Review Article

International Journal of Research and Review
Volume 11; Issue: 6; June 2024
Website: www.ijrrjournal.com
E-ISSN: 2349-9788; P-ISSN: 2454-2237

Recent Biomaterials in Implants: A Narrative Review

Dr. Arun Gupta[1], Dr. Kruti Gothi[2], Dr. Sandesh Gosavi[3], Dr. Pratik Bhatnagar[4], Dr. Gunjan Gupta[5], Dr. Rohan Shambhuvani[6]

[1]Professor and Head, Department of Prosthodontics, College of Dental Science and Hospital, Amargarh – 364 210, Gujarat, India
[2]PG Student – 2nd Year, Department of Prosthodontics, College of Dental Science and Hospital, Amargarh – 364 210, Gujarat, India
[3]Professor, Department of Prosthodontics, College of Dental Science and Hospital, Amargarh – 364 210, Gujarat, India
[4]Reader, Department of Prosthodontics, College of Dental Science and Hospital, Amargarh – 364 210, Gujarat, India
[5]Reader, Department of Periodontics, College of Dental Science and Hospital, Amargarh – 364 210, Gujarat, India
[6]Sr. Lecturer, Department of Prosthodontics, College of Dental Science and Hospital, Amargarh – 364 210, Gujarat, India

Corresponding Author: Dr. Arun Gupta

DOI: https://doi.org/10.52403/ijrr.20240603

ABSTRACT

A crucial element in the long-term viability of implants is the appropriate choice of implant biomaterial. Implants should be chosen to minimize the adverse biologic response while preserving appropriate function because the biologic environment does not accept all materials. With an aging population comes an increasing need for biomaterials that promote the replacement, repair, or healing of soft tissues and bones. Implants continue to fail because of infection, fracture, corrosion, and excessive load, despite extensive research over the past ten years to develop medical implants for bone regeneration and body tissue healing. Implantable materials include metals, ceramics, and polymers, depending on whether a permanent or temporary implant is needed. The article addresses the use of several polymeric materials, metals, and alloys as medical implants. The replacement of bone with titanium implants has showed promise, and the alloys used in these implants are essential to orthopaedic and dental treatments. Still, they exhibit a number of shortcomings, including Ti-6Al-4V alloy. The characteristics of titanium alloys and their potential applications as implantable materials have been widely explored. The published studies of in-vitro and in-vivo research have been critically addressed in the article, as biocompatibility and bone response are significant factors that determine implants' clinical efficacy. In order to improve medical implants and tissue engineering, biomaterials' overall performance and applications in biological systems are covered in this study. This review includes critiques aimed at aspiring young researchers who want to work on developing implants for biomedical uses. This article attempts to provide an overview of the several dental biomaterials that have been utilized in the past and the most recent materials that are now in use.

Keywords: Biomaterials, titanium implants, stainless steel implants, HAp, Hydroxyapatite implants, PEEK, Polyether

Ether Ketone implants, PMMA, Poly Methyl Methacrylate implants.

INTRODUCTION

The therapeutic goal of implant dentistry is not merely tooth replacement but total oral rehabilitation. Considering dental implants as a treatment option can provide patients with positive long-term results. Implant dentistry has gone through many pharus over the last 10years[3].

Medical implants that can be used to repair bone deficiencies in tissues brought on by aging and unintentional wounds. These implants are made of a variety of biomaterials[4]. Orthopaedic and dental implants have undoubtedly made great strides in the last few years, with good outcomes. The survival rate of dental implants is between 90 and 96.5%. Infection, fractures, septic inflammation, corrosion, or an excessive load on the implants as a result of the patient's excessive activity are the causes of failure in every instance[5]. Therefore, even with results that are adequate, there is always room for improvement and a need for effective materials. Modern dental implants are designed with a screw thread that anchors the metal alloy component to the bone, increasing the implants' efficacy. The ceramic fake tooth is supported by the smooth portion of metal that protrudes beyond the gums' soft tissue. Because of its intricate construction, it must be ensured that the implant's attached portion has sufficient bone to sustain[6]. The tissue replacement implant should be bioactive and non-toxic to form an interfacial bond with surrounding tissues. The characteristics and properties required in an ideal implant material are Nontoxic, bioactive, inexpensive, corrosion resistance, low elastic modulus, wear resistance and biocompatiable[1].

Out of all the properties, corrosion resistance is one of the essential characteristics in the case of permanent implant. Our body provides an exceptional corrosive environment as it includes water, sodium, chlorine, proteins, and amino acids. However, if the material is not a good resistant, it will degrade agonizingly, leading to the release of toxic ions, which results in failure and infection in body tissues[7]. A material having a young modulus of elasticity similar to bone can mitigate this phenomenon. Although conventional materials such as titanium, stainless steel, etc., have performed well as an implant in the body, rejection or implant failure is still evitable due to fracture, bending, cracking, severe wear, and adverse reactions in the body. So, to increase the average life expectancy of humans, research is going on to find relevant biomaterials with enhanced performance. The biological characteristics of several implant biomaterials, including as metals, polymers, and titanium alloys, are covered in this article.

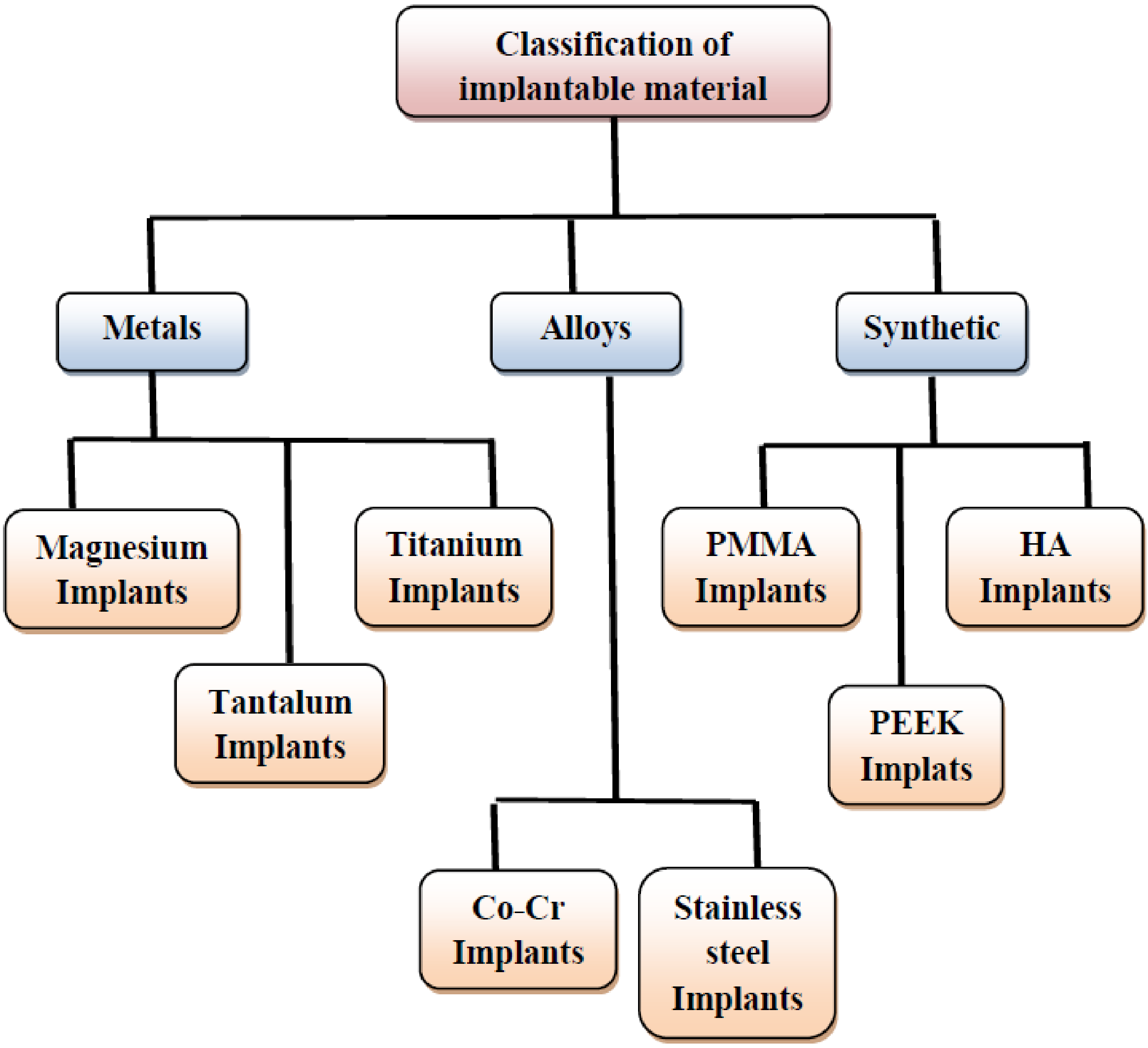
MATERIALS AND METHODS

The literature search was done using PubMed articles by using keywords “Biomaterials, titanium implants, stainless steel implants, HAp, Hydroxyapatite implants, PEEK, Polyether Ether Ketone implants, PMMA, Poly Methyl Methacrylate implants”.

Titanium alloys as medical implants:

Among various biomaterials used as an implantable material, titanium and its alloys are considered the most significant biomaterials due to their advantageous properties such as excellent tensile and mechanical strength, flexibility, biocompatibility, and high corrosion resistance, as discussed above and in the article. Titanium is one of the most successful implantable biomaterials, but its high friction coefficient and vulnerability to abrasive and adhesive wear are major concerns. To overcome these restrictions, titanium is alloyed with various other metals such as Aluminium, Vanadium, Nickel, Zirconium, etc. The Titanium alloys that have been discussed in the literature, such as Ti-6Al-4V, Ti-Zr and Ti-Ni, show excellent tribological behaviour, high mechanical strength, and are used for bone-tissue replacement under intensive wear use. These alloys can be toxic due to the addition of various other metals in titanium which can cause multiple allergies in our body. So, to understand the disadvantages and advantages of these alloys and their properties, a critical discussion has been included in the following sections[8].

Classification of metals and alloys used in medical implants



Titanium-Aluminium-Vanadium (Ti-6Al-4V) alloy

One of the most widely used and durable titanium alloys is Ti-6Al-4V. About 90% of its composition is titanium, 6% is aluminum (Al), and 4% is vanadium (V). It possesses numerous favorable and superior qualities that are necessary for the creation of a medical implant. Because the implant's surface has formed an oxide layer, it has greater resistance to corrosion. Because of its superior mechanical and tensile strength, it can be used to manufacture implants. Additionally, the alloy guarantees long-term load transmission to bone tissue, which is critical when prosthetics replace injured hard tissues. Although it experiences osseointegration, it remains highly biocompatible with the human body[9].

Dentists prefer implants made up of Ti-6AL-4V to replace affected teeth and to develop shape memory bracelets. Ti-6AL-

4V is also used to manufacture artificial hip joints, artificial knee joints, bone plates, screws for fracture fixation, cardiac valve prostheses, pacemakers, and artificial hearts. Xiong et al. investigated Ti-6Al-4V by introducing a dense core inside the alloy's porous scaffold. The yield stress, ultimate strength, fatigue strength, young modulus, and favorable porosity were all found to have increased, according to the data. The scaffold's compression, which raises the buckling elements and multiaxial stress environment, is what caused these modifications to be seen. The insertion was shown to be a successful means of maintaining favorable porosity and strengthening mechanical qualities[10].

Sharma et al. examined and contrasted the corrosion characteristics of cast and selective laser melted (SLM) Ti-6Al-4V alloy. We evaluated the corrosion characteristics in solutions including NaOH, NaCl, H2SO4, and SBF. According to the findings, the sample that was subjected to SLM exhibited a higher level of corrosion resistance in all the solutions except NaOH. Thus, it was determined that the alloy treated with SLM has superior corrosion resistance to cast alloy and can therefore be utilized to create medical implants[11].

The major drawback of Ti-6Al-4V is the release of vanadium metal ions which has toxic effects on the human body. There is another problem, i.e. the negative immunological response of the human body due to the presence of aluminium and vanadium. Hence, Ti-6Al-4V is one of the best alloys for the development of medical implants, and it offers lots of favourable properties. Future researchers can focus on decreasing the concentration of vanadium in the alloy to increase biocompatibility. Researchers should emphasise more on improving the bioactiveness and osseointegration property of the alloy[1].

Titanium-Zirconium (Ti-Zr) alloy

Ti-Zr is a titanium (Ti) and zirconium (Zr) alloy containing 84% Ti and 16% Zr. Zirconium belongs to group-4 of the periodic table, which is similar to titanium due to which both have similar chemical structures and properties. Zr becomes neutral and non-toxic when dissolved in Ti. Ti-Zr alloy has excellent corrosion resistance properties as both the metals form an oxide layer on the surface when exposed to oxygen. Ti-Zr alloy has excellent biocompatibility and also better mechanical strength than pure Ti. It also increases the osteoblast adhesion and bioactivity of the implant. Zr is also non-magnetic, insinuating that it does not impede diagnostic techniques, including magnetic resonance imaging (MRI). It mostly has its application in dental implants due to its excellent corrosion resistance property and is used to make root canals and teeth implants.

Sharma et al. investigated the mechanical properties of Ti-Zr alloy. The results reported decreased elastic modulus, increased hardness, and finer grain size of Ti-Zr alloy. It was concluded that it might be more suitable for high load-bearing implants than traditional Ti[12].

Ou et al. examined the cytotoxicity, adhesion, and proliferation of the Ti-Zr alloy in relation to its cytocompatibility. According to reports, the Ti-Zr alloy exhibits better biomechanics than conventional Ti and is non-toxic. The alloys have superior osteogenic activity, cytocompatibility, and stability. It was determined that it possesses the ideal strength needed for implant creation and has enormous potential as a dental implant material[12].

Ikarashi et al examined, using rat implantation, the tissue response and sensitization to Ti-Zr alloy. Rats were given implants containing specimens composed of Ti-Zr alloy and Ti, and they were observed for eight months. The body did not experience any harmful effects, and there was no change in body weight. For both specimens, there was no evidence of a sensitization response to Ti-Zr alloy, and the tissue inflammatory responses to the alloy were less severe than those to Ti. It was determined that as an artificial surgical implant, Ti-Zr is more biocompatible than Ti[13].

The drawbacks of alloy include low mechanical stability and complexity in its processing and synthesis. Hence, Ti-Zr has excellent properties and can have many dental implant applications. However, more focused research is required on Ti-Zr alloy as an implant material and enhancing its mechanical stability. Further research is needed to improvise its processing on an industrial scale and to discover an efficient technique for developing Ti-Zr medical implants[1].

Titanium-Nickel (Ti-Ni) alloy

The alloy known as titanium-nickel (Ti-Ni) has a nearly equiatomic composition of 51% titanium and 49% nickel. It's one of the most valuable alloys in the medical field because of its many special qualities. Its elastic modulus is comparable to that of human bone, and it is highly elastic and biocompatible. Because of the creation of a protective coating of TiO2 on the alloy's surface, the alloy is resistant to corrosion[14].

It is advantageous in making braces for setting the shape of teeth due to its shape memory effect, which is one of the unique properties of Ti-Ni alloy. The superelastic property of the alloy to return to its original shape after deformation is very useful in endodontology as it allows the construction of curved root canals. Ti-Ni alloys are also used to make self-expandable vascular stents. These stents are used to treat Atherosclerosis in the coronary arteries, carotid arteries, and peripheral arteries.

Kokorev et al. examined the Ti-Ni based alloy's evaluation both in vivo and in vitro. Using the self-propagating high-temperature synthesis (SHS) method, they created the porous Ti-Ni alloy and conducted an in vivo investigation on smarter rats. According to the findings, porous Ti-Ni is a biocompatible cell culture incubator that is relevant for this type of bioengineering and can be used in medical implants[15].

Naka et al. examined the fatigue behavior of foams made of Ti-Ni alloy and produced using the magnesium space holder method. The results of the fatigue testing showed that there would be no fatigue failure of the Ti-Ni alloy under the stress levels encountered in biomedical applications. According to the findings, the foam's mechanical qualities make it appropriate for use in biological fields. It was also discovered that the porosity levels of the alloy may be changed to modify its elastic modulus, hence preventing the stress shielding effect. Ti-Ni alloy was shown to be suitable for use as an implantable material[16].

There are some drawbacks of Ti-Ni alloy, which include the toxicity of the Ni element. As Ni is very toxic for the human body, the prolonged use of alloy could lead to the release of metal ions in the body which can cause various allergic reactions and diseases. Another weakness is the nickel manufacturing as it is very challenging due to its low thermal conductivity as high-temperature processes increase the working temperature, which is very difficult to bear by workers and machines[17]. Hence, Ti-Ni alloy has many unique properties that expand its application in the medical industry. Its toxicity and difficulty in manufacturing are the major factors that cannot be neglected. So, future researchers can focus on decreasing the toxicity of Ti-Ni alloy and work on improvising and innovating the manufacturing of nickel.

Synthetic polymeric materials for bone replacement

Synthetic polymeric materials have been used since the 1980s as implantable materials or as a coating on medical implants to enhance their properties. These polymers are macromolecules consisting of covalently bonded monomers, i.e. homopolymers and copolymers. They have an amorphous or crystalline structure depending on the carbon chain. Polymethyl methacrylate and poly ether-ether-ketone materials are composed of carbon and

oxygen atoms, whereas HydroxyApatite (HAp) is majorly made up of calcium and phosphorus atoms.
The main advantage of using polymers is that their physical characteristics can be moulded according to the application as their composition can be easily changed. However, they have lesser mechanical and physical strength than metals, and also, they lack adhesion to the living tissues. These are generally used as a coating on the surface of metallic implants to increase their biocompatibility, bioactivity, osteogenic property, and resistance against corrosion.

Polymethyl methacrylate (PMMA) coating

Polymethyl methacrylate (PMMA) is a synthetic polymer that is lightweight, non-biodegradable, and a cost-effective substitute in situations when great strength is not required. It was first used in orthopaedics in the middle of the 1950s and is a necessary component of dental dentures. PMMA is similar to human dentures in terms of its mechanical and physical characteristics, including its perfect porosity, low modulus of elasticity, and electrical and thermal passiveness.
Additionally, because it lacks hazardous components like bisphenol, which are mostly present in other polycarbonates, it has less of an adverse influence on human health. PMMA is a non-biodegradable polymer that is mostly used in applications requiring mechanically stable, permanent implants, like dental implants, hip joint replacements, and bone tissue regeneration[18].
PMMA is also used in various biomaterial applications such as in bone cement, as a bone substitute, and also as a contact lens. It is also one of the significant components in creams to remove wrinkles and scars on skin tissue permanently and is also used as a substitute for missing dental roots. Recently, PMMA has also been used as a moldable material to cast temporary spacers after removing failed joint prostheses that got infected in the body. Here, PMMA is used to give a provisional congruence to the joint ends and is not required for kinetic performance[19]. It is used as a drug therapy to control and eradicate the infection, and then new implant material is placed in the body through surgery. PMMA also has application in spinal surgery. In the case of vertebroplasty, a crushed vertebral body is restored to its original volume, and PMMA cement is used to fill the inner spaces to increase the mechanical strength.
The significant weakness of PMMA cement is that they do not degrade, and also its high curing temperature can cause necrosis of surrounding tissue which is of substantial concern.
Hence, PMMA is one of the most useful biomaterials used to coat medical implants and is primarily used in the case of permanent implants as it is nonbiodegradable. However, future researchers can focus on decreasing the curing temperature of PMMA cement by combining it with other biomaterials, those having low curing temperatures.

Poly ether-ether-ketone (PEEK) coating

The polyaromatic semicrystalline thermoplastic polymer known as poly ether-ether-ketone (PEEK) is composed of an aromatic molecular backbone with various combinations of ketone and ether functional groups. PEEK offers a better mechanical strength than many metals, provides stability at high temperatures, and is resistant to chemical and physical degradation.
The main advantage of using PEEK as a material in the medical implant is the co-relation of its mechanical properties with the human cortical bone. Young's modulus of PEEK is about 4GPa which is almost close to that of bone, i.e. 16 GPa and also PEEK has a low density similar to bone.
Costa et al. investigated the PEEK coating's corrosion behavior on the Ti-6Al-4V structure's surface. Since there was no sign of corrosion in the results, the findings indicated that the PEEK material's covering caused voids and gaps to form between the

material, increasing the material's resilience to corrosion. It was determined that PEEK material is a superior corrosion-resistant material due to its lack of electrochemical activity. PEEK material is utilized as a bearing element in complete joint replacements. For example, it is employed as the tibia in total knee replacements and as the acetabular cup in total hip replacements[20].

Lovald and Kurtz investigated and concluded that PEEK material could be used in trauma, total joint replacement, and also in cranial implants due to its mechanical and physical properties. PEEK material is also used in post teeth bleaching and also in various dental surgery. The strength of PEEK polymer can also be increased by using additives such as carbon fibres, glass fibre, Kevlar, and other bioceramic coatings. But the main disadvantage of PEEK polymer as a medical implant is that it reacts slowly with surrounding tissue, which makes it less bioinert and less suited to the human body. Additionally, it is far more costly than the conventional materials used in medical implants, which deters researchers from using it.

Because of its greater flexibility and minimal ability to buffer against stress on surrounding tissues, PEEK is also not very effective when used in permanent medical implants. PEEK polymer is therefore a good option for creating temporary medical implants. Future studies, however, can concentrate on enhancing the biocompatibility of PEEK polymer by adding surface coatings or bioactive ceramic fillers like hydroxyapatite. Owing to a lack of research, PEEK polymer's biomechanical evaluation is still lacking, and further study is needed to enhance its qualities as a long-term medical implant.

Hydroxyapatite (HAp) coating

Ca10(PO4)6(OH)2, or hydroxyapatite (HAp), is one of the main minerals that make up human bone. The remaining 70% of HAp is made up of water and collagen from the bones. Since HAp makes up the majority of bone, synthetic HAp has comparable chemical and physical characteristics to those of bone. It is one of the most biocompatible materials for bone replacement that is currently on the market. As a permanent medical implant, it possesses minimal fluid solubility, great bioactivity, and osteoconductivity.

A free layer of fibrous tissue made of carbonated apatite forms on the surface of HAp-based materials during implantation, aiding in the attachment of the implant to the living bone and enhancing implant fixation in the surrounding tissues[21].

Thus, HAp is primarily applied to the surface of different titanium or stainless steel implants to improve their biocompatibility and quicken the process of bone healing. It can also be used as cement between permanent implants or to create smaller, less laden medical implants. Regrettably, HAp cannot be used directly as a large load-bearing implant or to create dental dentures because of its poor mechanical strength and reduced wear resistance[22].

Hence, HAp has a lot of applications in the medical industry due to its biocompatibility and resemblance with human bone. However, its low mechanical strength and weak tensile strength are major concerns for its fewer applications in permanent medical implants. Future researchers can focus on increasing the mechanical strength of HAp by doping it with other bioceramics and other strong metals, which can lead to its application in heavy load-bearing implants.

CONCLUSION

The article reviews the biomaterials used in the production of medical implants. Metals are selected carefully to avoid toxicity and corrosion in the body. Among various metals, Titanium metal has lots of applications in the medical industry due to its biocompatibility and surface hardness. Various titanium alloys such as Ti-6Al-4V, Ti-Zr, and Ti-Ni have been reviewed in the article. Although these alloys have given satisfactory results as medical implants, there is still scope to improve their nanotoxicity and complexity in manufacturing. Various synthetic polymeric materials are present that are used as implantable materials. These materials are primarily used as a coating on the surface of metal implants to improve their properties and strength. Among polymeric materials, hydroxyapatite is employed chiefly due to its similar properties to the human bone, as 70% bone is made up of calcium phosphate (hydroxyapatite). Nanotechnology has played a significant role in fabricating a new generation of implant materials with high efficiency, low cost and high surface area to volume to ratio.

Declaration by Authors

Ethical Approval: Not Applicable
Acknowledgement: None
Source of Funding: None
Conflict of Interest: The authors declare no conflict of interest.

REFERNECES

1. Gautam, S., Bhatnagar, D., Bansal, D., Batra, H., Goyal, N.: Recent advancements in nanomaterials for biomedical implants. Biomed. Eng. Adv. 13, 100029 (2022). https://doi.org/10.1016/j.bea.2022.100029
2. Saini M, Singh Y, Arora P, Arora V, Jain K. Implant biomaterials: A comprehensive review. World J Clin Cases. 2015 Jan 16;3(1):52-7. doi: 10.12998/wjcc.v3.i1.52. PMID: 25610850; PMCID: PMC4295219.
3. Dhamankar, D., Gupta, A.R. & Mahadevan, J. Immediate implant loading: A case report. J Indian Prosthodont Soc 10, 64–66 (2010). https://doi.org/10.1007/s13191-010-0010-4
4. M. Qadir, Y. Li, K. Munir, C. Wen, Calcium phosphate-based composite coating by micro-arc oxidation (MAO) for biomedical application: a review, Crit. Rev. Solid State Mater. Sci. 43 (5) (2018) 392–416.
5. L. Gaviria, J.P. Salcido, T. Guda, J.L. Ong, Current trends in dental implants, J. Korean Assoc. Oral Maxillofac. Surg. 40 (2) (2014) 50–60.
6. M.I El-Anwar , M.M El-zawahry, New dental selection criterion based on implant design, Eur. J. Dent. 11(02)2017, 186-191.
7. S. Gautam, J. Singhal, H.K. Lee, K.H. Chae, Drug delivery of paracetamol by metal-organic frameworks (HKUST-1): improvised synthesis and investigations, Mater. Today Chem. 23 (2022) 100647.
8. J. W Nicholson, Titanium alloys for dental implants: a review, J. Prosthet. Orthot. 2 (2) (2020) 100–116.
9. R.ding. Z. Duo,A. Wilson, Microstructural evaluation of Ti-6Al-4V thermomechanical prosessing, mater sci. eng.,A 327(2) (2002), 233-245
10. Y. Xiong, W. Wang, R. Gao, H. Zhang, L. Dong, J. Qin, B. Wang, W. Jia, X. Li, Fatigue behavior and osseointegration of porous Ti-6Al-4V scaffolds with dense core for dental application, Mater. Des. 195 (2020) 108994.
11. Ashutosh Sharma, Min Chul Oh, Jung-Taek Kim et al. Investigation of electrochemical corrosion behavior of additive manufactured Ti–6Al–4V alloy for medical implants in different electrolytes. Journal of Alloys and Compounds. 2020; 830; 154620. https://doi.org/10.1016/j.jallcom.2020.154620.
12. P. Ou, C. Hao, J. Liu, R. He, B. Wang, J. Ruan, Cytocompatibility of Ti-xZr alloys as dental implant materials, J. Mater. Sci. Mater. Med. 32 (5) (2021) 1–10.
13. Y. Ikarashi, K. Toyoda, E. Kobayashi, H. Doi, T. Yoneyama, H. Hamanaka, T. Tsuchiya, Improved biocompatibility of titanium–zirconium (Ti-Zr) alloy: tissue reaction and sensitization to ti-Zr alloy compared with pure ti and zr in rat implantation study, Mater. Trans. 46 (10) (2005) 2260–2267.
14. S. Thompson, An overview of nickel-titanium alloys used in dentistry, Int. Endod. J. 33 (4) (2000) 297–310.
15. Kokorev et al. In vitro and in vivo evaluation of porous TiNi-based alloy as a scaffold for cell tissue engineering, arti nanotech biotech 44(2)(2016) 704-709.
16. G.İ. Nakaş, A.F. Dericioglu, Ş. Bor, Fatigue behavior of TiNi foams processed by the magnesium space holder technique, J. Mech. Behav. Biomed. Mater. 4 (8) (2011) 2017–2023.
17. S. Miyazaki, H. Kim, Basic characteristics of titanium–nickel (Ti-Ni)-based and titanium–niobium (Ti-Nb)-based alloys, in: Shape Memory and Superelastic Alloys, Elsevier, 2011, pp. 15–42.

18. O. Manoukian, N. Sardashti, T. Stedman, K. Gailiunas, A. Ojha, A. Penalosa, C. Mancuso, M. Hobert, S. Kumbar, Biomaterials for Tissue Engineering and Regenerative Medicine, 2018.
19. Merolli, Using bone repair materials in orthopaedic surgery, in: Bone Repair Biomaterials, Elsevier, 2009, pp. 349–377
20. Costal. et al. Corrosion behaviour of PEEK or β-TCP-impregnated Ti6Al4V SLM structures targeting biomedical applications, Trans. Nonferrous Met. Soc. China 29(12) (2019) 2523-2533.
21. W.S.W. Harun, R.I.M. Asri, A.B. Sulong, S.A.C. Ghani, Z. Ghazalli, Hydroxyapatite-based coating on biomedical implant, in: Hydroxyapatite: Advances in Composite Nanomaterials, Biomedical Applications and Its Technological Facets, IntechOpen, Rijeka, Croatia, 2018, pp. 69–88.
22. M. Kannan, Hydroxyapatite coating on biodegradable magnesium and magnesium-based alloys, in: Hydroxyapatite (HAp) for Biomedical Applications, Elsevier, 2015, pp. 289–306

How to cite this article: Arun Gupta, Kruti Gothi, Sandesh Gosavi, Pratik Bhatnagar, Gunjan Gupta, Rohan Shambhuvani. Recent biomaterials in implants: a narrative review. *International Journal of Research and Review*. 2024; 11(6): 18-26. DOI: *https://doi.org/10.52403/ijrr.20240603*

******