APPLICATION OF HYDROXYAPATITE IN IMPLANT: A REVIEW

[1]Vatsalkumar Jariwala, [2] Nishita Ghariwala, [3] Poonam Mondal, [4] Dhiraj Mehta
[1] Department of Biomedical Engineering,
[1] Parul Institute of Technology, Vadodara, India

Abstract - Hydroxyapatite is found out to be an essential substance in natural bones and other hard tissues, and therefore it has become a major source as a biomaterial in prosthetic applications. HA has evolve the bone regenerative process by impermanenting as bone fillers and scaffolds. Nevertheless, the main failing of this ceramic biomaterial is its poor mechanical properties, antimicrobial property and bioactivities like osteoconductivity and osteoinductivity. Therefore, to stabilise the addition of metal ions and polymer layer on its surface has been implemented and different characterisation techniques have been reported under this review like FTIR, XRD, TEM and SEM, and their results have confirmed the ions substitution through its changed stoichiometry ratios. This compound of HA with different polymers and metal ions showed its ability to bind biological molecules as to improve the functional properties of the tissues and enhancing the biocompability. This paper aims on the applications of Hydroxyapatite as an implant material for orthopaedic and dental in biomedical field.

IndexTerms - – ***Hydroxyapatite, Biomaterial, Orthopaedic Implants, Dental Applications***

I. INTRODUCTION

Recently, bone problems like osteogenesis imperfect, fractures and osteoporosis and other bone injuries has become a worldwide issue. The standard cure to this problems includes surgeries to alleviate the bone with exterior support like metal implants in this modern era[1]. These implants are generally made up of metals like iron (Fe), Titanium (Ti), Cobalt (Co), Silver (Ag) and many other. Orthopaedic and dental implants are emerging procedures showing interdisciplinary applications in biomedical field as it aims the evolution of biological replacements. Even after the implantation procedure the metallic implant needs to withstand many other factors such as stiffness, stress shielding, corrosion, osteoconduction and other issues.

Due to above mentioned drawbacks of metal implants, incorporation of bioactive materials consisting of bones and tooth composites like calcium and phosphorous have been introduced in several research as implant material for bone-tissue substitution, bone scaffolds, dental fillers and maxillofacial reconstruction [2]. They are capable to maintain and improve the bone function or a complete organ. Most extensively used bioceramic is Hydroxyapatite (HAP) with chemical composition $Ca_{10}(OH)_2(PO_4)_6$ which contains majority part of natural tooth and bones, providing excellent bioactivity, biocompatibility and osteoconductivity[3]. Additionally, HAP has been developed to increase adsorption, osteoinegration, bone bonding and decomposition activity of the metallic implant material [4][5].

HAP implants possess prominent properties like non-toxicity, biochemical tolerance and bioactivity in account of which it is used for implant coating and thin bio-films[6]. In the present review work, detailed summary of substitution of different metallic and polymer substance with HAP has been studied with their significant applications as an implant material.

RGINS.Somecomponents,suchasmulti-leveledequations,graphics,andtablesarenotprescribed,althoughthevarioustabletextstylesareprovided.Theformatterwillneedtocreatethesecomponents,incorporatingtheapplicablecriteriathatfollow.

II. ORTHOPAEDIC IMPLANTS

As per the population growth, every year the disease such as bone fracture, knee joint problems of numerous parts of musculoskeletal system is at an upsurge. To overcome such damages implantation of artificial body parts made up of some biomaterial is suggested. It includes implants such like Hip-joint, bone plates and rods many others as per concern to orthopaedics [7]. Many biomaterials: metals like Titanium (Ti), Copper (Cu), Aluminium (Al) are taken into consideration while implant is structured. But alongside metals somehow shows some limitation in its use i.e. low bone metabolism, poor bioactivity, and low antibacterial properties and may lead to swelling. Hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$) a fine bioceramic presentation outstanding properties like Biocompatibility, Bioactivity and Osteoconductivity is adapted as a coating over these metallic implants to eliminate these limitation of metallic implants and it has turned out to be efficient in long-term stability under biological environment[8] .

Jakubowicz et al [9] presented a study for surface modification of pure HAP with Titanium (Ti) doping by the means of Mechanoelectrochemical synthesis method. Using Surface Electron Microscope (SEM) the authors showed formation of sponge type pores in the compound of 1-15 um in diameter and 90% density which turned out to be an attractive property for implant application. Corrosion tests were also performed by the authors via Ringer's solution which resulted in better corrosion resistance on account of lower corrosion current. These results suggests applicability of Ti-HAP composite as an adaptable option for orthopaedic applications. Furthermore, antibacterial properties of the biomaterial also plays an important role in implantation procedure since, poor antibacterial properties may lead to surgical failure. Thian et al. [10] reported a work on the improving of antibacterial properties of HAP by incorporation of Zinc (Zn) ions. Experimental method involved use of Co-precipitation method between calcium hydroxide and orthophosphoric acid as calcium and phosphate source respectively and Zinc Nitrate was used as zinc source. The authors herein reported 1.6 wt% of Zn in ZnHAP which was the achieved for the first time. The results from characterizations performed indicated Rod-like morphology of ZnHAP nanoparticles. Also, ZnHAP was reacted biologically with S. aureus, results turned out to be reduction of bacteria content on the ZnHAP surface which in-turn stated improvement of antibacterial property in compare to normal metal or ceramic implant.

In agreement to the above researchers, it has been concluded that incorporation of metals into HAP turned out to be a beneficial bioceramic for the application as orthopaedic implants. Also properties like antimicrobial activity and structural properties has been improved in comparison to pure Hydroxyapatite.

III. DENTAL IMPLANTS

In the recent years, use of inorganic biomaterial as an antimicrobial agent has appealed interest for the control of microorganisms. The crucial benefits of inorganic antimicrobial agents are enhanced stability and safety. Hydroxyapatite being the main mineral phase in bones and tooth as it contributes in resorption process and calcification. HAP is the major bone substitute for many biomedical applications which also include dentistry and cosmetic surgery too[11] . HAP has been widely used for tooth caps and fillers due to its excellent biocompatibility, the exchange rate for cationic substitution of silver ions (Ag) into HAP is very favourable. On basis of this fact the composite of Ag-HAP is majorly put-upon for dental applications. Beside this, silver ions are well known for their wide spectrum antibacterial result even at very low concentration. Ciobanu et al [12] have performed incorporation of silver into HAP by means of co-precipitation method at 100°C. Morphological characteristics studied through Scanning Electron Microscopy (SEM) revealed homogeneous nature of this biomaterial and antimicrobial test was investigated in S. aureus resulting in reduced number of bacterial S. aureus onto AgHAP surface showing the strong antibacterial action.

Moreover, Poor denture cleaning is also of great concern for dental prosthesis which leads to infectious diseases. Therefore, titanium serves as a photocatalytic material on prosthesis materials as it maintain antimicrobial effect on the surface. Similarly, Sato et al. has prepared a dental base resin by adding titanium-HA to the polymathy methacrylate polymeric powder resin. S. sanguine, E. coli, A. naeslundii and S. aureus was chosen for the evaluation of Ti-Ha denture resin antimicrobial effects. The authors showed up the conclusion after characterisation study by EDX and SEM techniques results that Ti-Ha dental base resin exerts an antimicrobial effect on the biofilm which was composed of no single species but multiple species of human saliva hence proving its biocompatibility for dental applications. Table 1 shows the summary of HAP application.

Table 1: Detailed Summary of Hydroxyapatite Application

Sr No	Bio-material	Application	Reference
1	Polyester/HAP	Tissue engineering and scaffolding Applications	Ramazan Asmatulu et al – 2015 [1]
2	Agarose- hydroxyapatite	Orthopaedic and dental , bone regeneration, bone filling and replacement	S. S´anchez-Salcedo et al- 2007 [4]
3	Titanium -HAP	Tissue Regeneration, Body implant with high corrosion resistance.	J.Jakubowicza et al – 2008 [9]
4	Zn-HAP (1.6 wt% Zn)	Implant coating, self-setting bone cement	E.S.Thian et al – 2013 [10]
5	Cobalt doped HAP	Implant coating, reconstruct-tive surgery operation	W. Sato et al -2013[13]
6	Zinc-alginate HAP	Tissue regeneration , physical support for cells	Renam Costa Cuozzo – 2014 [8]
7	Zn-Brushite (ambient Temp) and Zn-HAP (Elevated Temp)	Repair bone defect , orthopaedic coating, dental implants	Dorota Walczyk et al – 2015 [14]
8	Silver doped hydroxyapatite(Ag-HAP)	Scaffold, skin donation, surgical instruments, artificial teeth.	Carmen Steluta Ciobanu et al -2011 [12]
9	Ta- HAP	Orthopaedic films, dental implants.	S. Ligot et al- 2012 [7]
10	Ce- HAP	Dental implants.	Lin Yingguang et al – 2006 [6]
11	Ti doped Hydroxyapatite	Dental implants, bone regeneration	Dong-Soo Park et al – 2010 [15]
12	zirconia-hydroxyapatite (ZH) composite ceramics	Structural implants, load tearing implant	V.V. Silva et al – 2000 [16]
13	Chitosan/HA	Orthopaedic implant	Diana Marcela Escobar-Sierra et al-2015 [17]
14	Hydroxyapatite-silk fibroin implant coating	Thin film implant coating	F.M.Mroiu et al- 2009 [3]

15	poly(methyl methacrylate) (PMMA)-modified hydroxyapatite	Bone cements and Implant coating	Manoj Kumar Singh et al – 2008 [18]

IV. CONCLUSION

Hydroxyapatite has shown as an excellent ceramic biomaterial due to its biodegradability and biocompatibility. It is easy to synthesise using methods like chemical precipitation, Mechanoelectrochemical Sol-Gel and Magnetic sputtering and also incorporation of polymer and metals ions by replacing calcium ions is an ease into hydroxyapatite, because of such substitution,

HA has been employed for both dental and orthopaedic implants. Therefore, this review provides a brief summary from synthesis to applications of bioceramic HA and its different composites with metal and polymer ions in biomedical field.

REFERENCES

[1] R. Asmatulu, S. Patrick, M. Ceylan, I. Ahmed, S. Y. Yang, and N. Nuraje, "Antibacterial polycaprolactone/natural hydroxyapatite nanocomposite fibers for bone scaffoldings," J. Bionanoscience, vol. 9, no. 2, pp. 120–126, 2015.

[2] G. E. J. Poinern, R. K. Brundavanam, X. Thi Le, P. K. Nicholls, M. A. Cake, and D. Fawcett, "The synthesis, characterisation and in vivo study of a bioceramic for potential tissue regeneration applications," Sci. Rep., vol. 4, pp. 1–9, 2014.

[3] F. M. Miroiu, G. Socol, A. Visan, N. Stefan, D. Craciun, V. Craciun, G. Dorcioman, I. N. Mihailescu, L. E. Sima, S. M. Petrescu, A. Andronie, I. Stamatin, S. Moga, C. Ducu, "Composite biocompatible hydroxyapatite-silk fibroin coatings for medical implants obtained by Matrix Assisted Pulsed Laser Evaporation," Mater. Sci. Eng. B Solid-State Mater. Adv. Technol., vol. 169, no. 1–3, pp. 151–158, 2010.

[4] S. Sanchez-Salcedo, A. Nieto, and M. Vallet-Reg,"Hydroxyapatite/tricalcium phosphate/agarose macroporous scaffolds for bone tissue engineering," vol. 137, pp. 62–71, 2008.

[5] A. Paz, D. Guadarrama, M. López, J. E. González, N. Brizuela, and J. Aragón, "A comparative study of hydroxyapatite nanoparticles synthesized by different routes," Quim. Nova, vol. 35, no. 9, pp. 1724–1727, 2012.

[6] O. Kaygili, S. V Dorozhkin, and S. Keser, "Synthesis and characterization of Ce-substituted hydroxyapatite by sol – gel method Synthesis and characterization of Ce-substituted hydroxyapatite by sol – gel method," Mater. Sci. Eng. C, vol. 42, no. November 2017, 2014.

[7] S. Ligot, T. Godfroid, D. Music, E. Bousser, J. M. Schneider, and R. Snyders, "Tantalum-doped hydroxyapatite thin films: Synthesis and characterization," Acta Mater., vol. 60, no. 8, pp. 3435–3443, 2012.

[8] R. Costa Cuozzo, M. H. M. Da Rocha Leão, L. De Andrade Gobbo, D. N. Da Rocha, N. Mohammed Elmassalami Ayad, W. Trindade, A. Machado Costa, and M. H. P. Da Silva, "Zinc alginate-hydroxyapatite composite microspheres for bone repair," Ceram. Int., vol. 40, no. 7 PART B, pp. 11369–11375, 2014.

[9] J. Jakubowicz, K. Jurczyk, K. Niespodziana, and M. Jurczyk, "Mechanoelectrochemical synthesis of porous Ti-based nanocomposite biomaterials," Electrochem. commun., vol. 11, no. 2, pp. 461–465, 2009.

[10] E. S. Thian, T. Konishi, Y. Kawanobe, P. N. Lim, C. Choong, B. Ho, and M. Aizawa, "Zinc-substituted hydroxyapatite: A biomaterial with enhanced bioactivity and antibacterial properties," J. Mater. Sci. Mater. Med., vol. 24, no. 2, pp. 437–445, 2013.

[11] Oktar F. N., Kesenci K., Piskin E., "Characterization of processed Tooth Hydroxyapatite for potential Biomedical Implant Application,"Artificial Cells, Blood Substitutes and Immobilization Biotechnology. vol. 7, 1999.

[12] C. S. Ciobanu, F. Massuyeau, L. V. Constantin, and D. Predoi, "Structural and physical properties of antibacterial Ag-doped nano- hydroxyapatite synthesized at 100°C," Nanoscale Res. Lett., vol. 6, no. 1, p. 613, 2011.

[13] W. Sato and Y. Yoshida, "applied sciences Antimicrobial Effect of Titanium Hydroxyapatite in Denture Base Resin," 2018.

[14] D. Walczyk, D. Malina, M. Krol, K. Pluta, and A. Sobczak-Kupiec, "Physicochemical characterization of zinc-substituted calcium phosphates," Bull. Mater. Sci., vol. 39, no. 2, pp. 525–535, 2016.

[15] D. Park, I. Kim, H. Kim, A. Hung, K. Chou, B. Hahn, L. Li, and S. Hwang, "Improved biocompatibility of hydroxyapatite thin film prepared by aerosol deposition," pp. 353–358, 2010.

[16] V. V Silva, F. S. Lameiras, and R. Z. Domingues, "Microstructural and mechanical study of zirconia-hydroxyapatite (ZH) composite ceramics for biomedical applications," vol. c, pp. 301–310, 2001.

[17] D. M. Escobar-Sierra, J. Martins, and C. P. Ossa-Orozco, "Chitosan/hydroxyapatite scaffolds for tissue engineering manufacturing method effect comparison," Rev. Fac. Ing. Univ. Antioquia, no. 75, pp. 24–35, 2015.

[18] J. D. A. Gracio, M. D. Sousa, K. S. Manoj, T. Shokuhfar, M. Da, F. Fereira, H. Garmestani, and S. Ahzi, "Hydroxyapatite Modified with Carbon-Nanotube-Reinforced Poly (methyl methacrylate): A Nanocomposite Material for Biomedical Applications," pp. 694–700, 2008.