Journal of Chitwan Medical College 2021;11(38):1-3
Available online at: www.jcmc.com.np

EDITORIAL

ADVANCES IN BIOMATERIALS FOR CLINICAL APPLICATIONS

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DOI:https://doi.org/10.54530/jcmc.593

INTRODUCTION

There has been considerable advancement in the biomaterials used for biomedical applications. This improvement has been made possible due to strong interdisciplinary collaboration between engineers, chemists, molecular biologists, and clinicians.[1] Biomaterials have erroneously encompassed implants and materials to replace damaged or diseased tissue.

Generally solid materials are classified into four basic categories; metallic, bioceramic, polymeric, and composite bimaterials. Metallic biomaterials remain fully functional during their expected life expectancy and are widely used in medicine due to their acceptable mechanical, chemical, and biocompatibility.[2] Bioceramics are inorganic materials which include amorphous glasses, crystalline ceramics, and glass-ceramics and they are used in the repair, replacement, or regeneration of bone or teeth, but their applications are becoming broader.[3] The use of polymeric materials have been increased for biomedical applications not only due to the excellent surfaces of polymeric materials but also their desired mechanical and biological properties, low production cost, and ease in processing, allowing them to be tailored for a wide range of applications.[4]

The major challenge of biomaterials for bone tissue engineering includes producing the material that can be coupled with both the mechanical and biological concern of real bone tissue matrix and the vascularization.[5] Newer biomaterials tend to solve these problems of biocompatibility of biomaterials in the human body. In addition, these advanced biomaterials are being employed not only in therapeutic applications but also in the diagnosis and treatment of diseases in medicine and dentistry. In addition, smart biomaterials are introduced which can recognize, respond to and even record their environment.[6]

METALLIC BIOMATERIALS

The commonly used metallic biomaterial in dental and orthopedic implants are Ti and its alloy, cobalt-chromium-molybdenum and its alloy, and stainless steel.[7,8] Together, there are numerous coating and surface modification techniques followed to improve the quality of implants and eliminate the slightest possible functional deflection. Various metallic biomaterials used in medicine and dentistry include fixed and removable dentures/appliances, plates, joints, screws, as well as implants, which are used to restore anatomical and functional disorders or defective tissues in the body. Recently, digital technologies and additive manufacturing (AM) or 3D printing has been adopted as an advanced alternative method of for the fabrication of metal prostheses and medical implants.[9,10] In recent years, AM has become an essential part of healthcare technology solving complex medical problems.

CERAMIC BIOMATERIALS

Ceramic biomaterials are inert and are used where a strong hard surface is needed, e.g., a joint replacement or dental prostheses.[3,11] Biocompatibility is excellent and it is one of the beneficial biological response from the body's host environment to the implanted devices.[12] It has been found that ions released by bioceramics can stimulate and guide cells. This has extended bioactivity beyond bone applications, e.g., to wound healing.[3] In addition, Yttria stabilized tetragonal zirconia polycrystalline showed better mechanical properties and superior resistance to fracture than the conventional dental ceramics.[13] Recent advances in bioceramic includes translucent monolithic zirconia[14,15] to merge strength with improved tooth-colour matching and fast/speed sintering of zirconia[16,17] to reduce the laboratory and patient waiting time.

POLYMERIC MATERIALS

Polymeric materials are the organic compounds that are chemically based on carbon, hydrogen, and other nonmetallic elements (i.e., oxygen, nitrogen, and silicon). Additionally, they have a very large molecular structures, often chainlike in nature with often a backbone of carbon atoms. Polymeric biomaterials are widely used in medicine and dentistry.[4] Natural and synthetic polymers have been extensively explored in the field of tissue engineering and regenerative medicine.[18] Various polymeric materials are clinically used in wound dressings which help in the healing process.[19] Additional uses of synthetic polymeric materials and films includes foam dressings, hydrocolloids, alginate dressings, and hydrogels. Biodegradable polymers are mainly used where the transient existence of materials is required and applications include as sutures, scaffolds for tissue regeneration, tissue adhesives, hemostats, and transient barriers for tissue adhesion, as well as drug delivery systems.[20,21] For such applications, they have unique physical, chemical, biological, and biomechanical properties for specific purpose to provide efficient therapy.

COMPOSITE MATERIALS

A composite is composed of more than two materials, which come from metals, ceramics, and polymers. The composites have combination of properties that is not displayed by any single material, and to incorporate the best characteristics of each of the component materials.[22] Bionanocomposites are promising class of hybrid materials derived from natural and synthetic biodegradable polymers and organic/inorganic fillers.[23] They have wide biomedical applications from tissue engineering to load-bearing composites for bone reconstruction according to the composition and chemistry. Polymer/metal nanocomposites consists of polymer as matrix and metal nanoparticles as commonly nanofiller and show various advantages such as electrical, mechanical and optical characteristics.[24]

Various nanoparticles, such as carbon-based, polymeric, ceramic, and metallic nanomaterials can be incorporated within the hydrogel networks to obtain nanocomposites with tailored functionality and superior properties.[25, 26] Nanocomposite hydrogels can be engineered to improve biological physical, electrical, and chemical, properties.[26] Recently graphene nanocomposites is widely studied and it has been shown that it is biocompatible[27], antibacterial[27, 28] with improved the mechanical[29] and electrochemical[30] properties which can be applied in medicine and dentistry. They have also used in the tissue engineering and bone regeneration.[31-33]

3D/4D PRINTED BIOMATERIALS

The 3D printing prints an object of a digitally designed model in specific patterns by a 3D printer.[34-36] 3D printing has become a flourishing technology to fabricate dental prostheses, orthoses and prosthetic devices, and ophthalmological implants.[37-41] Various materials can be printed from a 3D printer for different applications such as ceramics, polymers, and metals. Commonly used 3D printed polymers are polylactic acid polyether ether ketone, polyether ketone ketone, polyglycolic acid, polyurethane, acrylonitrile butadiene styrene, polymethyl methacrylate, polybutylene terephthalate, polycaprolactone, polycarbonates, polyurethanes, etc. The three major applications of 3D bioprinting are regenerative medicine, functional organ replacement, and drug delivery. 3D/4D printing can be integrated with artificial intelligence and machine learning to apply for patient-specific medical technologies. The challenges in 3D/4D bioprinting are associated with the material and cellular aspects. Still, 4D is in the initial stage and more research is needed for the clinical applications.

SMART BIOMATERIALS

Smart biomaterials have the ability to respond to changes in physiological parameters and exogenous stimuli or have intelligently properties and functions that can stimulate tissue repair and regeneration.[6, 42] Smart materials can promote promising therapies and improve treatment of debilitating diseases producing a great impact in modern medical science. The smart material include smart scaffolds and stem cell constructs for bone tissue engineering; smart drug delivery systems to enhance bone regeneration; smart pH-sensitive dental materials to selectively inhibit acid-producing bacteria; smart dental resins that respond to pH to protect tooth structures; smart polymers to modulate biofilm species away from a pathogenic composition and shift towards a healthy composition; and smart materials to suppress biofilms and avoid drug resistance.[43, 44]

CONCLUSION

Various biomaterials (metallic, bioceramic, polymeric, and composites) have a long history for wide applications but there has been a considerable advancement in these biomaterials. The metallic biomaterials are promising materials that demonstrate the benchmark for success due to its characteristic involving biocompatibility and load-bearing ability, corrosion resistance, and function. Ceramic biomaterials are inert and are used where a strong hard surface is needed, e.g., a joint replacement or dental prostheses. The polymeric and composite biomaterials have extensively used in the tissue engineering and bone regeneration. In addition, there has been huge progress in 3D printing technologies which helped in the fabrication of complex structures conveniently for biomedical applications. The major applications of 3D bioprinting are regenerative medicine, functional organ replacement, and drug delivery. 3D/4D printing can be integrated with artificial intelligence and machine learning to apply for patient-specific medical technologies. Smart biomaterials have been applied in tissue engineering, drug delivery systems, immune engineering, and medical devices.

REFERENCES:

1. Bhat S, Kumar A. Biomaterials and bioengineering tomorrow's healthcare. Biomatter.2013;3(3):e24717. [DOI]
2. Prasad K, Bazaka O, Chua M, Rochford M, Fedrick L, Spoor J, et al. Metallic Biomaterials: Current Challenges and Opportunities. Materials. 2017;10(8):884. [DOI]
3. Jones JR, Gibson IR. 1.3.4 - Ceramics, glasses, and glass-ceramics: basic principles. In Wagner WR, Sakiyama-Elbert SE, Zhang G, Yaszemski MJ (Eds). Biomaterials science (Fourth Edition): Academic Press 2020:289-305.[DOI]
4. Rokaya D, Srimaneepong V, Sapkota J, Qin J, Siraleartmukul K, Siriwongrungson V. Polymeric materials and films in dentistry: An overview. J Adv Res. 2018;14:25-34. [DOI]
5. Agarwal KM, Singh P, Mohan U, Mandal S, Bhatia D. Comprehensive study related to advancement in biomaterials for medical applications. Sensors Int. 2020;1:100055. [DOI]
6. Kowalski PS, Bhattacharya C, Afewerki S, Langer R. Smart biomaterials: recent advances and future directions. ACS Biomater Sci Eng. 2018;4(11):3809-17. [DOI]
7. Niinomi M. Metallic biomaterials. J Artif Organs. 2008;11(3):105-10. [DOI]
8. Niinomi M. Design and development of metallic biomaterials with

ISSN 2091-2889 (Online) ISSN 2091-2412 (Print) JCMC/ Vol 11/ No. 4/ Issue 38/ Oct-Dec, 2021

biological and mechanical biocompatibility. J Biomed Mater Res A. 2019;107(5):944-54.[DOI]

9. Salmi M. Additive manufacturing processes in medical applications. Materials. 2021;14(1):191.[DOI]

10. Humagain M, Rokaya D. Integrating digital technologies in dentistry to enhance the clinical success. Kathmandu Univ Med J (KUMJ). 2019;17(68):256-7. [PMID]

11. Heboyan A, Manrikyan M, Zafar MS, Rokaya D, Nushikyan R, Vardanyan I, et al. Bacteriological evaluation of gingival crevicular fluid in teeth restored using fixed dental prostheses: An In Vivo Study. Int J Mol Sci. 2021;22(11).[DOI]

12. Heboyan A, Syed AUY, Rokaya D, Cooper PR, Manrikyan M, Markaryan M. Cytomorphometric analysis of inflammation dynamics in the periodontium following the use of fixed dental prostheses. Molecules. 2020;25(20):4650. [DOI]

13. Miyazaki T, Nakamura T, Matsumura H, Ban S, Kobayashi T. Current status of zirconia restoration. J Prosthod Res. 2013;57(4):236-61.[DOI]

14. Ghodsi S, Jafarian Z. A review on translucent zirconia. Eur J Prosthodont Restor Dent. 2018;26(2):62-74. [DOI]

15. Kongkiatkamon S, Booranasophone K, Tongtaksin A, Kiatthanakorn V, Rokaya D. Comparison of fracture load of the four translucent zirconia crowns. Molecules. 2021;26(17).[DOI]

16. Kaizer MR, Gierthmuehlen PC, Dos Santos MB, Cava SS, Zhang Y. Speed sintering translucent zirconia for chairside one-visit dental restorations: optical, mechanical, and wear characteristics. Ceram Int. 2017;43(14):10999-1005. [DOI]

17. Soult MD, Lien W, Savett DA, Gallardo FF, Vandewalle KS. Effect of high-speed sintering on the properties of a zirconia material. Gen Dent. 2019;67(5):30-34. [PMID]

18. Kohane DS, Langer R. Polymeric biomaterials in tissue engineering. Pediatr Res. 2008;63(5):487-91. [DOI]

19. Mir M, Ali MN, Barakullah A, Gulzar A, Arshad M, Fatima S, et al. Synthetic polymeric biomaterials for wound healing: a review. Prog Biomater. 2018;7(1):1-21. [DOI]

20. Nair LS, Laurencin CT. Polymers as biomaterials for tissue engineering and controlled drug delivery. Adv. Biochem. Engin./Biotechnol. 2006;102:47-90. [DOI]

21. Song R, Murphy M, Li C, Ting K, Soo C, Zheng Z. Current development of biodegradable polymeric materials for biomedical applications. Drug Des. Devel. Ther. 2018;12:3117-45. [DOI]

22. Gendelberg N, Bird D, Ravindra NM. Chapter 7 - Nanocomposites for biomedical applications. In Song K, Liu C, Guo JZ, (Eds). Polymer-based multifunctional nanocomposites and their applications: Elsevier 2019:175-99. [DOI]

23. Hule RA, Pochan DJ. Polymer nanocomposites for biomedical applications. MRS Bulletin. 2011;32(4):354-8. [DOI]

24. Zare Y, Shabani I. Polymer/metal nanocomposites for biomedical applications. Mater Sci Eng C. 2016;60:195-203. [DOI]

25. Gaharwar AK, Peppas NA, Khademhosseini A. Nanocomposite hydrogels for biomedical applications. Biotechnol. Bioeng. 2014;111(3):441-53. [DOI]

26. Barrett-Catton E, Ross ML, Asuri P. Multifunctional hydrogel nanocomposites for biomedical applications. Polymers. 2021;13(6). [DOI]

27. Santos CM, Mangadlao J, Ahmed F, Leon A, Advincula RC, Rodrigues DF. Graphene nanocomposite for biomedical applications: fabrication, antimicrobial and cytotoxic investigations. Nanotechnology. 2012;23(39):395101.[DOI]

28. Pipattanachat S, Qin J, Rokaya D, Thanyasrisung P, Srimaneepong V. Biofilm inhibition and bactericidal activity of NiTi alloy coated with graphene oxide/silver nanoparticles via electrophoretic deposition. Sci Rep. 2021;11(1):14008.[DOI]

29. Rokaya D, Srimaneepong V, Qin J, Thunyakitpisal P, Siraleartmukul K. Surface adhesion properties and cytotoxicity of graphene oxide coatings and graphene oxide/silver nanocomposite coatings on biomedical NiTi alloy. J Nanosci Nanotechnol. 2019;19(7):3804-10.[DOI]

30. Srimaneepong V, Rokaya D, Thunyakitpisal P, Qin J, Saengkiettiyut K. Corrosion resistance of graphene oxide/silver coatings on Ni-Ti alloy and expression of IL-6 and IL-8 in human oral fibroblasts. Sci Rep. 2020;10(1):3247. Sci Adv Mater. 2019; 11(10):1474-87.[DOI]

31. Aydin T, Gurcan C, Taheri H, Yilmazer A. Graphene based materials in neural tissue regeneration. Adv. Exp. Med. Biol. 2018;1107:129-42.[DOI]

32. Geetha Bai R, Muthoosamy K, Manickam S, Hilal-Alnaqbi A. Graphene-based 3D scaffolds in tissue engineering: fabrication, applications, and future scope in liver tissue engineering. Int J Nanomedicine. 2019;14:5753-83. [DOI]

33. Lalwani G, D'Agati M, Gopalan A, Rao M, Schneller J, Sitharaman B. Three-dimensional macroporous graphene scaffolds for tissue engineering. J Biomed Mater Res A. 2017;105(1):73-83.[DOI]

34. Douroumis D. 3D Printing of Pharmaceutical and Medical Applications: a new era. Pharm. Res. 2019;36(3):42.[DOI]

35. Amornvit P, Rokaya D, Peampring C, Sanohkan S. Confocal 3D optical intraoral scanners and comparison of image capturing accuracy. Comput. Mater. Contin. 2021;66(1):303-314. [DOI]

36. Amornvit P, Sanohkan S. The accuracy of digital face scans obtained from 3D scanners: An in vitro study. Int J Environ Res Public Health. 2019;16(24):5061.[DOI]

37. Pugliese R, Beltrami B, Regondi S, Lunetta C. Polymeric biomaterials for 3D printing in medicine: An overview. Ann 3D Print Med. 2021;2:100011. [DOI]

38. Alqurashi H, Khurshid Z, Syed AUY, Rashid Habib S, Rokaya D, Zafar MS. Polyetherketoneketone (PEKK): An emerging biomaterial for oral implants and dental prostheses. J Adv Res. 2021;28:87-95. [DOI]

39. Aimar A, Palermo A, Innocenti B. The role of 3D printing in medical applications: A state of the art. J Healthc Eng. 2019;2019:5340616. [DOI]

40. Yan Q, Dong H, Su J, Han J, Song B, Wei Q, et al. A review of 3D printing technology for medical applications. Engineering. 2018;4(5):729-42. [DOI]

41. Ghilan A, Chiriac AP, Nita LE, Rusu AG, Neamtu I, Chiriac VM. Trends in 3D printing processes for biomedical field: opportunities and challenges. J Polym Environ. 2020;28(5):1345-67. [DOI]

42. Zhang K, Wang S, Zhou C, Cheng L, Gao X, Xie X, et al. Advanced smart biomaterials and constructs for hard tissue engineering and regeneration. Bone research. 2018;6:31. [DOI]

43. Mantha S, Pillai S, Khayambashi P, Upadhyay A, Zhang Y, Tao O, et al. Smart hydrogels in tissue engineering and regenerative medicine. Materials. 2019;12(20):3323.[DOI]

44. Haryanto, Khan MM. Chapter Nine - Smart polymer biomaterials for tissue engineering. In Bhawani SA, Khan A, Jawaid M, (Eds). Smart polymer nanocomposites: Woodhead Publishing 2021:205-14.[DOI]