam, dental ceramic, gold alloy, dental resin, zirconia, Ti alloy were taken; (4 samples each) and different mechanical properties of these material were compared to those with enamel and dentin. Secondly which among the above material [dental restorative material] are suitable for clinical treatments was found out. Samples were prepared and were compressed in UTM at constant speed of 0.1mm/min. Maximum stress, Maximum strain, elastic modulus, hardness was measured and compared. Whose properties are near to natural material. i.e. enamel and dentin was studied and found out. One of the most important results found out were that Abrasion resistance of restorative materials should be less that enamel and mechanical properties like maximum stress and strain, elastic modulus, hardness values should be greater than Dentin [13]. A brief comparison of mechanical properties of different composites is given in Table-2.

Table-2. Comparison of mechanical properties of different dental restorative materials [13].

Materials	Maximum stress (MPa)	Maximum strain (%)	Vickers hardness values (HV)
Enamel	62.2 ± 23.8	4.5 ± 0.8	274.8 ± 18.1
Dentin	193.7 ± 30.6	11.9 ± 0.1	65.6 ± 3.9
Amalgam	115.0 ± 40.6	7.8 ± 0.5	90
Dental ceramic	55.0 ± 24.8	4.0 ± 0.1	420
Gold alloy	291.2 ± 45.3	12.7 ± 0.8	130-135
Dental resin	274.6 ± 52.2	32.8 ± 0.5	86.3 -124.2
Zirconia	2206.0 ± 522.9	63.5 ± 14.0	1250
Titanium alloy	953.4 ± 132.1	45.3 ± 7.4	349

3.4 Wear Properties

There is always an impact of biting and chewing action on teeth. This induces stress in restorative material. Therefore, wear analysis is a major concern for dentists. Three different composites samples were taken for study. By varying some parameters like speed, sliding distance and load experiments were performed. Wear analysis of these samples were examined. The main finding of the experiment conducted by Sovitkar was that wear resistance of composites increases by reinforcing inorganic fibers to the matrix [18].

Comparative study of commercially available composites showed that wear resistance of fibre reinforced composites is greater than usual monophasic restorative materials. Abrasive action of teeth and mastication process causes wear of restorative material used to fill the cavity in the teeth [19].

4. BIOLOGICAL PROPERTIES

Powder sintering of Y-TZP (yttria-tetragonal zirconia polycrystals) was done on aluminium- iron-zirconia composite. The invitro testing of the composite was done on lab rats. The implant was kept in mouth cavity of rat. Results of this study were, it showed shown that the tested samples tend to be surrounded by fibrous connective tissue. And thus, it proved to be biocompatible [11].

Biological properties mainly include Bioactivity, Biodegradability, Biocompatibility, etc. These are crucial properties, which are to be given great importance while selecting any dental restorative material or implant material. Composites of poly lactic acid-Hydroxyapatite (PLA-HA) show great biocompatibility, bioactivity and biodegradability. Samples with varying weight %, ratio of HA-PLA were taken. In-vitro study was done and crystal structure and morphology of samples were analyzed using X-ray diffract meter (XRD) and scanning e-microscope (SEM) which shows that HA-PLA has the ablity to generate new connective tissues which make it a widely used biomaterial in dentistry. HA-PLA forms a widely used class of polymer organic ceramic composite, which helps in bone regeneration [21].

5. CONCLUSIONS

There are many material including composites which are used in dentistry as restorative materials. Earlier Amalgam, Zinc oxide, Dental ionomer were used. But nowadays composites are mainly used. Considering state of the art, composites have gained popularity due to its extraordinary enhancement in mechanical properties. Hydroxyapatite is also being used to a greater extent as a reinforcing material in composites. Advantages of Hydroxyapatite are biocompatibility, bioactivity, and non-inflammatory nature. It mimics the natural property of human tissues which helps in growing new connective tissues faster. In future attempts are to be made to develop a new material which will have properties very near to the enamel and dentin along with the enhanced mechanical properties like wear, compressive strength, hardness, scratch resistance which are generally taken into consideration while dealing with dental application of restorative materials.

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