STM JOURNALS

Journal of
Polymer & Composites

ISSN: 2321-2810 (Online)
ISSN: 2321-8525 (Print)
Volume 11, Special Issue 8, 2023
DOI (Journal): 10.37591/JoPC

http://engineeringjournals.stmjournals.in/index.php/JoPC/index

Review JoPC

Biomaterials and its Role in Dentistry–A Review

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Abstract

Increasing success through modern techniques in implantology brought a new transformation in dentistry field to successfully replace missing teeth. To inflate the success rate, regular and continuous attempts are done to improve the materials, techniques for comprehensive understanding of implant behavior to the biological system. Biomaterials used for implants and brought in contact with the biological environment play the most symbolic role in the success of treatment modality. This has led for innovation/invention of new biomaterials. Efforts made by people through research studies have given rise to new biomaterials used in manufacturing of dental implants. In recent years, various biomaterials constructed and are surface modified to obtain better results. Therefore, it is the primary task of the dentist/clinician to look at all available information regarding the implant biomaterials for careful selection and use in implant dentistry.

Keywords: Biomaterials, Dentistry, Mechanical properties, Implant, Osseointegration

INTRODUCTION

Humans in spite of lack of understanding regarding the interaction mechanisms between biological environments and materials has been using appliances for dental application proposes for thousands of years [1]. Based on geographical location, the technological advancement level and population customs, these dental appliances would be a purely aesthetic or more fully in a practical function [2]. Researchers in recent years mainly focus on developments occurred in the medical fields covering the medical practices and surgical aspects [3].

Human desire to get lost teeth replaced is not modern, and is one oldest practice in dental implant surgery. Dental implants usage goes back to centuries ago and many scientists and researchers have made attempts in various ways to restore the missing teeth and obtain comfortable masticatory function and facial esthetics [4]. Before the era of osseointegration, different dental implants with distinct designs were adopted to support dentures. In these days dental implants has become one of the important and indispensable part in field of dentistry. Globally the market for dental implant is growingly constantly and it is expected steadily in future coming years. Past 25 years brought a significant light for innovation in the field of dental implantology and the new results were discovered and published [5]. Through advances in material sciences, research, manufacturing processes and clinical studies made the usage of dental implants an essential part of contemporary restorative dentistry.

With advent of new biomaterials, the broad definitions on "Biomaterial" defined among the years and are redefined among the years based on its intended functions. Rapid development in technology of biomaterial was seen evolution of 20th century. Biomaterials still find their extensive

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Received Date: July 24, 2023
Accepted Date: October 19, 2023
Published Date: February 23, 2024

Citation: B. Vadiraj, Pothamsetty Kasi V. Rao, K. Kiran Kumar. Biomaterials and its Role in Dentistry–A Review. Journal of Polymer & Composites. 2023; 11(Special Issue 8): S339–S352.

usage in applications of Dental, Medical and Biotechnology at turn of 21st century [6]. Biomaterials in dentistry used in implantology are materials that replace or augment any tissue and thereby facilitating the function of natural biological tissue. Biomaterials selected should have ideal mechanical, biological, chemical and physical properties [7]. Also, these biomaterials should be biocompatible and must function well when mechanical forces are applied. Therefore, it is clear that, there is a further need in continuation of innovation for implant biomaterials that actively stimulates the formation of bone and accelerating the process of osseointegration.

BIOMATERIALS CLASSIFICATION

Understanding of biomaterials for dental applications has widened the knowledge due to its potentiality in engineering biomechanics. As time changed, there is a redirection in terms of introduction and refocusing on fresh innovations. Biomaterials is science in field of materials evolved from knowledge material structure. Biological tissue response towards mechanical implant depends on the surface property of biomaterial and the compatible nature of the biological environment. As human body is highly dynamic in nature and its properties changes from time to time, there is no widely accepted concept that has been established yet between the mechanical and physicochemical properties with regard to body nature and the artificial structure [8]. Biomaterials and Natural products (derived from animals and plants) are the two major research areas, which indeed can improve the physicochemical and mechanical properties of the biomaterials used in dental applications. In this way the aspects namely biology, medicine, chemistry, material science and tissue engineering are included. Demand over last decade has significantly increased for products possessing biodegradable, biocompatible and bioresorbable qualities [9].

Classification of biomaterials is made in two ways based on its use in fabrication of dental implants. Chemically grouped into: (i) Metals, (ii) Ceramics (iii) Polymers and (iv) Natural products (both animal and plant). Figure 1 shows the Biomaterial classification. Natural biomaterials considered for use are those which are been derived from animal or plant sources. Interest is rapidly emerging in natural products and is witnessed as source that can be adapted for production of medicine and treatments, at the same time use of these natural products are trending as pharmaceuticals [10].

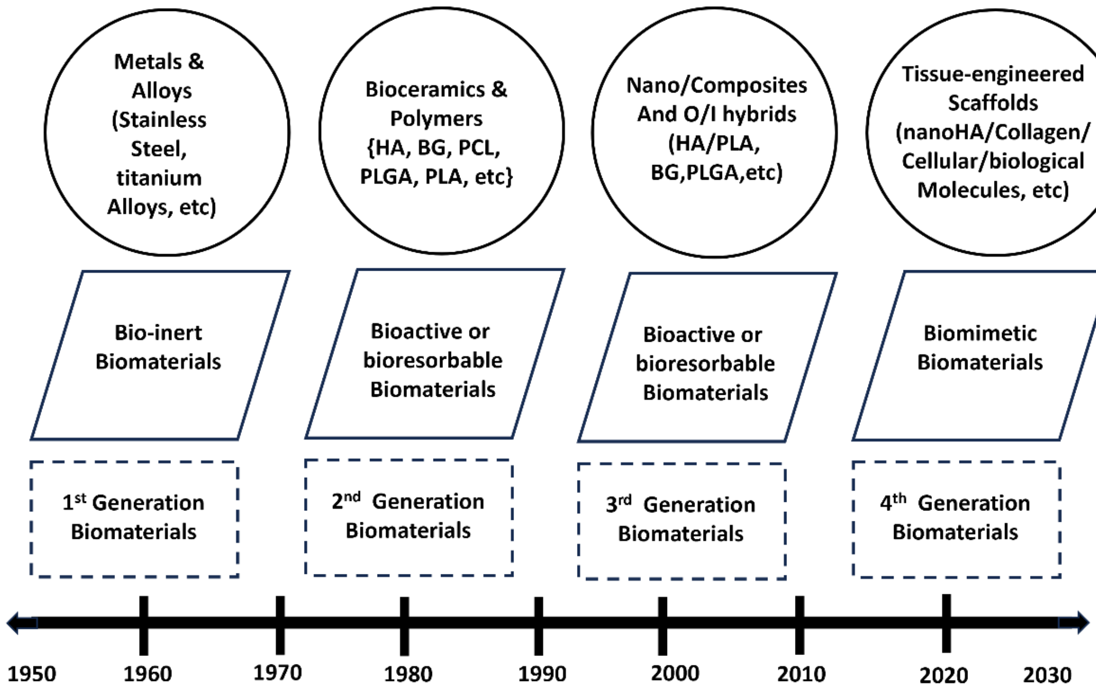

Figure 1. Biomaterial classification [10].

ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

On biocompatibility view point, categorized into: (i) Biotolerant, (ii) Bioinert, (iii) Bioactive, (iv) Biodegradable. Figure 2 shows the Biomaterial classification and response to surrounding structure

Biotolerant materials when implanted in biological living tissue forms a capsule surrounding it by fibrous layers and is as seen in Figure 2(a). Bioinert materials accelerate the growth of new bone on to the surface by close apposition (contact osteogenesis) and is seen in Figure 2(b). Bioactive materials have the phenomenon of ion exchange with its surrounding tissue thereby leading to a chemical bonding and development of new bone around it (bonding osteogenesis) and is as seen in Figure 2(c). Biodegradable materials dissolve themselves when implanted, by coming in contact with the fluids and is as seen in Figure 2(d). Such materials are mostly used for medical goods like tissues in growth materials [11]. There is no material that is completely accepted by the biological system due to its levels of biocompatibility. So, to optimize biologic performance and to minimize the negative biologic response artificial structures should be selected for adequate functioning.

Metals

Previously in the past, various metals and its constituent alloys were considered in implant manufacturing. But, showed an adverse reaction with the biological tissues thereby reducing their success rate and making them to be minimally used in long-term applications. Biomechanical properties, manufacturing processes and previous experiences are some of the vital factors to be considered in Dental implants.

Titanium

Around 1981 since introduction to titanium alloys, there has been increase in the use of implants in dentistry for the purpose of restoring lost teeth in patients [12]. Magnificent nature of biocompatibility with bone-contact has made its extensive use in biomedical field and also complications associated with failures are rare [13]. The strength of titanium alloys can be enhanced by heat treatment. Various surface modification procedures for dental implants such as like machining, plasma spraying etc, can be used to improve and accelerate osseointegration [14].

Titanium used in field of dentistry for fabrication of implants has six different types. Commercially pure titanium (CpTi) is the first type. According to the purity and the processing oxygen content [15] it is graded and numbered from 1 to 4. The grades differ in ductility and strength, corrosion resistance and oxygen content. Grade 4 CpTi has highest oxygen content of around 0.4%. [16]. The other two titanium alloys are Ti-6AI-4V and TI-6AI-4V-ELI. Table 1 show the data on grades, composition of titanium and its alloys.

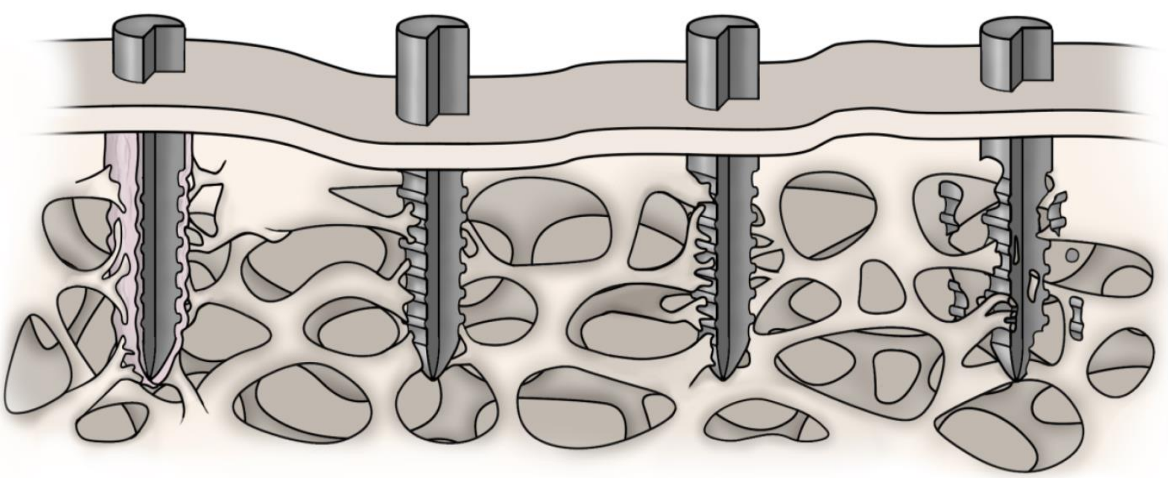

Figure 2. Biomaterial classification representation and its response to surrounding structure [11].

Table 1. Data on grades, composition of titanium and its alloys [17].

Material	O (wt%)	C (wt%)	Fe (wt%)	H (wt%)	N (wt%)	Al (wt%)	V (wt%)	Ti (wt%)
CpTi, grade I	0.18	0.1	0.02	0.015	0.03	-	-	Balance
CpTi, grade II	0.25	0.1	0.03	0.015	0.03	-	-	Balance
CpTi, grade III	0.35	0.1	0.03	0.015	0.03	-	-	Balance
CpTi, grade IV	0.4	0.1	0.05	0.015	0.03	-	-	Balance
Ti-6Al-4V	0.2	0.08	0.3	0.015	0.05	5.50–6.75	3.50–4.50	Balance
Ti-6Al-4V (ELI)	0.13	0.08	0.1	0.012	0.05	5.50–6.50	3.50–4.50	Balance

Table 2. Mechanical properties of human bones and titanium alloys [20]

	Material	Yield strength (MPa)	UTS (MPa)	E (GPa)
Human Bone	Cortical bone	30−70	194−195	5−23
	Cancellous bone	–	0.9−8.80	0.01−1.57
α microstructure	Cp Ti (grade 1)	170	240	115
	Cp Ti (grade 2)	275	344	105
	Cp Ti (grade 3)	380	450	115
	Cp Ti (grade 4)	480	550	105
α+β microstructure	Ti-3Al-2.5V	585	690	100
	Ti-6Al-7Nb	921	1024	105
	Ti-5Al-2.5Fe	914	1033	110
	Ti-6Al-4V (annealed)	825–869	895–930	110–114
β microstructure	Ti-12Mo-6Zr-2Fe	1000–1060	1060–1100	74–85
	Ti-(10–80) Nb	760–930	900–1030	65–93
	Ti-15Mo-5Zr-3Al 870	870–968	882–975	75
	Ti-16Nb-10Hf	730–740	740–850	81
	Ti-15Mo-2.8Nb-3Al	771	812	82
	Ti-13Nb-13Zr	900	1030	79
	Ti-15Mo	544	874	78
	Ti-24Nb-0.5O	665	810	54
	Ti-24Nb-0.5N	665	665	43
	Ti-29Nb-13Ta-4.6Zr	368	593	65
	Ti-23Nb-0.7Ta-2Zr	280	400	55
	TI-36Nb-2Ta-3Zr-0.3O	670–1150	835–1180	32
	Ti-23Nb-0.7Ta-2Zr-1.2O	830	880	60
	Ti-35Nb-5Ta-7Zr	530	590	55

Interest in usage of Titanium and its alloys for dental applications has increased due to its excellent properties. Previous investigations show that, titanium alloys such as Ti–Zr–Nb–Sn alloys prepared by Arc melting method was developed as Ni-free super-elastic alloys with large super-elastic recovery strain and excellent biocompatibility [18]. Titanium alloys with lower Young's modulus are receiving great attentions due to its potentiality to prevent stress shielding effect. This effect of stress shielding leads to problems such as, poor remodeling of bone. Commercially available pure Ti (CP Ti) is one of the metals that find difficult in processing mainly due to its high melting temperature, chemical reactivity and inherent failures during the casting process [19]. Titanium presents two phases α and β, the β phase can be obtained when alloyed with β stabilizers. β Ti alloys in recent days is generating new interest in research of biomedical materials due to its Young's moduli closer to that of bone tissue [20]. Table 2 show the Mechanical properties of human bones and titanium alloys.

Cobalt-Chromium-Molybdenum-based Alloys

The alloy is a composition of Cobalt 63%, Chromium 30%, and Molybdenum 5%, used in cast or cast and additionally annealed metallurgic states [21]. These alloys are adapted in development of dental implant with custom designs such as subperiosteal frames and partial dentures. Additions of elements like manganese, nickel, and carbon provide greater strength. But the alloy is not as corrosion resistant as titanium but superior in abrasion resistance [22]. While chromium contributes resistance to corrosion, molybdenum provides strength. Cobalt-based alloys are one of the least ductile among the implants in dentistry, when manufactured properly show excellent biocompatibility.

Earlier investigations reported that, Cobalt-based alloy specimens produced by Selective Laser Melting (SLM) technique were manufactured and a commercial Cobalt-Chromium-Molybdenum block was used for dental restorations which was sintered was used for comparison with the specimens produced by SLM are discussed to check the compatibility for dental applications [23]. In another study, Cobalt chrome molybdenum alloy properties and characteristics together with machinability under different machining conditions were assessed and machining trend are also adequately discussed. [24].

Iron-Chromium-Nickel-based alloys

Alloys of Stainless steel have a very long history of its use in surgical devices. Iron-Chromium-Nickel-based alloys is basically the austenitic steel or surgical steel and is the oldest one used in the field of medicine for dental and orthopedic devices. Main composition of this alloy is iron and chromium 18% and nickel 8% [25]. Alloy combinations with titanium systems exhibits high ductility and strength. These alloys are commonly used in development of stabilizer pins and mucosal insert systems. Steel alloys are most susceptible to biocorrosion and this nature makes its usage limited as a biomaterial. Among the available alloys for implants, this alloy is easily prone to pitting corrosion. Due to the presence of nickel, care has to be taken in usage and to retain its oxide surface condition and should be avoided for use to allergic patients. Another aspect of concern of iron-based alloys is galvanic corrosion due to its galvanic potentials they possess which may result in biocorrosion. These alloys when used properly can function well without any significant breakdown, which has been demonstrated from retrievals of Long-term devices [26].

It is been established that, among various alloys available currently for restorations in prosthodontics, nickel-chromium casting alloys are mostly used in dental applications for fabrication of bridges, crowns and partial dentures. Also, the corrosion behavior of this alloy when demonstrated in artificial saliva shown that the behavior depends on pH values. This alloy in combination with other elements shown good mechanical properties which makes its use in clinical applications [27]. In addition to above benefits, this alloy provides superior properties in metal-ceramic restoration, that is these alloys are fused to porcelain veneer put on to restoration. This application is known as porcelain-fused-to-metal (PFM) and is used for purposes of aesthetics. The superior properties involve, higher Young's modulus and hardness allowing decrease in restoration cross section thickness and provide more space for porcelain veneer along with appropriate strengths [28].

Precious Metals

Several precious metals have been used as biomaterial in dentistry for restoration and implant manufacturing. Precious metals like gold, platinum, tantalum, palladium, indium and alloys are used as biomaterial for dental implants [29]. For many years, gold was used as biomaterial because of its properties like good biocompatibility and corrosion resistance. Notably among these metals, gold and platinum are precluded due to low strength which limits implant design also high cost.

Studies suggest that, use of precious metals in alloy forms are more advantageous when compared to that be used in pure form, because the constituent present in the alloy influence and enhance the mechanical and physical properties [30]. The alloys have to be chosen on understanding of an alloy system, and the selection of alloys proven from quality manufacturers along with clinical situation requirement given. Most of the metals and its alloys such as gold, cobalt-chromium, stainless steel, are now obsolete within the oral implant industry. Regardless of any trends, use of precious alloys is safer in clinical practices provided with good oral health [31, 32].

Ceramics

Bio-ceramics are the biomaterials find its application in dentistry for producing of dental prostheses, used to restore missing or reconstruct damaged dental structures. Strength and Toughness improvements in bio-ceramics in implant prostheses will help in its regular physiological functions [33]. Bioinert bio-ceramics from alumina (Al_2O_3) and zirconia (ZrO_2) was developed initially, followed by bioactive ceramics. Several materials with good biocompatibility like hydroxyapatite, Calcium phosphates (CPs), dicalcium phosphate dehydrate, tricalcium phosphate are used as materials for bone replacement. Bioactive ceramics main function is to help in osteoconduction due to their inorganic phase (CP) [34].

Zirconium Oxide (ZrO_2)

Zirconium oxide (ZrO_2) application in dental prostheses has been since from 1995. Clinically, dental applications include frameworks for ceramic crowns, fixed partial dentures and abutments [35]. Fracture toughness resembling to steel and iron makes ZrO_2 in Biomedical fields like in hip replacement, biosensors, cancer treatment. Apart from high strength, wear resistance and other good mechanical properties ZrO_2 possesses minimal bacterial adhesion and low cytotoxicity. Due to all the above mentioned there is a significant increase in the number of ZrO_2 based biomaterial used in dental implantology. Evaluation of biocompatibility of ZrO_2 had made for adoption and development of ceramic based implants enhancing the process of osseointegration [36].

Few study articles suggests that the osteointegration process and biological behavior of the zirconia biomaterial can be enhanced by the state of art surface treatments like machining, acid etching, sandblasting, coating etc. [37]. Figure 3 the Zirconia surface treatments. Zirconia due to its compatibilities has gained popularity in reconstruction of hard tissue which includes dental and bone tissues. Responses of cells and tissues to zirconia and surface treatments to improve and enhance bioactivity has made zirconia to be used in manufacture of dental prostheses, implanted medical devices, scaffolds and other biocompatible devices [38].

Figure 3. Zirconia surface treatments [37].

Aluminium Oxide (Al_2O_3)

Al_2O_3 was introduced in 1970s and clinical applications at early stages showed a fracture rate as high as 13%. Ceramics have approximately 3 to 5 times strength to that of compact bone. Al_2O_3 as a biomaterial show good compatibility, excellent corrosion resistance, higher strength and wear resistance. Excellent biocompatibility and enhanced strength make ceramics a viable choice as a biomaterial for dental implant and also to develop implant with that vary in design. White hue of color of metallic oxide ceramics makes them viable option for implants in esthetic areas. Minimal reactivity with oral tissues along with low thermal and electrical conductivity are few notable benefits [39].

Studies showed that the in-vitro tests conducted on Alumina biomaterial to evaluate toxicity by cell culturing through extraction and direct contact methods confirmed highest cell growth of 93.05% with zero cytotoxicity [40]. Going a step further, now a days alumina as a ceramic biomaterial is gaining popularity as particle agent, used for surface modification of dental implants using acid-etching and sandblasting. This is done to develop rough surface thereby enhancing the growth of bone tissue and adhesion to the implant surfaces [41]. Investigations reported that nanoscale surface patterns with low aspect ratio influence the morphology and response of osteoblast-like cells [42].

Carbon and Carbon silicon compounds

Carbon is an element which exist and available in various forms. Carbon and carbon silicon compounds usage were first reported during 1970 in Implant Dentistry. Their nature of chemical inertness and absence of ductility has made Carbon and carbon silicon materials to regard as ceramics. Mechanical property such as elasticity is so resemblance to bone tissue making it to have good biocompatibility. Carbon and carbon silicon compounds do not suffer from fatigue compared to other materials, but its brittle nature, low tensile strength made its usage limited in major stress or load bearing zones [43]. Limitations and mismatches in biocompatibility and material properties, applications and design led to failure in clinical applications thereby resulting in withdrawal of these carbon-based biomaterials in design of dental implants.

Nevertheless, active research is ongoing on carbon and silicon compounds for use in biomedical applications. Few of the previous investigations have reported the challenges in usage of carbon and silicon in current research trends for application in dental treatments. Eco-friendly and renewable carbon-based nanomaterials (CBMs) possess extraordinary biological, chemical, and physical properties. Some of the CBMs are carbon nanotube (CNT), graphene (G), graphene quantum dots (GQD) etc. This CBMs having mechanical strength and high surface area had influenced its use in dental tissue engineering and other dental applications [44, 45]. Another study discussed about the utilization of CBMs in biomimetic dental implants for diabetes patients. Structural changes made adopting this CBMs enhanced osseointegration process and enabled antibacterial properties and immunomodulation [46]. Figure 4 shows biomimetic dental implants with CBMs for diabetes patients.

Polymers

Polymeric films (PMFs) and Polymeric material (PMs) use has been increasing in the field of dentistry for restorative and regenerative therapies. This attributed interest is not only due to the ease in processing, but also due to their excellent surfaces and their desired biological and mechanical properties. These properties they possess make them for tailor for a wide variety of biomedical applications. PMFs and PMs are specifically used in dental applications for their abilities in preventive, antimicrobial, corrosion prevention, friction reduction and drug delivery properties [47]. Figure. 5 shows the Polymeric materials and films application in dentistry.

Polyetheretherketone (PEEK) and Polyetherketoneketone (PEKK) are the new materials added to the family of polymers and are the well-known members of polyaryletherketone (PAEK) family. Production changes in polyketone-based materials had ensured consistent development of these polymers for biomedical applications.

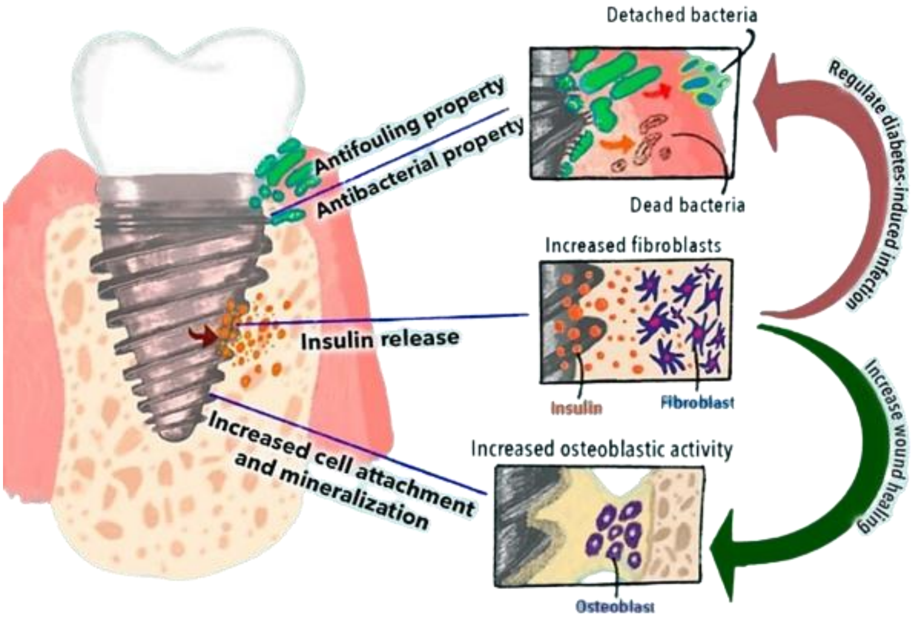

Figure 4. Biomimetic dental implants with CBMs for diabetes patients [46].

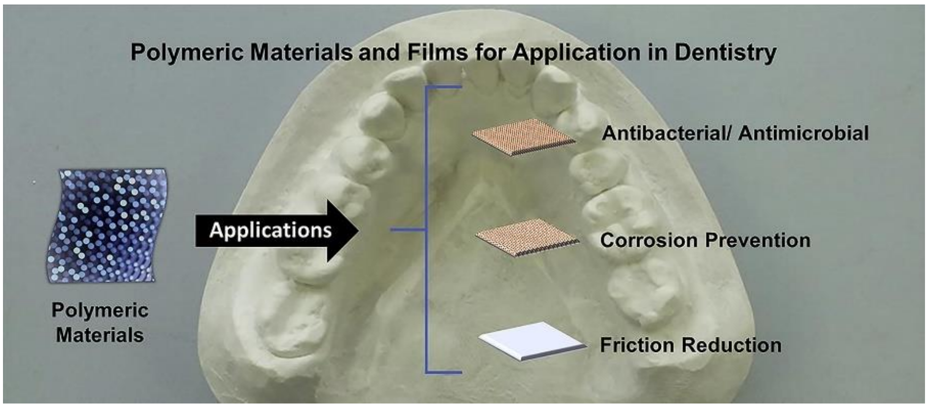

Figure 5. Polymeric materials and films application in dentistry [47].

History says that the PEEK availability arrived during the time of increased interest in manufacture of Isoelastic stems for hips and fixation of fracture plates. PEEK's elastic modulus is close to that of human bone, and its high strength and resilience makes it a desirable biomaterial in implantology [48]. Color of this material resembles to natural tooth which makes it aesthetic appearance considerably better than other materials and suit to patients who are allergic to titanium. PEEK offers qualities such as osseointegration, fracture resistance, shock cancellation, stress distribution which makes it as a biomaterial with increasing demand in market and surprisingly this has a high success rate. Application range of PEEK in dentistry involves as an implant biomaterial, abutment material, crowns, prosthetic material, post and core material, partial dentures [49].

In recent days PEKK is gaining interest and evolving as a new polymeric material. PEKK emerge as a leading polymer thermoplastic with high-performance, replacing many implant metal components due to its good mechanical strength and chemical resistance. Its excellent mechanical, physical, and chemical properties make it suitable to be used in oral prosthodontics and implantology applications. Good potentiality of PEKK have shown low stress shielding effect compared to that of titanium biomaterial for dental applications. PEKK wide application range in dentistry include, restorations, endoposts, crowns, denture frameworks, bridge, dental implants and fixed prosthesis [50]. Figure 6 show PEKK in Dental applications.

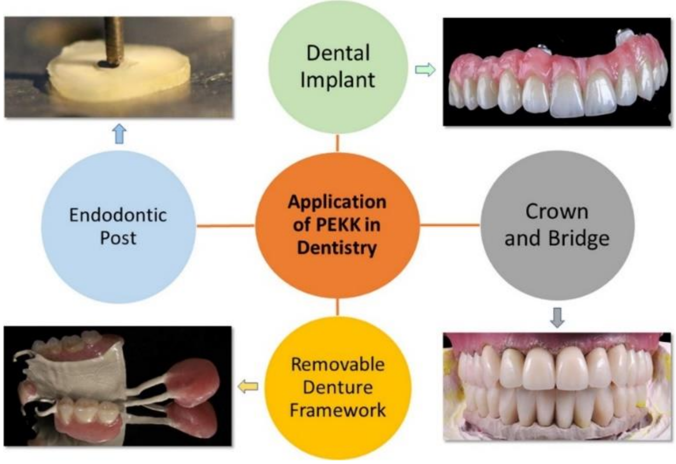

Figure 6. PEKK in Dental applications [50].

Despite of high price, the parts manufactured by these polymers offers lightweight and high strength. Increased research on these materials have fragmented in biomaterials and materials science. Ongoing research on PEEK and PEKK biomaterials show excellent compatibility with regard to bioactive materials which proves to be a great benefit to mankind in field of life sciences. With such magnificent application range these biomaterials provide all in one complete package for dental applications.

Coating for Dental Implants

Over last two decades, development in field of material science and biotechnology has led to the invention of biomedical materials that have been used in manufacturing of tissue replacement medical devices. Meanwhile focus of many researchers is on accelerating and improving the process of osseointegration, but the postoperative infection that occur after surgery cannot be overlooked because it is an important aspect which lead to complications after the process of implantation [51]. Usage of antibiotics is one common way to reduce and control the infection, but it is a challenge to treat the infections related to implants. This is due to the formation of a biofilm of bacteria on the surface of implant. Moreover, there exists an issue of microbial resistance, due to extended usage of antibiotics. Alternate methods such as modification for implant surfaces with use of coating decreases the bacterial activity and providing a good antibacterial effect [52]. Coating antibacterial ability gets weakened gradually due to release of antibacterial components and may affect the process of osseointegration.

Many coatings are introduced in implant dentistry to improve osseointegration. This includes utilization of both bioactive ceramics and bioinert ceramics. Coating to be applied depends on various factors like its nature such as porous or dense, thickness variation, method employed. Various methods to coat implants comprise of plasma spraying, sol-gel coating, spin coating, sputter-deposition, biomimetic precipitation or electrophoretic deposition [53, 54]. Figure 7 show Plasma spraying process, its variables and parameters. Since ancient times, various oxides namely Silver, Aluminium, Zirconium, copper, Titanium are well known antimicrobial agents for their excellent demonstration of antimicrobial properties. In these, Titanium dioxide (TiO_2) finds its potential application in field of dentistry because of its property of controlling and reducing the effect of bacterial activity. [55]

Existing previous studies suggest that Titania (TiO_2) coatings are one of the excellent remedies in disinfection of pathogens from surfaces. Also, TiO_2 coatings in dental metal implants showed good bio-corrosion resistance, biocompatibility, durability, new bone-generation capability, and antimicrobial efficiency [56]. An experimental study was conducted on animals to investigate effect of Titania (TiO_2) coated on to implants that were sandblasted, acid etched (SLA) to determine stability of implant. In this experiment, 24 implants were used and placed on six rabbits for four weeks. Histological analysis revealed high degree of organization of bone on surface of implant, which indicated that TiO_2 applied for surface treatment indicated positive effect on acceleration of new bone formation (osseointegration) and also on implant biomechanical nature [57]. Figure 8 show implant treated with SLA and its Scanning Electron Microscopy images at 1000x and 5,000x magnification. Titania under UV light produces oxidative effect, hence in biomedical field adopted as photocatalytic disinfectant. Titania photocatalysts are effective disinfectant of bacteria even for indoor environment. Interestingly, studies demonstrated the effectiveness of titania in disinfecting of SARS-CoV-2 [58]. Figure 9 show Titania photocatalysts, its photocatalytic effect as disinfectant against various bacteria and viruses Hence, Titania attracts mainly as an antimicrobial agent and used as surface coating for implants, as it possesses the properties of photocatalytic activity, stability, non-toxicity, physicochemical and inexpensiveness.

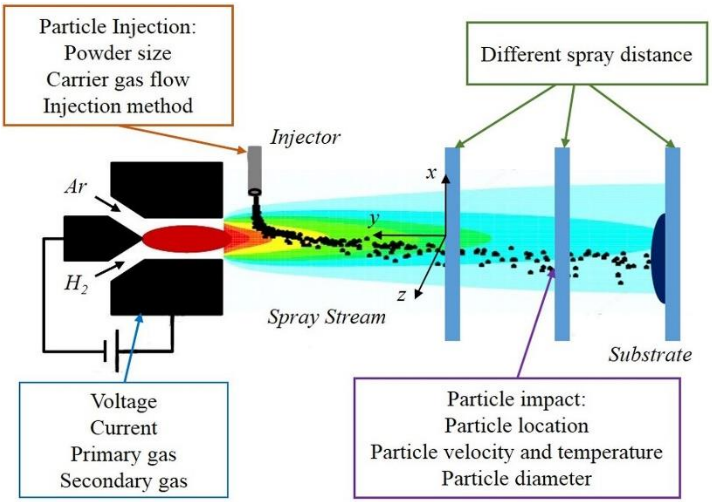

Figure 7. Plasma spraying process, its variables and parameters [53, 54].

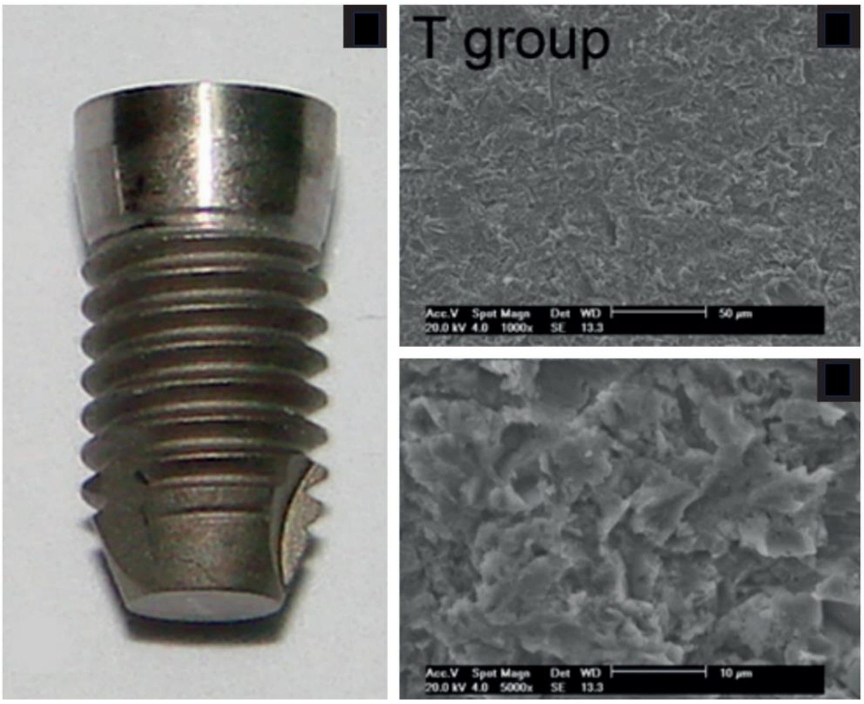

Figure 8. Implant with TiO_2 and its scanning electron microscopy images [57].

Journal of Polymer & Composites
Volume 11, Special Issue 8
ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

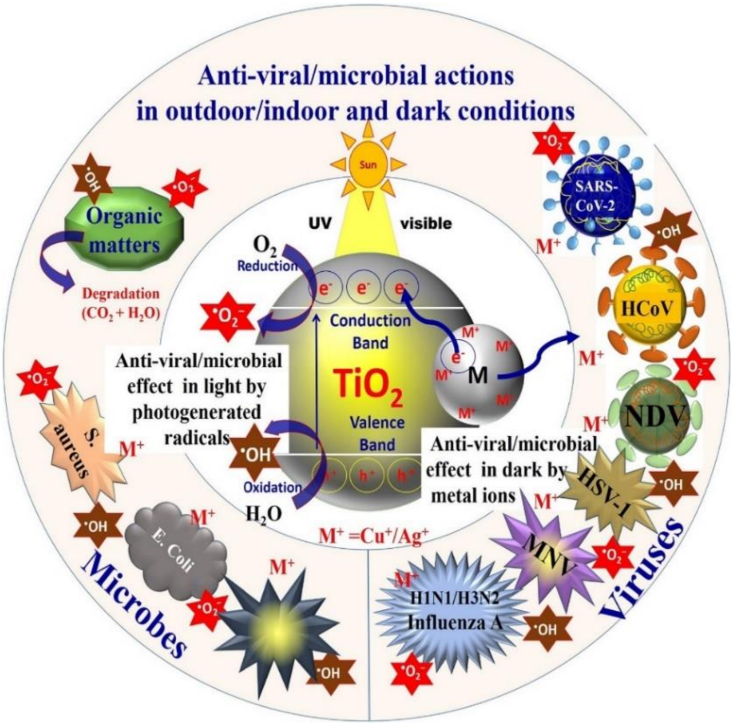

Figure 9. Titania photocatalytic and disinfectant effect against various bacteria and viruses [58].

CONCLUSIONS

Technological advancements in field of healthcare led to significant increase in innovation of biomaterials for dental implants in past few decades. Attempts of investigators through research studies and scientific findings have driven to innovation in artificial materials to incorporate within a biological system. Professionals working in healthcare are facilitated with devices which are chemically and mechanically clean for use in disciplines of surgery.

The attention of this review article is to through a light on the biomaterials. Information of this kind on biomaterials helps in innovation of future generation implants. Dentists/Dental practitioners/Clinicians must have a good knowledge of different biomaterials and its properties for successful clinical practice. Selecting a particular biomaterial is a challenging task but can be accomplished through prompt diagnosis and treatment plan.

Future Work Recommendations

Recently due to modern innovations in technology have seen rise in the use of the biomaterials in healthcare applications. Also, these innovations look promising in clinical outcomes. Further research is needed in the use and innovation of different kinds of models designs that are viable to restore edentulous space such as one-piece implant using bio-ceramic materials. Viewing from the biomaterials angle, bio-ceramics are more suitable due to non-corrosion properties they possess. This becomes one form of novel idea that needs attention of exploration, thereby opening the door for research in customizing implants for dental applications.

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