The Modeling of the Apatite Nanocrystals of Bone, Illustrating its Physicochemical Evolution and Surface Reactivity

L.F. Sukhodub,
Department of Biophysics, Biochemistry, Pharmacology and Biomolecular Engineering, Medical Institute, Sumy State University, 2, Rymskogo-Korsakova st.,
40007 Sumy, Ukraine,
l_sukhodub@yahoo.com

K. Dyadyura,
Faculty of Technical Systems and Energy Efficient Technologies, Sumy State University, 2, Rymskogo-Korsakova st.,
40007 Sumy, Ukraine,
dyadyura@pmtkm.sumdu.edu.ua

Ihor. V. Prokopovich,
DSc, Assoc. Prof., Director ESIME ONPU
Educational and Scientific Institute of Medical Engineering,
Odessa National Polytechnic University,
1, Shevchenko avenue, Odessa, Ukraine, 65044
i.v.prokopovich@opu.ua

Hennadii. O. Oborskyi,
DSc, Prof., Rector ONPU
Odessa National Polytechnic University,
1, Shevchenko avenue, Odessa, Ukraine, 65044
oborsky@opu.ua

***Abstract*— This study intends to present a review of the different types of ceramic-polymeric nanocomposites. Nanocomposites have been shown to be ideal bioactive materials due the many biological interfaces and structures operating at the nanoscale. Polymer − ceramic nanocomposite systems are particularly interesting as they can be closer to bone in terms of its constitution which is mostly an intricate combination of two phases at the nano-level: hydroxyapatite and collagen. The present article has as its main goal to analyze the most recent reported studies based on polymer-ceramic nanocomposites produced for bone replacement and regeneration. The present information about the in vivo and in vitro studie s that have been performed and their contribution for the development of an ideal nanocomposite material to be used in bone. Structural, morphology, micrograph and chemical composition of this nanocrystalline composites were characterized by XRD, AFM, SEM and FTIR, respectively.**

Keywords — bone; hydroxyapatite; nanocomposites; process of biomineralization; chitosan

I. Introduction

Bone is often defined from a material point of view as a nanocomposite constituted of calcium phosphate apatite nanocrystals embedded in a collagen matrix [1-4]. Bone structure and function are dependent on complex interactions between cells, matrix, cell-derived factors, and systemic factors. Composition of bone and its structure are of considerable interest both from the point of view of fundamental research at the molecular level, and in numerous applications of interactions between different components of the bone. [3, 4]. Despite the structure of bone has been defined, there is not a well-agreed explanation of the mechanism of mineralization [5, 6]. The interactions between the various components of the bone are a system that obeys the principles of self-organization [6]. Here, techniques involving chemical

REFERENCES

[1] A. S. Brydone, D. Meek, and S. Maclaine, "Bone grafting, orthopaedic biomaterials, and the clinical need for bone engineering," Proceedings of the Institution of Mechanical Engineers Part H, Journal of Engineering in Medicine, vol. 224, no. 12, pp. 1329-1343, 2009.

[2] Phuong Nguyen-Tri, et al., "Nanocomposite Coatings: Preparation, Characterization, Properties, and Applications," International Journal of Corrosion, vol. 2018, Article ID 4749501, 2018.

[3] Kerstin Müller, et al., "Review on the Processing and Properties of Polymer Nanocomposites and Nanocoatings and Their Applications in the Packaging, Automotive and Solar Energy Fields," Nanomaterials vol. 7, pp. 74, 2017.

[4] O. Korotych, Yu. Samchenko, L. Sukhodub, Boldeskul, Z. Ulberg, and N. Zholobak, "N-isopropylacrylamide-based fine-dispersed thermosensitive ferrogels jbtained via in situ technique," Mat. Sci. Eng. C., vol. 33, pp. 892-900, 2013.

[5] L. Cardoso, et al., "A review of recent advances in the assessment of bone porosity, permeability, and interstitial fluid flow," J. Biomech., vol. 46, no. 2, pp. 253-265, 2013.

[6] C. Rey, et al., "Physico-chemical properties of nanocrystalline apatites: implications for biominerals and biomaterials," Mater. Sci. Eng. C, vol. 27, pp. 198-205, 2007.

[7] Y. Liu, D. Luo, and T. Wang, "Hierarchical structures of bone and bioinspired bone tissue engineering," Small, vol. 12, no. 34, pp. 4611-4632, 2016.

[8] F.Z. Cui, Y. Li, and J. Ge, "Self-assembly of mineralized collagen composites," Mater. Sci. Eng. R Rep., vol. 57, pp. 1-27, 2007.

[9] Fa-Ming Chen, and Xiaohua Liu, "Advancing biomaterials of human origin for tissue engineering," Prog. Polym. Sci., vol. 53, pp. 86-168, 2016.

[10] M. Mazor, E. Lespessailles, R. Coursier, R. Daniellou, T.M. Best, and H. Toumi, "Mesenchymal stem-cell potential in cartilage repair: an update," J. Cell. Mol. Med., vol 18, no. 12, pp. 2340-2350, 2014.

[11] S.A. Christopher, N. Satoshi, T. Lindsay, W. Jefferson, K. Brian, J. Harrop, D. Choi, and M.G. Fehlings, "Traumatic Spinal Cord Injury – Repair and Regeneration Neurosurgery," vol. 80, no. 3S, pp. S9-S22, 2017.

[12] B.R. Yunus, T.S. Sampath Kumar, and M. Doble, "Design of biocomposite materials for bone tissue regeneration," Mater. Sci. Eng. C Mater. Biol. Appl., vol. 57, pp. 452, 2015.

[13] K. Jahan, and M. Tabrizian, "Composite biopolymers for bone regeneration enhancement in bony defects," Biomater. Sci., vol. 4, no. 1, pp. 25, 2015

[14] L. Sukhodub, "Materials and coatings based on biopolymer-apatite nanocomposites: obtaining, structural characterization and in vivo tests," Mater. Sci. Eng. Technol., vol. 4, pp. 318-325, 2009.

[15] L. F. Sukhodub, et al, "Nanocomposite apatite-biopolymer materials and coating for biomedical applications," J. Nano-Electron. Phys., vol. 6, no. 1, pp. 01001, 2014.

[16] Dawei Zhang, Xiaowei Wu, Jingdi Chen, and KailiLin, "The development of collagen based composite scaffolds for bone regeneration," Bioactive Materials, vol. 3, no 1, pp. 129-138, 2018.

[17] H. Zhou, and J. Lee, "Nanoscale hydroxyapatite particles for bone tissue engineering," Acta Biomater., vol. 7, pp. 2769-2781, 2011.

[18] R.E. McMahon, L. Wang, R. Skoracki, and A.B. Mathur, "Development of nanomaterials for bone repair and regeneration," J. Biomed. Mater. Res. B. Appl. Biomater., vol. 101, no. 2, pp. 387-397, 2013.

[19] J. Venkatesan, and S.K. Kim, "Nano-hydroxyapatite composite biomaterials for bone tissue engineering – a review," J. Biomed. Nanotechnol., vol. 10, no. 10, pp. 3124-3140, 2014.

[20] D.W. Hutmacher, "Scaffolds in tissue engineering bone and cartilage," Biomaterials, vol. 21, no. 24, pp. 2529-2543, 2000.

[21] R. Murugan, and S. Ramakrishna, "Development of nanocomposites for bone grafting," Compos. Sci. Technol., vol. 65, no. 15–16, pp. 2385-2406, 2005.

[22] JY. Rho, L. Kuhn-Spearing, and P. Zioupos, "Mechanical properties and the hierarchical structure of bone," Med. Eng. Phys., vol. 20, pp. 92-102, 1998.

[23] R. James, M. Deng, C. Laurencin, and S. Kumbar, "Nanocomposites and bone regeneration," Front Mater. Sci., vol. 5, no. 4, pp. 342-357, 2011.

[24] E. Beniash, "Biominerals-hierarchical nanocomposites: the example of bone," Wiley Interdisciplinary Reviews Nanomedicine and Nanobiotechnology, vol. 3, no. 1, pp. 47-69, 2011.

[25] Jan Henkel, et all., "Bone Regeneration Based on Tissue Engineering Conceptions – A 21st Century Perspective," Bone Res., vol. 1, no. 3, pp. 216-248, 2013.

[26] J.D. Currey, "Bone at the molecular level," In Press PU, editor. Bones: Structure adn Mechanics 2002. p. 456.

[27] J.T. Compton, F.Y. Lee, "A review of osteocyte function and the emerging importance of sclerotin," J. Bone Joint Surg. Am., vol. 96, no. 19, pp. 1659-1668, 2014.

[28] S. Boonrungsiman, E. Gentleman, R. Carzaniga, D. Nicholas Evans, and W. David McComb, E. Alexandra Porter, and M. Molly Stevens, "The role of intracellular calcium phosphate in osteoblast-mediated bone apatite formation," PNAS, vol. 109, no.35, pp. 14170-14175, 2012.

[29] V.M. Kuznetsov, L.B. Sukhodub, and L.F. Sukhodub, "Structural and substructural features of apatite-biopolymer composites: The comparison of data obtained using X-Ray diffraction and scanning electron microscopy with electron diffraction," J. Nano- Electron. Phys., vol. 6, no. 4, 2014.

[30] J.J. Li, Y.P. Chen, Y.J. Yin, F.L. Yao, and K.D. Yao, "Modulation of nano-hydroxyapatite size via formation on chitosan-gelatin network film in situ," Biomaterials, vol. 28, pp. 781-790, 2007.

[31] H.L. Nichols, N. Zhang, J. Zhang, D.L. Shi, S. Bhaduri, and X.J. Wen. "Coating nanothickness degradable films on nanocrystalline hydroxyapatite particles to improve the bonding strength between nanohydroxyapatite and degradable polymer matrix," J. Biomed. Mater. Res. A, vol. 82A, pp. 373-382, 2007.

[32] T.J. Cypher, and J.P. Grossman, "Biological principles of bone graft healing," The Journal of foot and ankle surgery: official publication of the American College of Foot and Ankle Surgeons, vol. 35, no. 5, pp. 413-417, 1996.

[33] S.K. Nandi, S. Roy, P. Mukherjee, B. Kundu, De D.K, and D. Basu, "Orthopaedic applications of bone graft & graft substitutes: a review," The Indian Journal of Medical Research, vol. 132, pp. 15-30, 2010.

[34] C. Laurencin, Y. Khan, and S.F. El-Amin, "Bone graft substitutes," Expert Review of Medical Devices., vol. 3, no. 1, pp. 49-57, 2006.

[35] N.G. Sahoo, Y.Z. Pan, Li L, and C.B. He, "Nanocomposites for bone tissue regeneration," Nanomedicine (London, England)., vol. 8, no. 4, pp. 639-653, 2013.

[36] D.R. Paul, and L.M. Robeson, "Polymer nanotechnology: Nanocomposites," Polymer, vol. 49, no.15, pp. 3187-3204, 2008.

[37] C Wu, and Y. Xiao, "Evaluation of the in vitro bioactivity of bioceramics," Bone and Tissue Regeneration Insights, vol. 2, pp. 25-29, 2009.

[38] S. Fu, P. Ni, B. Wang, B. Chu, L. Zheng, F. Luo, et al., "Injectable and thermo-sensitive PEG-PCL-PEG copolymer/collagen/n-HA hydrogel composite for guided bone regeneration," Biomaterials, vol. 33, no. 19, pp. 4801, 2012.

[39] S.N. Khan, E. Tomin, and J.M. Lane, "Clinical applications of bone graft substitutes," The Orthopedic Clinics of North America, vol. 31, no. 3, pp. 389-398, 2000.

[40] M. Okada, and T. Furuzono, "Hydroxylapatite nanoparticles: fabrication methods and medical applications," Sci. Technol. Adv. Mater. vol. 13, pp. 064103, 2012.

[41] W.H. Lee, A.V. Zavgorodniy, C.Y. Loo, and R. Rohanizadeh, "Synthesisand characterization of hydroxyapatite with different crystallinity: effects on protein adsorption and release," J. BiomedMater. Res. A, vol. 100, pp. 1539-1549, 2012.

[42] R.E. McMahon, L. Wang, R. Skoracki, and A.B. Mathur, "Development of nanomaterials for bone repair and regeneration," J. Biomedical Mater. Res. Part B, Appl. Biomater., vol. 101, no. 2, pp. 387-397, 2013.

[43] S.C. Tjong, "Structural and mechanical properties of polymer nanocomposites," Mater. Sci. Eng. R: Reports., vol. 53, no. 3-4, pp. 73-197, 2006.

[44] G.M. Whitesides, and B. Grzybowski, "Self-assembly at all scales," Science, vol. 295, no. 5564, pp. 2418-2421, 2002.

[45] M. Uda, A. Momotake, and T. Arai, "Synthesis and isomerization of azobenzene dendrimers," Photochemical & Photobiological Sci., vol. 2, no. 8, pp. 845-847, 2003.

[46] A.M. Mieshkov, T.O. Berestok, L.F. Sukhodub, and A.S. Opanasyuk, "Structural properties of zinc sulfide polymer nanocomposite with alginate," J. Nano-Electron. Phys., vol. 7, no. 3, pp. 03018, 2015.

[47] A.M. Mieskov, L.I. Grebenik, T.V. Ivahnuk, and L.F. Sukhodub, "Antibacterial properties of the nanoparticles with the zinc sulfide quantum dots," IFMBE Proceedings, vol. 55, pp. 267-270, 2016.

[48] M. Hoppe, N. Abaii, V. Postica, O. Lupan, O. Polonskyi, F. Schutt, L. F. Sukhodub, V. Sounta, T. Strunskus, F. Faupel, and R. Adelung, "(CuO-Cu_2O)/ZnO:Al heterojunctions for volatile organic compound detection," Sensor. and Actuat. B: Chem., vol. 255, pp. 1362-1375, 2018.